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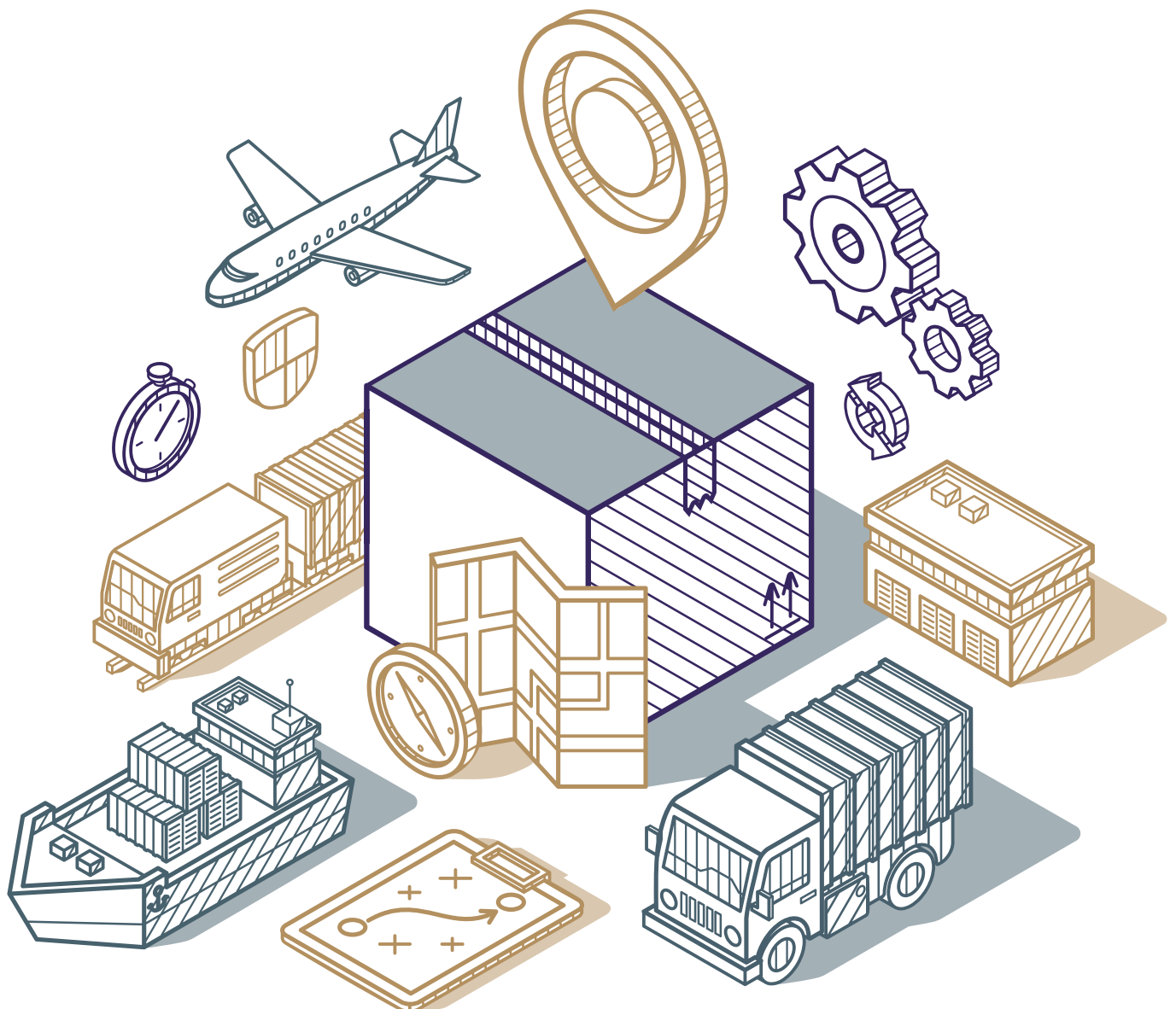
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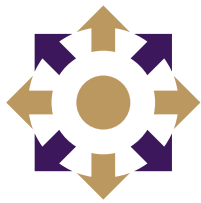
*Sustainable and resilient supply
chains in disruptive times*

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"I'm truly impressed with the variety of topics discussed at this year's LRN conference: climate change, behaviour, humanitarian efforts, policy & regulations to name but a few. We need to have more of these transdisciplinary events that bring together multiple communities to discuss these important themes".

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CIRCULAR AND SUSTAINABLE SUPPLY CHAIN



RENEWABLE ENERGY SOURCES AS ENABLERS AND LEVERS OF SUSTAINABILITY IN ENERGY SUPPLY CHAINS

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1. Introduction

Renewable energy (RE) is harnessed from natural processes, which are replenished constantly and do not result in the depletion of the earth's resources (Vakulchuk et al., 2020). RE sources provide cleaner energy in a responsible way (Büyükožkan and Güler, 2016), and are reliable, affordable, and environmentally friendly (Hussain et al., 2017). The rapid increase in energy demand and growing concern about its economic and environmental impacts call for RE adoption. Fossil fuels including oil, natural gas, and coal remain the dominant sources of energy globally, and these will account for over three-quarters of the total energy supply by 2035 (BP, 2017). However, countries are facing severe environmental challenges, including drought and air and water contaminations due to excessive use of fossil fuels (Praveen et al., 2020).

Sustainable transition to renewable energy (STRE) deserves research attention, considering it could have significant environmental, economic, and social ramifications for the energy industry and on societies. This should be an exciting time for the Gulf Cooperation Council (GCC) countries, such as the Sultanate of Oman, with abundant RE resources. Transition to RE is necessary towards the realisation of a key national priority for the Sultanate of Oman Vision 2040: "Environmental and Natural Resources" (Oman, 2020), which is mapped to the United Nation's Sustainable Development Goals (SDGs) 6; 7; 11; 12; 14; and 15 respectively (United Nations, 2018). Fossil fuels are finite and not environmentally friendly (Mahapatra et al., 2021). The Sultanate of Oman has the capacity to develop into a leading producer of RE due to its rich RES. Despite this promising development, the transition to RE in the Sultanate of Oman is slow, with renewable energy sources (RES) accounting for less than 1% of total power generation, which impacted the country's competitiveness as a major energy producer (Al-Sarihi and Bello, 2019). Given that prior studies have empirically established the sustainable impacts of RE, there is a potential for energy networks, such as the Sultanate of Oman energy sector, to embrace the transition to RE to improve sustainability and competitiveness.

Despite the increasing number of RE-related literature, no single study has proposed a comprehensive framework of STRE to improve awareness and to assist practitioners in decision-making. This study aims to close this research gap by systematically analysing prior literature published between 2000 and 2021. Viable RES in the Sultanate of Oman as a case study are explored from the literature towards developing a comprehensive framework of STRE to guide practitioners, researchers, and policymakers in selecting, designing, and deploying viable RES required for competitiveness and sustainability. The viable RES in the Sultanate of Oman and the key factors that drive STRE are identified and explored systematically from prior literature using template analysis (Zubairu et al., 2021; King and Brooks, 2017), and later validated by experts.

2. Literature review

2.1 Renewable energy sources

The GCC countries, including the Sultanate of Oman, are heavily dependent on oil and gas resources for energy generation (Abdo et al., 2018). The Sultanate of Oman has good potentials for generating RE due to its geographical location (Kazem, 2011). There are various RES accessible in the Sultanate of Oman, such as solar, wind, geothermal, tidal, wave, hydro, and biomass (Kazem, 2011). Solar energy is attracting huge attention in the GCC due to the high solar irradiation density in the region (Malik et al. 2019). Although wind energy is regarded as a vital RES in the Sultanate of Oman, wind technologies cannot be implemented in all regions, except the coastal areas in the south and east of the country. Other types of RES explored in the Sultanate of Oman include geothermal, biomass (Umar, 2018), and hydro (Kazem, 2011). A study of geothermal energy demonstrates that the cost of producing electricity and emission of greenhouse gases are lower compared to the other types of RES such as wind energy. The geothermal boreholes in the Sultanate of Oman have water temperatures ranging from 68°C to 137°C, making these boreholes ideal locations for harnessing geothermal energy (Kazem, 2011).



2.2 Renewable energy transition

Studies argued that the transition to RE in the GCC countries is motivated by factors such as the increase in energy demand; unfavourable impact of fossil energy on the environment; the awareness that fossil fuels are limited deplorable resources; the awareness that RE is economically feasible; and RE is more geographically distributed. The Sultanate of Oman and the GCC countries encounter harsh environmental challenges such as annual tropical hurricanes, desertification (Malik et al., 2019), and an increase in greenhouse gases emission due to the excessive consumption of fossil fuel (Praveen et al., 2020). It is construed that fossil fuel production is a major cause of water contamination due to discharging of oil and liquids into the water. Contrary, RE such as wind energy uses the lowest water and secretes the minimum greenhouse gases. This leads to an intensifying focus on harnessing wind energy in the Sultanate of Oman.

STRE is associated with job creation, which facilitates economic growth (Praveen et al., 2020). A crucial initiative made by the GCC countries is the enhancement of the coordination among stakeholders to enable integration and collaboration amongst industry practitioners. The innovative RE technologies used in the GCC countries are also encouraging.

2.3 Threats facing renewable energy transition

Recent research revealed that the transition to RE in the GCC countries has five key challenges. These challenges include the high subsidy on fossil fuels, dearth of RE policies, resistance from the fossil fuels supply chain participants, scarcity of RE technologies, and limited understanding of climate change (Abdo et al., 2018). It is confirmed that inadequate supportive policies and subsidies make the price of RE uncompetitive and impede transition (Lilliestam and Patt, 2015). The continuous reduction in fossil fuel prices deters the transition to RE (Salim and Alsyounf, 2020). The over-reliance on fossil energy in the GCC countries inhibits energy diversification, which slowdown the scalable adoption of RES. It is posited that harnessing solar energy is associated with high cost, political and technical challenges (Kazem et al., 2011). Solar energy as an important RE alternative in the Sultanate of Oman faces metrological threats, including very high temperature and dust accumulation, which affects the performance of the Solar PV (Yousif et al., 2017). Wind energy also encounters some challenges, consisting of high installation costs and maintenance difficulties (Charabi and Abdul-Wahab, 2020). Geothermal energy faces a challenge associated with the reduction of thermal interference (Wenzlaff et al., 2019). Building biomass plants in the Sultanate of Oman is constrained by many issues, including the availability of input materials, because these materials have other uses, such as fertilizer. Moreover, the wastewater system covers only a small part of the country which is insufficient to energise a power plant (Al-Badi et al., 2009). Another barrier for RE transition in the GCC region is the intermission of generating wind and solar energy due to differences in geographical composition. There are also difficulties in integrating the RE harnessed from remote locations into the existing grid systems to satisfy demand (Lilliestam and Patt, 2015).

2.4 Research gap

Transition to RE is vital towards the realisation of several of the United Nation's SDGs (United Nations, 2018). However, despite the rising number of RE-related studies, no single paper has suggested a comprehensive framework of STRE to augment existing knowledge, and to assist practitioners in decision-making, indicating a significant research gap. A RE-related literature search conducted in this study spanning over 20 years from January 2000 covered the new millennium, which stimulated interest in sustainability. The literature search revealed that contrasting prior studies within the GCC and the Sultanate of Oman, which considered various RES or enablers of RE transition, but not both. Assessing and selecting the most feasible RE sources is key to business competitiveness, and for the Sultanate of Oman's transition to RE.

3. Description of problem

A case study approach was deemed appropriate for this research because it allows for the development of a comprehensive framework to generate insights regarding the feasibility of RES from the context of the Sultanate of Oman as a major energy-producing country. To achieve such insights, this case study research systematically draws on extant literature data, which were evaluated using template analysis. Analysing prior RE literature data using template analysis facilitates replicability and improves the nobility of this paper as the first systematic literature review (SLR) on RE that employed template technique.

3.1 Systematic literature review

SLR approach was employed with an emphasis on reviewing published research work systematically to develop a comprehensive framework of STRE and to recommend directions for future research opportunities. SLR adopts a technique that is scientific and replicable for analysing and interpreting previous research publications relevant to a phenomenon of interest. SLR assists in developing useful insights based on a theoretical synthesis of existing research and identifies possible gaps in the literature. Akin to a study by Sharma et al. (2020), the three-stage SLR approach comprising of planning the review, conducting the review, and Review findings were followed in this work.



3.1.1 Planning the review

This paper aims to study RES, identify viable RES in the Sultanate of Oman, explore the factors that drive STRE, establish the associated advantages, and examine the threats that may inhibit adoption and performance. To achieve these, academic databases were interrogated systematically. The searches for relevant articles published between January 2000 and February 2021 encompass the beginning of the 21st Century, which saw a growing interest in RES as sustainable sources of energy.

3.1.2 Conducting the review

The start of the 21st Century witnessed an increase in energy demand and growing awareness about environmental challenges associated with fossil energy, which provoked interest in RE studies. In this study, RE related literature search was conducted spanning over 21 years from 2000 to 2021. Keywords searches were performed using EBSCO Masader and ProQuest scholarly databases. These are aggregators comprising a wide range of peer-reviewed journals belonging to major publishers such as Elsevier, Taylor and Francis, Springer, MDPI, Emerald, and Wiley. To limit the number and improve the quality of articles under review, only peer-reviewed are included in the search. Using keyword searches, a total of 414 publications were found as an outcome. The keyword search was executed through a pairwise query considering one keyword at a time. A review of the abstracts of these papers revealed that not all publications focused on RE. The inclusion benchmarks used for conducting the review include: a study must have published in a peer-reviewed journal, the research is focused on RES, and papers are written in English language. The selection criteria resulted in a comprehensive sample of 90 articles (Figure 1). A validity is attained through validation tests performed by three researchers using deductive and inductive approaches. Utilising Microsoft Excel software enables organised grouping and minimises error.

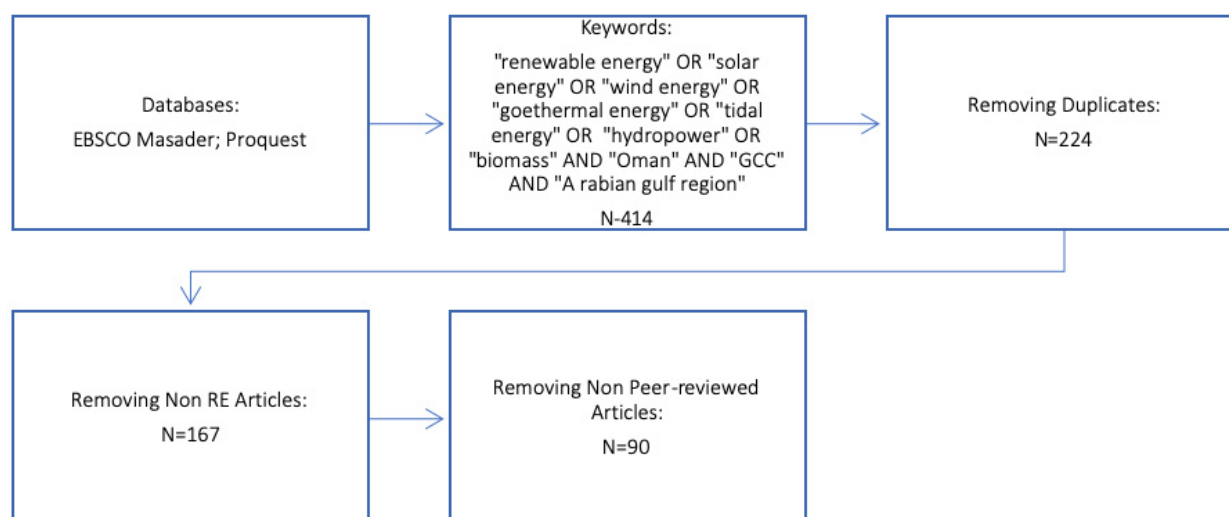


Figure 1: Steps conducted for this review



4. Research work

4.1 Descriptive analysis

Ninety scientific articles published between January 2000 and 2021 were evaluated to identify key themes, which also enables the study to identify gaps in the literature. Analysis of the selected publications suggested that the pace of research in RE picked up from 2017–18, indicating increased interest by researchers to contribute towards embracing viable RES in the Sultanate of Oman and the GCC region. Papers on the topic peaked in 2019 with a total of 21 publications during that period (Figure 2).

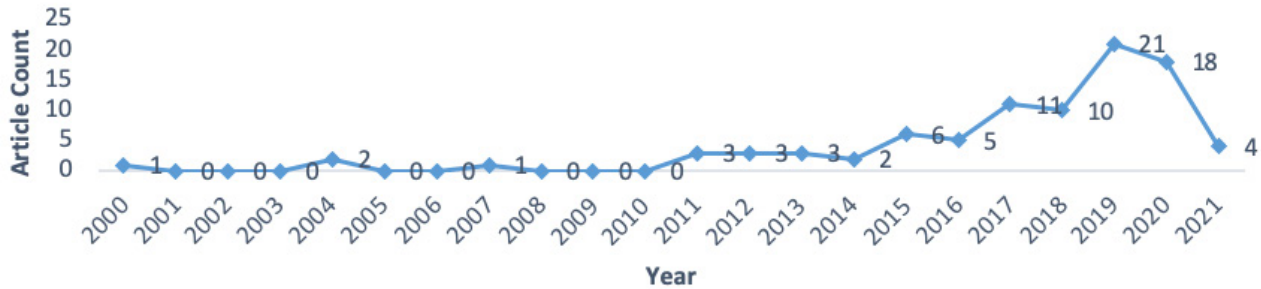


Figure 2: Year-wise publications

Analysis of the selected papers revealed that more interest is given to solar energy, with a total of 58 out of 90 studies. There are 37 wind energy-related studies, which makes it second. The other 34 articles explored biomass, geothermal, hydro, and tidal energies, representing only 11%, 3%, and 1%, respectively. This underlined the limited research interest in hydro and tidal energies, which could be linked to their feasibility. A few of these papers used a combination of different RE options (Figure 3).

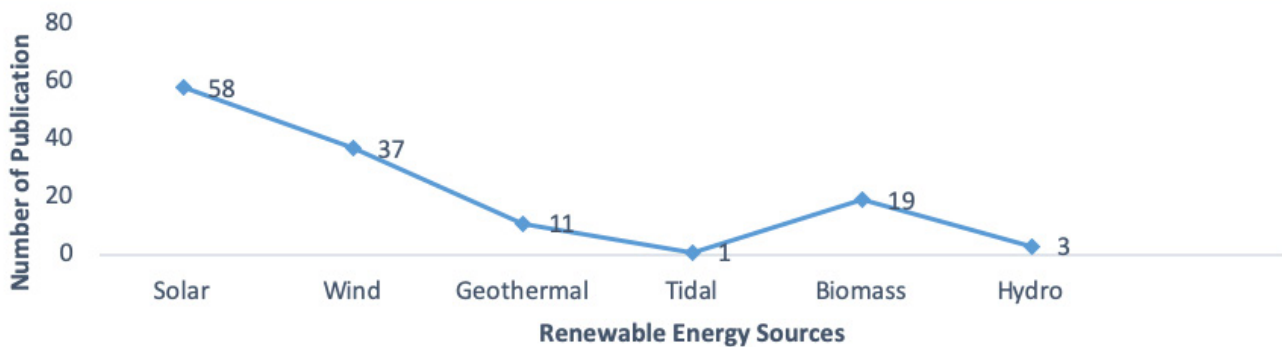


Figure 3: Renewable energy sources

Findings indicated that most of the sample studies were performed using various quantitative approaches, with 65 articles constituting 78%. Conceptual and review papers represented only 9% and 4%, respectively. There is no single qualitative or mixed study out of the entire qualifying articles, indicating a significant gap in research methodology applied to study RES in the Sultanate of Oman and the GCC region (Figure 4).

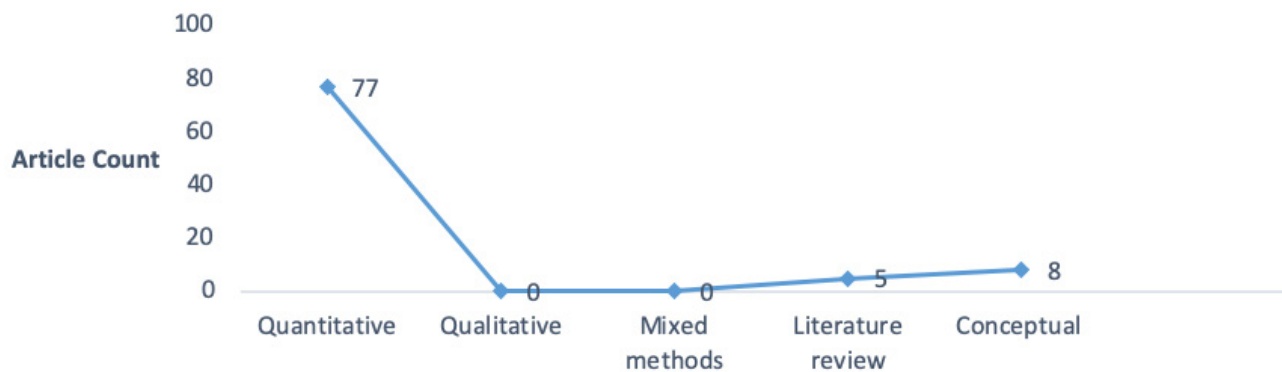


Figure 4: Methodologies employed



5. Results and discussion

SLR was conducted to identify the viable RES and to explore the key factors that facilitate STRE. The SLR assisted in obtaining relevant data. Template analysis of data assisted in the identification of the feasible RES and the key factors that drive STRE. Results from the template analysis facilitated the development of a framework of STRE and supported in identifying gaps in the literature.

5.1 Viable renewable energy sources

5.1.1 Solar energy

Results established that integrating solar energy into the electricity grid will have a positive environmental impact by reducing fossil fuels utilised for electric power production (Qamber, 2021). Findings revealed that the high solar radiation in the GCC region makes solar a feasible source of energy. The high solar density in the Sultanate of Oman and the other GCC countries has resulted in an increasing focus on solar energy in the region. Findings demonstrated that solar PV, which converts the solar radiations into electricity is the dominant solar energy technology used in the GCC countries, including the Sultanate of Oman (Praveen et al., 2020). However, there are other similar and associated solar technology options like grid-connected photovoltaic, and PV cooling systems (Ahmad et al., 2018). To make solar energy investment attractive, energy regulators in the Sultanate of Oman and other GCC countries should develop policies to take advantage of the high solar radiation, especially in the summer period, which coincides with peak electricity demand for cooling.

5.1.2 Wind energy

Wind energy is a good alternative to overcome the climatological limitations of solar energy in a hot arid region of the Sultanate of Oman. The southern and south-eastern parts of the Sultanate of Oman are associated with high wind speed (Kazem and Khatib, 2013). Results revealed the availability of various technologies for harnessing wind energy in the Sultanate of Oman, such as windmills, wind turbines, and wind energy conversion systems. Wind turbines, which are newer and more modern than windmills are commonly used in the GCC regions, including the southern and south-eastern parts of the Sultanate of Oman (Al-Badi et al., 2009). However, findings revealed challenges associated with wind energy generation, which include noise pollution caused by the wind turbines that may disturb the people living close to the wind facilities.

5.1.3 Geothermal energy

Geothermal energy is a carbon emission-free RE source that contributes towards environmental sustainability (Umar, 2018). Conventional geothermal energy may have limited potential in the Sultanate of Oman, with boreholes' locations within the Petroleum Development Oman concession area having the highest temperature of 174°C (Al-Lamki and Terken, 1996). This is below the temperature required for running a steam power plant (Al-Badi et al., 2009). However, the boreholes in the Sultanate of Oman have temperatures of more than 100°C, which makes them ideal for the binary cycle power plant (Umar, 2018). Results revealed that the potential depletion of underground steam sources is a threat to geothermal energy. This could be the reason why only not many of the qualifying articles researched geothermal energy. However, the potential of geothermal energy is at par with other mainstream RE technologies (Hussain et al., 2017).

5.1.4 Biomass energy

It is estimated that 2651.81 GWh p.a. of electricity can be generated from animal manure and wastewater in the Sultanate of Oman (Umar, 2018). However, the total biomass energy production from water waste is approximately 335,990 m³ daily, which can generate 47.37 GWh of electricity (Umar, 2017). Building biomass power plants operating on crop and animal wastes in the Sultanate of Oman is limited by several factors, such as availability and collection of materials because these materials are processed and used as fertilizer. Moreover, the wastewater system covers only a small part of the country, which is not enough to energise a power plant. These are highlighted by the relatively low number of biomass-related studies from the sample papers when compared to solar and wind as RES. However, there are several landfills in the country, which could be utilised to produce methane gas that can be used as a fuel (Al-Badi et al., 2009).



5.2 Drivers of sustainable transition to renewable energy

Considering the significance of sustainability to RE selection, investment and implementation, sustainability concerns are vital in evaluating the viability of RES. Existing studies argued that the transition to RE in the GCC countries is motivated by the unfavourable impact of fossil energy on the environment, the awareness that fossil fuels are finite depletable resources, and RE is geographically more distributed (Praveen et al., 2020). It is established that all the three sustainability pillars of environment, economic and social concerns drive STRE in the Sultanate of Oman. However, the least dominant criterion is the social aspect. In addition to the three sustainability dimensions, findings established that technology is also a major driver for viable transition to RE in the Sultanate of Oman. RE supply chains have grown rapidly due to considerable cost reductions for RE technologies (Praveen et al., 2020). Transition to RE will lead to electricity cost reduction, which will ease economic pressure.

6. Conclusions, implications, and directions for future research

A comprehensive literature review is performed, which seeks to identify feasible RES in the Sultanate of Oman, explore the factors that drive STRE, establish the associated benefits, and examine the factors that may impede adoption and performance. A total of 90 articles were selected, systematically reviewed, and evaluated using template analysis. A framework is developed to guide RE supply chain participants, researchers, and policymakers in selecting and designing viable RES necessary for supply chain competitiveness and sustainability. The paper revealed consideration for environmental, economic, and social benefits as drivers for transition to RE, implying that all the three sustainability dimensions enable the transition to RE. Considering the high investment implications and the volatility of the energy market, policy and regulatory framework, advanced and cost-effective technologies, competitive subsidy regime, infrastructure, and access to land play important roles in RE investment and deployment. The gaps in the literature are identified to suggest future research opportunities.

Practical and research impacts

The study offers a strategic platform by paving the way to propose a comprehensive framework of STRE to guide practitioners and policymakers in selecting and designing RE supply chains necessary for improved stakeholder value and sustainability. Findings from this study indicate that RE promises a cleaner environment, free of pollution, and a more prosperous world. It is envisaged that if findings from this study are carefully considered by practitioners, researchers, and policymakers in selecting and designing viable RE supply chain networks can significantly facilitate STRE.

Acknowledgement

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GREEN AND NEW: SUSTAINABILITY-ORIENTED INNOVATION IN LOGISTICS

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1. Introduction

The theme of sustainability is becoming a very relevant trend that is gaining growing attention over time for organizations, spanning all business processes. This theme has become of great relevance also for the management of logistics and supply chains, as reported by Lazar et al. (2021), who stated that over 81% of the studies reviewed in their work in the area of logistics and supply chain sustainability were related to at least two sustainable development dimensions, and over 47% were related to all three. “Sustainable development, logistics, and supply chain are being combined into three increasingly connected and topical global research areas” (Lazar et al., 2021). Therefore, there is a strong link among “the priorities of the United Nations’ Sustainable Development Goals (SDGs) and sustainable development dimensions in supply-chain- and logistics-management-related studies” (Lazar et al., 2021). Given that sustainable development has become an imperative for organizations too, companies are trying to orient themselves towards the achievement of the SDGs. The great concern around the degraded state of the environment, grown due to the tangible effect of climate change and social inequality, is urgently calling for initiatives and solutions (Almeida et al., 2013). In this landscape, the logistics industry accounts for a significant environmental impact. It is responsible for a significant rate of global pollution (Kohn and Huge Brodin, 2008; Mangiaracina et al., 2016), in terms of emissions in air and water, noise, and consumption of resources.

To devise those initiatives and solutions driving organizations towards the achievement of the SDGs, “innovation” can play a fundamental role, and a whole stream of research on “sustainability-oriented innovation (SOI)” has appeared (Adams et al., 2016). Sustainability-oriented innovation can be defined as “the integration of ecological and social aspects into products, processes, and organizational structures” (Klewitz and Hansen, 2014).

Therefore, it becomes interesting to study how sustainability-oriented innovation has been adopted within the logistics industry to investigate how the logistics sector has reacted towards the achievement of the SDGs through innovative actions. In fact, notwithstanding the traditional view according to which logistics is a “black box”, a static cost-saving oriented business function, innovation has been a driving force of its rise as a strategic function within organizations (Cui et al., 2010).

Research has highlighted the recent interest of the logistics sector towards sustainability and that logistics can embrace the dimension of innovation given its current strategic role within organizations. However, how the logistics sector has embraced “sustainability-oriented innovation” is still a topic in its infancy: the purpose of this paper is to explore how sustainability has been incorporated in the approaches to innovation within the logistics industry, to raise awareness of how innovation can foster sustainability in the logistics industry. We conducted a structured literature review (SLR) combined with some bibliometric analyses to achieve this objective.

Methodology

The adopted research methodology is the Systematic Literature Review (SLR) (Denyer and Tranfield, 2009), and the adopted research framework, derived from Thomé et al. (2016), is reported in Figure 1.

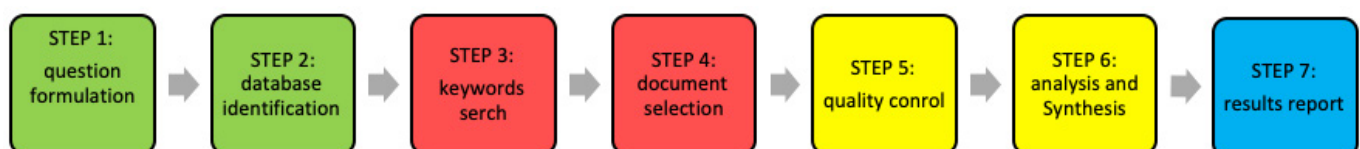


Figure 1 – The adopted SLR framework

The goal is to identify how the trend of “sustainability-oriented innovation in the supply chain” affects the logistics companies and how they are dealing with this important theme. This research starts from previous research that has highlighted the fact that sustainability is an important topic when dealing with innovation in the supply chain. So, the main question this research is trying to address is the following:



RQ: “How do logistics companies deal with the theme of sustainability while considering innovation in their processes?”

This overarching research question can be better detailed in the following sub-questions:

RQa: “What kind of innovation for sustainability is taking place in the supply chain?”

RQb: “What areas are the object of sustainability-oriented innovation within logistics companies?”

First, to embed the scope of the research into the literature review, a set of keywords has been identified, moving from the main areas focus of this research, which are represented by the themes of “logistics”, “sustainability” and “innovation”. However, it is well known that the term logistics has a very wide meaning and different synonyms exist. To focus on the specific object of the work, the keyword “logistics” was broken down into “(logistic service*” OR “logistics management” OR “freight transport*” OR “logistics industry” OR “logistics service provider*” OR “third party logistic*” OR “logistics outsourcing”)”. In conclusion the final research string composed as follows: ((“logistics service*” OR “logistics management” OR “freight transport*” OR “logistics industry” OR “logistics service provider*” OR “third party logistic*” OR “logistics outsourcing”) AND “innovation” AND “sustainab*”). The search string was applied to the Scopus database and, as a result, 155 papers were retrieved.

Subsequently, to isolate only relevant papers among the 155 retrieved ones, different selection criteria were adopted: i) topic of the document: an abstract review was performed to identify documents belonging to the management engineering area (111 documents were kept while 44 were discarded); ii) publication year: we chose to discard documents published before 2010 since we wanted to focus on the most recent contributions given that innovation is concerned (103 documents met this requirement and so kept, while the other eight were discarded); iii) document type: we have chosen to discard the category of conference reviews, which seemed of lesser quality (4 documents were discarded). The sample of papers consisted then of 99 documents. The screening and selection process is summarized in Figure 3.

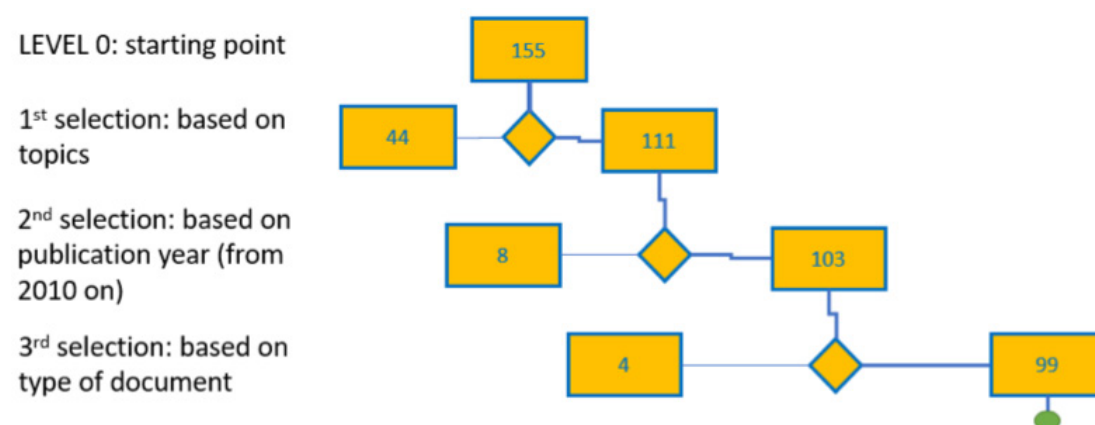


Figure 3 – Document screening and selection

In terms of analysis and synthesis of the results, we adopted the traditional thematic/content analysis approach, integrated with the analysis of the keywords, which is typical of the bibliometric analysis works (e.g., Do et al., 2021).

Results

By reading the full text of the selected 99 documents, to “develop new knowledge and insights about the topic that was not visible through reading every article alone” (Denyer and Tranfield, 2009), a critical analysis was carried out on the findings and the emerging themes through (i) a content-analysis firstly and (ii) the analysis of the clusters of keywords secondly. As already stated, the majority of the documents are included in the management engineering area.



Content analysis

The content analysis has allowed the creation of some groups based on the subject matters inside the abstracts and the full texts. In particular, we noticed that some themes were recurring, and these were classified into five groups, as listed below:

- A. Last-mile delivery
- B. Corporate strategies for sustainability
- C. Industry 4.0
- D. Smart cities
- E. Green supply chain management and alliances

The first group (A) collects papers related to the last mile delivery and the concept of routing (ranging from e-commerce to urban freight transportation). The last mile represents the final step of transportation and of the delivery process. As stated by Macharis and Melo (2011) “the last mile may be defined as the final leg in a business-to-consumer delivery service whereby the consignment is delivered to the recipient”. Strictly connected to the last mile, it is the concept of routing - i.e., the planning of movements aiming at maximizing value by minimizing distribution costs and time. This topic has recently dealt with drones, electric vehicles, and other eco-efficient solutions. This is a “new” focus because “last-mile is regarded as one of the most expensive, least efficient and most polluting sections of the entire logistic chain” (Macharis and Melo, 2011).

The second group (B) includes papers related to the broader approach of companies to sustainability in all their activities, logistics included. Several documents explore how to achieve sustainability with a broader perspective, beyond simply the logistics activities, through a corporate strategy approach. In this group, papers discuss the redesign of the supply chain to follow the “green thinking” approach, which embraces businesses, products, materials and services that are conscious towards the environment and are more socially responsible (Green et al., 2012). Also, papers exploring the role played by the logistics activities in the strategic (re)orientation of the value chain towards sustainability are included in this group.

The third group (C) includes documents related to recent technologies applied to the supply chain and how they can contribute to the improvement of sustainability. Overlapping with the concept of technological innovation, the papers in this group deal with the concept of Industry 4.0. It has been defined by multiple forms but lacks an explicit definition (Zheng et al., 2021). However, we can state that Industry 4.0 is the implementation of technologies, which are changing the way we work, leading to the automation of production lines in companies (Zheng et al., 2021). All the Industry 4.0 technologies are used to produce and deliver in the most optimized way. The latter refers to the efficient use of all resources and thus, indirectly, it can be related to sustainability even if it is not the primary target.

The fourth group (D) collects papers dealing with the solutions implemented and the models used to develop a smart city environment ranging from product transportation to passengers mobility. There are several definitions of what a smart city is, ranging from “cities that undertake actions towards innovation in management, technology, and policy, all of which entail risks and opportunities” (Gil-Garcia et al., 2016) to “political jurisdiction where a smart government applies emerging technologies and innovation” (Gil-Garcia et al., 2014) passing by “innovative solutions, not limited to but mainly based on ICT, which improve urban everyday life and enhance local sustainability in terms of people, governance, economy, mobility, environment and living” (Anthopoulos and Reddick, 2016). The European Commission gives another important definition that describes smart cities as “user-driven open innovation environments”. So, it is easily understandable how all the definitions are based on the concepts of renewing urban environments in which the technology contributes largely and deeply to the improvement of a sustainable environment and society of the agglomerations of population and activities.

The final group (E) includes papers related to green supply chains alliances and networks. We found that many companies were not able to develop a sustainable supply chain on their own, due to financial, knowledge or resources constraints. For those reasons, several companies were engaged in implementing partnerships and alliances with experts/technology providers/clients and suppliers to access the needed knowledge and develop a sustainable and green supply chain. Alliances are defined as “a cooperative arrangement between two or more organizations designed to achieve a shared strategic goal” (Rakowski, 2009).



Keywords analysis

Further analysis has been performed on the authors' keywords and index keywords of the documents. To this aim, a tool - named VOSviewer - was employed to cluster those keywords and point out links based on the citations of the documents. VOSviewer is an academic software tool for the construction and visualization of bibliometric networks, which offers text mining functionalities that can be used to construct and visualize co-occurrence networks of important terms extracted from a body of scientific literature. To build the clusters of keywords, a minimum number of co-occurrences has been set to 5 (default value of the threshold). As a result, 43 items were selected as relevant and, based on that, five clusters were created and reported in Table 1.

Cluster	Colour	Description	No. Of Papers	Items List
1	Red	It is related to Industry 4.0 and new technologies. Composed of elements strictly related to technological innovation	12	City logistics, e-commerce, environment, green innovation, IoT, logistics outsourcing, LSP, modeling, omnichannel retail, RFID smart, urban freight, urban freight transportation
2	Green	It is related to the management and the decision-making process and the management of alliances	12	Collaboration, competitive advantage, freight, halal logistics, innovation, life cycle assessment, management mechanism, reverse logistics, supply chain, supply chain management, sustainability, third-party logistics
3	Blue	It is related to transportation and last mile, with great attention to efficient and environmental-friendly solutions	7	Carbon footprint, eco-efficiency, freight transportation, innovations, logistics innovation, logistics service provider
4	Yellow	It deals with the managerial approaches to develop sustainability in the supply chain	7	Case study, data envelopment analysis, framework, retailers, survey, sustainable logistics
5	Purple	It deals with general terms of adoption and diffusion of technology related to the supply chain	5	China, cloud computing, innovation diffusion, logistics services, technology adoption

Table 1 – Clusters of keywords and related items

The five clusters identified by the software are a bit different from those created by the content analysis. Different items characterize every cluster, and as we can see, the clusters do not have all the same size in terms of items included. The different clusters are presented in different colours (see Table 1 and Figure 4).

VOSviewer also provides a visualization of the different clusters, the nodes, and the link with their relative strength (bigger is the bubble in the following graph, more frequently the keyword is used).

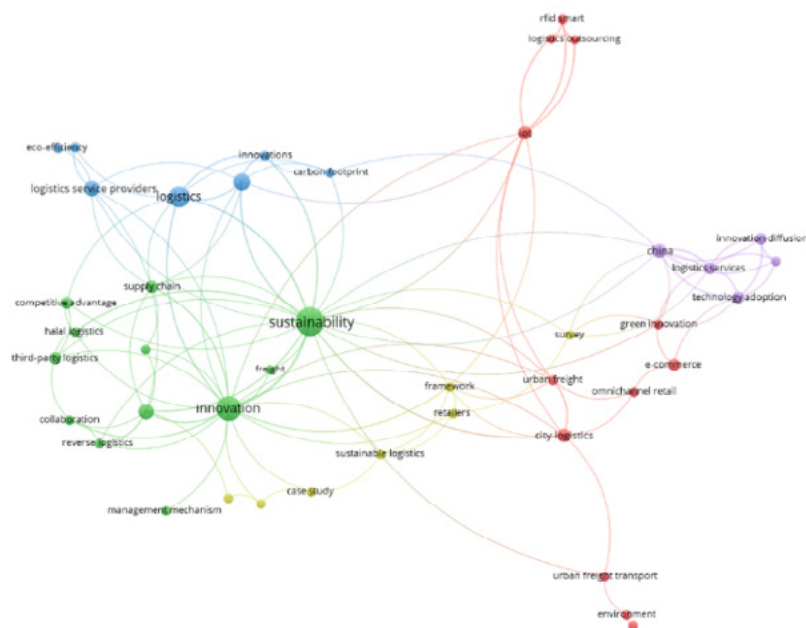


Figure 4 - keywords network



Comparing the groups, emerging from the content analysis, with the clusters identified through the keywords, some remarks emerge:

- Cluster 1 on “Industry 4.0” (RED), can be related to group C “Industry 4.0”. The two overlap in terms of technological innovation commonalities (items like RFID, IoT, and new approaches of the supply chain such as omni-channel retail and e-commerce are very common in both cases).
- Cluster 2 on “decision making and alliances” (GREEN) is strictly related to the group E “Green supply chain management and alliances”. Some items such as “third-party logistics”, “collaboration” and “competitive advantage” are commonly diffused across the two cases.
- Cluster 3 on “transportation and last mile” (BLUE) can be connected with group A concerning “last-mile delivery”. In fact, in both cases, the topic of last-mile delivery in several contributions is dealing with new smart vehicles powered by renewable energy and dealing with the topic of eco-efficiency.
- Cluster 4 on “managerial approaches” (YELLOW) can be connected to group B “corporate strategy approach”. In both cases the concepts presented are largely connected with a renewed management of the company, considering all value chain activities and towards a more positive impact on the environment and/or the society.
- Cluster 5 on “adoption and diffusion of technology” (PURPLE) has not a strong connection with the remaining group D of smart cities and infrastructure. However, some commonalities emerge: elements of the cluster such as “cloud computing”, “innovation diffusion” and “technology adoption” are present also in the definition and analysis of smart cities as enabling factors.

In conclusion, clusters are not completely overlapping with the groups described in the content analysis since some items inside a cluster can refer to other groups (as the relation is not unique or mutually exclusive) and overall it can be said that the two analyses confirm, complement and reinforce each other.

Another representation of the network of keywords, based on the year of publication, was performed. Some preliminary remarks highlight the recent development of sustainability-oriented innovation in this field, and the most recent developments of city logistics and last-mile topics.

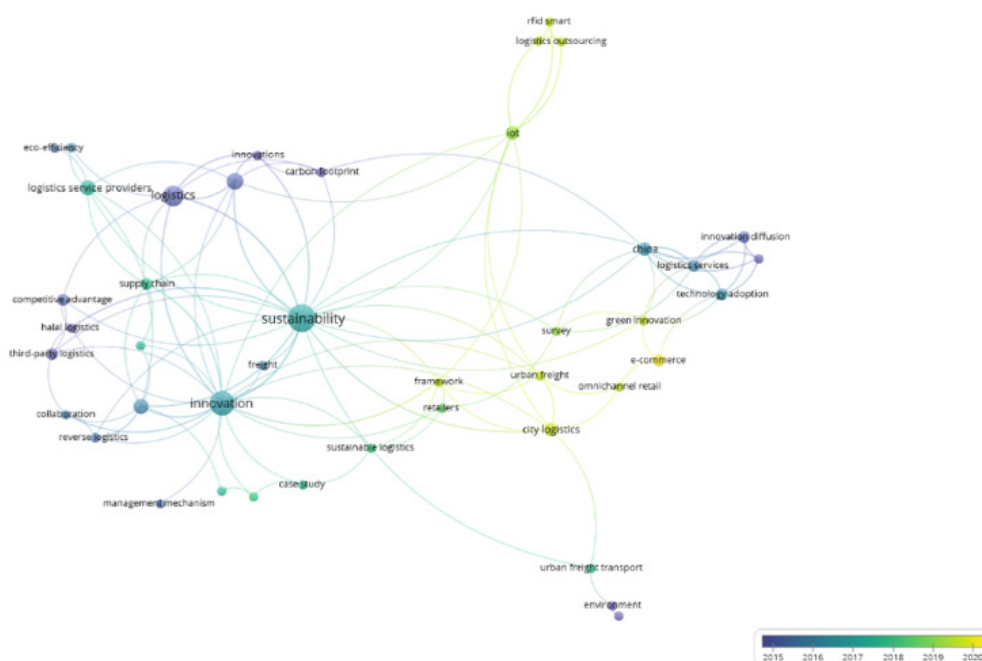


Figure 2: year of publication of the documents

Discussion and conclusions

We have identified five groups in terms of areas of interest when dealing with the topic of sustainability-oriented innovation in the supply chain. Therefore, we have answered our research questions. As shown by the items in the keywords network, sustainability is a central topic touched by almost all the papers investigated. It is present in almost every cluster identified. For example, “green innovation” is included in the first cluster, “LCA” (i.e. life cycle assessment) in the second, “Carbon footprint” in the third, and finally “sustainable logistics” in the fourth. These results are in line with the main contributions presented that state that sustainable development, logistics, and supply chain are becoming three connected and topical global research areas (Lazar et al., 2021; Cui et al., 2010).

The overlap between groups (defined through content analysis) and clusters (defined through the keywords analysis) pinpoints how sustainability and innovation are key pillars of the analysed literature. However, from the analysis of the publication year, sustainability in the supply chain emerged as a current and developing trend. Specifically, three main themes can be synthesised and drawn as more recent research trajectories, and these could become the object of an agenda for future research endeavours:

- I. Open innovation: is defined as the company’s attempts to both change or sustainably design its supply chain recurring to external sources/partners of innovation due to a lack of internal capabilities. In fact, open innovation is described as “valuable ideas that can come from inside or outside the company and can go to market from inside or outside the company as well” (Loren, 2011). So, the company is seeking to find someone able to help them through collaboration or alliances to design a “green thinking” approach and design for the supply chain.
- II. Big data and KPIs: it is related to the adoption of a key performance indicators control and the study and collection of big data are listed. According to some papers, companies are trying to develop a green supply chain relying on data about transportation and purchasing. In particular, they are trying to collect and use big data analytics to predict and control the supply chain. It should be remembered that “big data can be understood as a massive amount of data generated by the internet, mobile phones, tablets, cameras, smart devices, sensors, etc.” (Paliszkiewicz, 2020). Moreover, leveraging Industry 4.0 technologies, big data support the control of the KPI, defined as “key performance indicators focus on the aspect of organizational performance that are the most critical for the current and future success of the organization” (Parmenter, 2015) to maintain high service level without wasting resources.
- III. E-commerce and last-mile: it is related to the fast-growing concept of e-commerce described as “a broad concept that covers any transaction that is effected via electronic means” (Pinto, 2003). In fact, due to globalization and to the rise of global players, the new way to shop has drastically changed the supply chain. For this reason, nowadays more and more products are shipped daily compared to what used to happen in the past. Some companies are trying to keep up the pace of this growth and they think the theme of sustainability is strictly connected to the theme of this innovation. Moreover, once again companies are trying to identify the best route-to-market by optimizing resources and minimizing costs.

In conclusion, some remarks can be drawn:

- Sustainability has become the key driver when dealing with supply chain technologies. The adoption of new technologies, coming from Industry 4.0 and lean manufacturing, has been used to reduce resource consumption and supply products with a “zero-waste” mindset.
- Companies cope with sustainability in different ways. Some of them are implementing the above-mentioned tools, particularly big data analytics and KPIs measurement. At the same time, other companies are redesigning their supply chain from scratch, accessing other companies’ knowledge and know-how to develop more sustainable supply chains.
- Linked to the above, the creation of alliances and networks seems to be the best way from a company’s point of view to design and develop a sustainable supply chain. Companies are, in fact, using the idea of open innovation to find out some ideas coming from experts outside their own company to create a sustainable supply chain.
- In the majority of cases, it comes all to the strategy identified by the company. As already stated, most companies do not have the internal capability to design a green supply chain. However, they have some financial capabilities to acquire some other knowledge, also knowing that the governments always support environmental awards.

If implications for scholars and researchers are more evident, also managers and entrepreneurs can find valuable insights. Practitioners can appreciate the ever-growing importance of sustainability in logistics and supply chain management. In fact, sustainability-oriented innovation in logistics does not touch just the “classic” areas of debate (i.e., few environmental topics often associated with green marketing, greenwashing, or concurrent cost minimization), but it addresses novel subjects. These include the intersection among innovation, sustainability, technology, managerial and organizational practices such as alliances, with specific reference to the need to cope with the growing demand for last-mile services due to the growth of e-commerce.



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CIRCULAR SUPPLY CHAIN 4.0: A TRIANGULATION ANALYSIS REVIEW

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1. Introduction:

Digital technologies have significantly altered communication and information exchange among societies (Nasiri et al., 2020). Technological innovations promise more efficient production processes, increase profit margins, cost minimisation, advanced reliability, and efficient management control (Bag et al., 2018; Ahmed et al., 2021). Every industry passes through a speedy transformation to cope with today's intense market competition and changing financial, social, environmental, and technological circumstances. Consequently, the future of every industry is determined by its openness to innovation and technology that appeared with Industry 4.0 revolution (Kalsoom et al., 2020; Ahmed et al., 2021). The changes are occurring at an incredible speed in all business environments and industries. Supply chains (SC) as an integral part of industries cannot remain static. The dynamic business drifts with digital technological novelties have altered the way SCs operate (Nasiri et al., 2020). To transform SCs in the fourth industrial revolution and CE era can be seen as the most appropriate way (Ozkan-Ozen et al., 2020; Atif et al., 2021). Integration of CE in the supply chain management (SCM) approach balances the forward and reverse loops of the SC and enhances the overall SCM's sustainability (Genovese et al., 2017). In some studies, the term "circular supply chain (CSC)" links CE with SCM (Genovese et al., 2017; De Angelis et al., 2018; Mbolli et al., 2020). The working definition of circular supply chain management (CSCM) emerged in the literature very recently (Farooque et al., 2019).

The popularity of CE principles in the era of I4.0 has attracted significant attention from both researchers and practitioners, which is reflected in the recent surge of publications in international journals (Atif et al., 2021). However, despite this prominence, the research on CSCM under the umbrella of I4.0 technologies is fragmented between several research streams. Majority of current research focuses on digitalisation and CE (Antikainen et al., 2018; Okorie et al., 2018; Alcaayaga et al., 2019; Ingemarsdotter et al., 2019) and SC and I4.0 (da Silva et al., 2019; Chalmeta et al., 2020; Chiappetta Jabbour et al., 2020; Garrido-Hidalgo et al., 2020; Kalsoom et al., 2020) separately. In this context, very few studies specifically present the research linked to the integration of I4.0 on the transition towards CSCM. Thus, this study is intended to bridge this gap by offering a state-of-the-art literature review.

This study adds to the knowledge by mapping the status of I4.0 technologies to underpinning CSCM. A systematic literature review of 87 studies is conducted. We present a triangular analysis that includes a bibliometric analysis, content analysis, and ReSOLVE framework to drill down into a detailed discussion. Thus, the study's primary purpose is to identify the main trends, characteristics, and key I4.0 technologies of implementing CSCM in the fourth industrial revolution.

1. Research Methodology



Systematic Literature Review (SLR), the research method adopted for this review, is a powerful tool to assess the published research in scientific fields and minimises bias through exhaustive literature search (Ahmed et al., 2021; Mehmood et al., 2021). An SLR followed by a bibliometric analysis and content analysis has been used for this study, known as an approach called 'Triangulation Analysis Review' to meet the purpose of this review. A version of the five-step approach drafted by (Denyer et al., 2009) was adopted for the study. Figure 1 represents the steps followed in SLR.

Figure 1: Summary of the SLR Process

Setting Scope and Objectives: Step 1 involved setting the scope and research questions to meet the objectives of this review. The study explores the relationship of I4.0, IoT and CSCM; and identify the drivers and barriers. Three research questions have been developed to achieve this aim: 1) What is the status of I4.0 implementation in CSCM? 2) How I4.0 technologies are influencing the transition towards CSCs by using the ReSOLVE framework? 3) What are the challenges and enablers to implementing digital technologies in CSCM?

Identifying Keywords: In Step 2, we started with the selection of the best keywords that were relevant to our topic. Multiple brainstorming sessions among the authors helped in the identification of twenty-two keywords. The keywords such as 'circular economy', 'Industry 4.0', 'IoT', 'supply chain' and 'smart manufacturing' were used to filter raw data gathered from data sources. Validity was enhanced using Boolean logic, and the keywords were pooled into a series of 14 strings to refine them for the research. This helped us to reform the search strings using 'AND' and 'OR' with all the possible combinations between the keyword sets in different databases.



Figure 2: Publication from 2012-2020

Selecting Databases and Setting Timespan: In Step 3, the search strings were applied to the titles and abstracts of publications in the five central online databases that include Web of Science, Science Direct, Emerald Insight, Taylor & Francis and Wiley. These databases are widely used and are reliable online sources of literature for review studies. Moreover, high-quality peer-reviewed journal articles with full-length abstracts are available on these databases. Although research within CE and IoT domain is not a new phenomenon, we believe that CSCM within the I4.0 domain has gathered more focus and momentum during the 2000s, as described in Figure 2. Therefore, to restrict the scope of this review, it was decided to analyse articles published from 2012, as a consistent hike was observed in research within the context of CE, I4.0 and IoT. Hence, a period of 9 years (2012-2020) was specified for our study.

Setting Quality Criteria: In this study, a triad approach was adopted to ensure the reliability, validity and quality of the shortlisted articles (Cronin et al., 2008). Firstly, the articles were manually screened to ensure subject relevance. Secondly, articles were sorted using an inclusion/exclusion criterion applied (Figure 3). Finally, articles were further refined by going through the title, abstract, purpose, objectives, findings, and conclusions to ensure widespread coverage of extant literature in the context of CE, IoT, I4.0 and SCM. The Association of Business Schools (ABS) ranking of the concerned journal was used to identify the relevance and reliability of the selected papers for the study in the second step. The rationale behind this was that ABS ranking ensures the significance of the selected papers as these journals are evaluated based on citation scores, expert judgments and peer reviews. In addition, quality attributes (QA) identified by a series of questions were also applied to finalise the review articles described in Figure 3. The involvement of the authors in crosschecking the quality attributes of the nominated articles allowed us to eradicate the presence of any subjective biases, enhancing the validity and reliability of data. Figure 3 represents the strategy to narrow down the search; a total of 87 articles were found useful for the study.

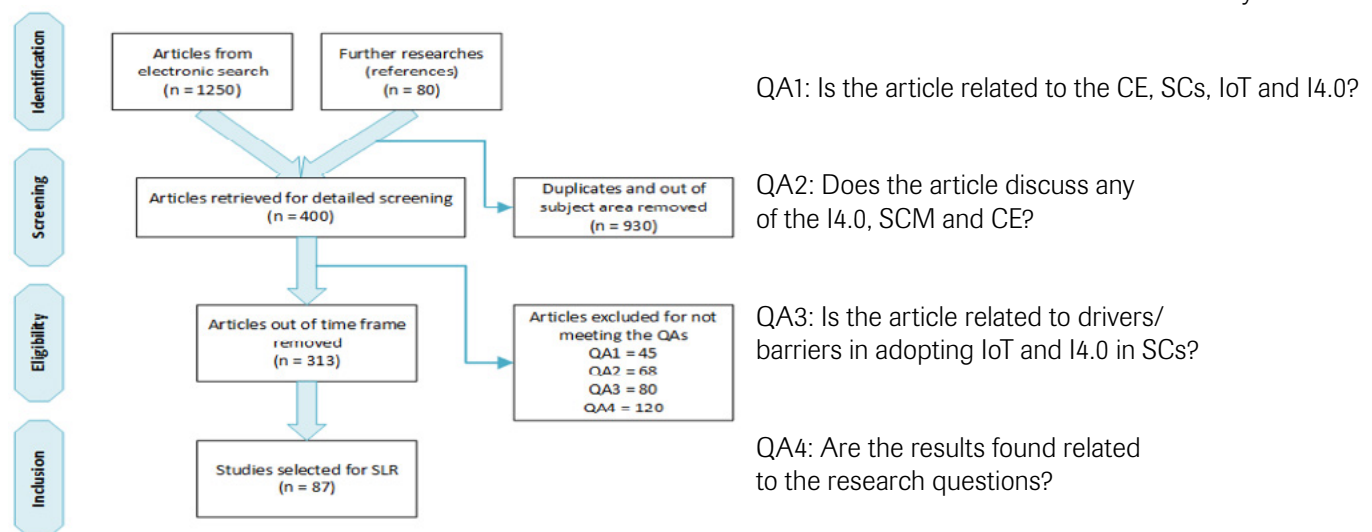


Figure 3: PRISMA flow diagram showing a selection of articles



Analysis

3.1 Bibliometric Analysis

Geographical Location Analysis

The geographical location analysis has revealed that research on relevant topics took a global approach. A large number of the publications have been found in Europe ($n=25$), followed by Asia ($n=19$), South America ($n=15$), North America ($n=14$), Australia and Middle East ($n=5$) and Africa ($n=4$). Figure 4 shows the region-wise and country-wise distribution of publications. The VOSviewer software was used to envision the network map of country co-authorship presented in figure 5. It provides valuable information and helps researchers to produce, envisage and discover maps based on network data. The frequency of occurrence formed clusters; the dimension of the circle illustrates the number of publications, and the size of lines represents the collaboration size. Figure 5 shows that the largest set of connecting countries comprises 13 countries in 4 clusters. The results further illustrated that only 13 of 41 countries were collaborating in publishing more than five documents. Figure 5 highlights that Italy collaborates more with other countries globally. The link strength of Italy with USA, England and India was 7, 2 and 1 respectively. Moreover, the Italian researchers have collaborated with other researchers from France, Germany, Brazil, and Australia.

Region-wise Publications

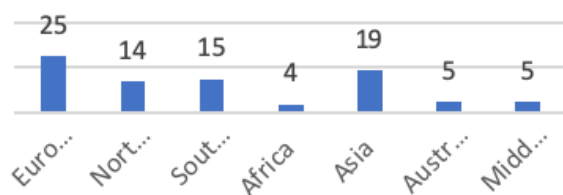


Figure 4: Region-wise publications



Figure 5: Network visualization map of country co-authorship

Research Method Analysis:

43 publications out of the total finalised for the analysis are qualitative, 21 are quantitative, and 17 have used mixed methods, as shown in Figure 6. More quantitative and evidence-based studies are needed to understand and implement IoT and I4.0 technologies within SCs to promote the CE. Figure 7 shows the distribution of selected studies based on the methodological approaches adopted by the researchers. It has been observed that 25 studies adopted conceptual approach followed by empirical with 22, applied compassing 18 while analytical to consist of 14 studies. There is a need to have more analytical studies in this context.

Research Methodology

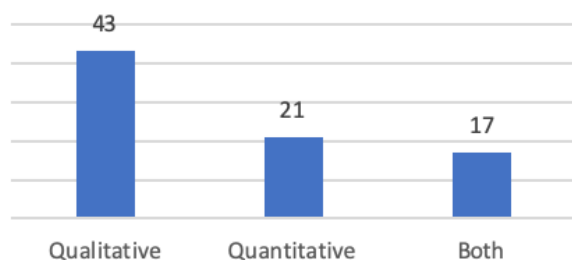


Figure 6: Distribution of adopted research methodology

Methodological Approach

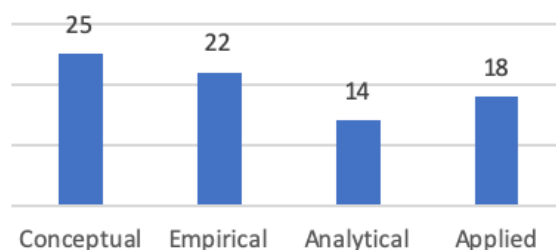


Figure 7: Distribution of adopted methodological approach

Industrial Distribution Analysis:

It has been observed in Figure 8 that 24% of the supply chains sector takes up the majority of the academic research interest, followed by general industry (21%) and logistics (15%). Notably, the waste sector (3% representation) has shown little interest in current studies related to the CE. Moreover, 6% of publications did not state any particular industry, taking 26% out of the total, representing that this concept has been applied to different sectors and not just one specific sector. Other sectors with low attention currently and future research perspectives include fashion, retail, household, and electrical appliances.



2.2 Content Analysis

Keyword Analysis: Using VOSViewer, the co-occurrence of the author's keyword network was created because a keyword must appear in at least five papers to be included in the analysis (Ejsmont et al., 2020) and Figure 9 illustrates that 41 of 87 papers fulfil the criteria. VOSviewer generated seven different clusters, which comprises 741 links with total link strength of 280. The positive and high link strength depicted that given keywords often coexisted in the scientific discourse. For example, it was revealed that the word CE has the most significant node and the most frequently used word and had shown a significant association with sustainability and I4.0. In contrast, supply chain management has a smaller node with 34 links and 15 total link strengths.

Co-authorship Analysis: Co-authorship network analysis illustrates the collaboration between the researchers. Collaboration among researchers increases productivity and competitiveness within the research communities (Zekhnini et al., 2020). In co-author network analysis, we set the author's minimum number of publications to 2 in VOSviewer. However, only 31 of 319 authors were connected, see Figure 10. Furthermore, 13 clusters with 26 links and 31.50 link strength show that clusters were dispersed and disconnected. The overall results highlight that collaboration among the research in this field is not well established. In contrast, the association among authors in producing co-publications can significantly promote the generation of innovative studies.

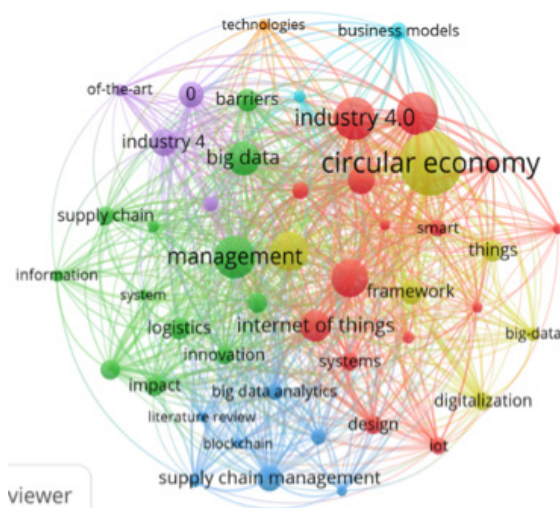


Figure 9: Keyword network visualization map based on co-occurrence



Figure 10: Network visualization map of co-authorship

3. Integration of CE, Supply Chain Management and I4.0

CE can be perceived as the most applicable way to revolutionize the supply chain in the era of I4.0 to incorporate the sustainability factor under the current circumstances (Bag et al., 2020). According to de Sousa Jabbour et al. (2018), there is a synergistic relationship between I4.0 and sustainability, bringing revolutionary changes throughout the production system worldwide. To further elaborate the relationship between them Garcia-Muiña et al. (2018) stated that CE and I4.0 are the two sides of the same coin. To guide the organisations through the implementation of CE principles, the Ellen MacArthur Foundation has offered a framework that comprises six business actions called ReSOLVE. Regenerate is based on the concept of moving to renewable energy resources. A biological cycle is involved in facilitating the flow of energy and material. Share includes shared economy perspective, where assets are shared between individuals and possession of asset loses importance. Optimise is a technology centred approach. Organisations need to digitise the manufacturing technologies such as big data, Internet of Things (IoT), radio-frequency identification (RFID), automation, sensors to reduce waste during production within the supply chains. Loop is an approach centred on biological and technical cycles. Biological cycles recapture the worth of organic waste, whereas technical cycles restore the value of post-consumption products. Virtualise is based on service focused strategy in which physical products replaces with virtual and dematerialised products. Finally, the exchange approach is based on exchanging old and non-renewable commodities for innovative and renewable goods.



Supply chain refers to all activities, processes, and functions involved in sourcing, producing, and delivering goods and services (Winsner, 2014). In the scope of the supply chain, every firm's function includes logistics, purchasing, manufacturing, marketing, research and development, product design, and total value. Therefore, considering the definitions above of supply chains, we divide supply chain processes into four broader categories, i.e., procurement, operations, logistics/reverse logistics and servitisation and developed matrix presented in figure 11 to the CE business models projected by ReSOLVE framework and I4.0 technologies identified in the reviewed article. For constructing the matrix, we followed the Jabbour et al. (2018) framework.



Figure 11 ReSOLVE Framework

Regenerate business model can be supported by I4.0 technologies to retain the biological resources and restore ecosystem health. Using IoT (RFID and sensors) in agricultural land productivity can be maintained by monitoring the soil content, humidity, and moisture level (Wasson et al., 2018). Moreover, IoT, Cyber-Physical System (CPS) based Operations management (OM) including, operation analysis, operation planning, operation optimization and production decisions, can reduce the consumption of natural resources, improve the yield, and enhance the biological life of land (Rad et al., 2015)

I4.0 technologies facilitate people to connect and share market information. These technologies can support the share business model by connecting people. Procurement is an essential part of finding and agreeing on mutual terms while transmitting or shifting product ownership. Big data analytics (BDA), IoT, and blockchain are recognised as critical future solutions in helping decision-makers to optimize procurement processes through sharing of real-time information between customers and vendors (Ibem et al., 2014; Rejeb et al., 2018; Bag et al., 2020). Products can be monitored by using sensors in products during customers use, and their life span can be extended by regular performance monitoring and maintenance. Consequently, it will bring new investment opportunities for organizations in product up-gradation before shifting the ownership (Bag et al., 2018). IoT and cloud manufacturing (CM) data can improve operations and logistics decisions (Tu et al., 2018)

Optimise business model could profit from I4.0 technologies such as IoT, CPS, RFID and BDA. These technologies accumulate data from the processes and physical objects, like machines and enable a firm to effectively control the information and material flow (Lamba et al., 2017) and transform the firms into real-time enterprises. This real-time information helps inventory management, system efficiency management, maximising productivity, and minimising waste (Alwadi et al., 2017). However, currently, most of the logistics automation management system is still in the state of manual or semi-automation that costs lot of work time and probability of failure is higher because warehouse workers mostly rely on manual operations. Therefore, digitization of logistics management is necessary to optimise resource usage (Chen et al., 2019). Additionally, the use of sensors helps identify various defects before something goes wrong; as a result, timely actions can be taken to prevent any crashes, which might create waste in pre and post-production processes (Shah et al., 2020).

Loop business model is based on the circularity of material and energy principle of the circular economy. The I4.0 technologies from reviewed articles supporting the Loop business model are cloud manufacturing, CPS and IoT. IoT can provide real-time interaction between people, goods, and devices during purchasing secondary material, making the process more flexible and efficient (Dev et al., 2020). Pairing products with sensors and chips during operations could ensure that they are returned and reused after their first lifecycle (Gligoric et al., 2019). Smart logistic systems based on CPS can improve resource planning, warehousing, and transportation system (Barreto, Amaral, and Pereira 2017). Moreover, in logistics, IoT in terms of RFID, visualization and AR-based on 3D printing could improve the visibility of goods and diminish the potential errors which could cause substantial losses (Ginters et al., 2013). Reverse logistics handles the collection of returns or post-consumption of goods. IoT sub systems like RFID and cloud-based ERP systems provide real-time information to the reverse logistics partners for reuse, remanufacturing, or refurbished components (Dev et al., 2020).



The virtualization business model can gain an advantage from IoT, AM and CM technologies of I4.0 (Coreynen et al., 2017). The focus of the virtualization model is servitisation so both IoT and CM can connect vendors, customers, and organisations to offer services rather than physical goods. Additionally, IoT based servitisation could unlock innovative product-service systems (Rymaszewska et al., 2017). Additive manufacturing (AM) in terms of 3D printing with IoT can support the Exchange business model. Additive manufacturing, often referred to as 3D printing enables operations management more flexibility by producing customised products without cost penalties and reducing material use, consequently producing less waste (Lipson, 2013). IoT based services help optimise procurement decisions related to innovative and renewable raw materials (Lopes de Sousa Jabbour et al., 2018).

4. Conclusion

This review investigated the extant literature on integrating I4.0 technologies into CSCM, using a systematic literature review approach. It has been observed that there is insufficient literature directly addressing I4.0 and CSCM; however, the majority of the papers focused on investing research concentration on the I4.0 revolution in CE and SC separately. Several reviews have focused on sharing the opinion that I4.0 can act as an enabler of CE. Some scholars have described the relationship between I4.0 and CSCM through the digitalisation of CE, which provides the potential to the companies to improve their performance. Additionally, the ReSOLVE framework indicates that the most common I4.0 technologies used in CSCM were IoT, CPSs and BDA. Although several relations have been observed in this paper, many unsolved domains in need of additional attention have been found. Firstly, empirical evidence on how CE and I4.0 technologies are applied in practice by SCs towards CSCM4.0 is scarce. This requires an enhanced understanding of how I4.0 technologies with the integration of CE principles can support suppliers and stakeholders involved in all the phases of the SCs. Secondly, the practical implementation of I4.0 technologies in CSCM requires continuous monitoring and control of the whole lifecycle becomes circular and integrated. Finally, the ReSOLVE framework illustrated that ample room is left for exploring the other I4.0 technologies for CSCM. This study has provided a reference framework for future research investigations to explore the other I4.0 technologies. This review has some limitations—classified papers in the review used mostly on results from academic journals. However, industrial reports, conference papers, books, and book chapters are excluded, improving this analysis' outcome.

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DIGITAL TRANSFORMATION IN SUPPLY CHAIN



IMPLEMENTING BLOCKCHAIN IN THE FOOD SUPPLY CHAIN: AN EMPIRICAL STUDY

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1. Introduction

In recent years, Blockchain technology has gathered significant interest from both managers and researchers in the area of the food supply chain (FSC). Fundamentally, Blockchain is a distributed ledger technology which can store and share information in a decentralized, secure, and trusted manner (Wong et al., 2020). Anticipated to have the potentials to solve critical challenges in food supply chain management (FSCM) such as end-to-end traceability, information asymmetry, and low level of visibility, Blockchain has seen increasingly uses in the food industry (Zhao et al., 2019). A number of notable examples include Carrefour using Blockchain for poultry product range (Food blockchain | Carrefour Group, 2020), and Walmart piloted Blockchain for tracking mangoes and pork (Hyperledger, 2019).

The literature on Blockchain technology in the context of FSC has also seen significant growth in the past few years, exploring various aspects such as applications, drivers, barriers, and adoption (Zhao et al., 2019; Vu et al., 2021). Among few studies that addressed the adoption of Blockchain (i.e. Queiroz and Fosso Wamba, 2019; Wong et al., 2020), the focus is often on the single-stage where the decision of adopting Blockchain is made. When studying the adoption of new technology, understanding the pre-adoption steps (i.e. assessing the suitability of the technology) and the post-adoption steps (i.e. deploying the technology at the organizational level) is crucial to successfully adopt a new technological innovation to generate values (Zhu et al., 2006; Martins et al., 2016). Therefore, this study seeks to answer the question “How to implement Blockchain for organizations in FSC?”. While attempting to answer the research question, this study found that the process of adopting Blockchain at the organization level typically unfolds over three main phases Initiation – Adoption – Implementation, and the main determinants to such process come from the Technology – Organization – Environment – Management contexts. Thus, the contribution of this paper is twofold. First, it provides a holistic view of the end-to-end Blockchain implementation process in FSC, with specific activities and influential factors. Second, this study proposes an evident-based framework for implementing Blockchain in the FSC, proving a practical reference for managers in the field when considering the use of Blockchain.

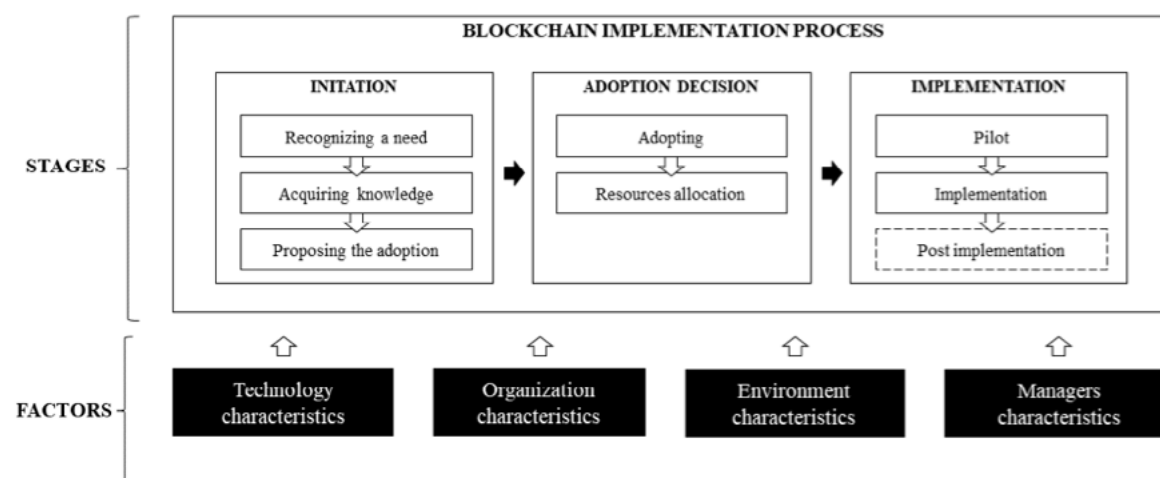
2. Background to the research

The body of literature regarding the adoption of innovation is vast, with various theories and models. It is argued that relying on a single theory might not be sufficient to reflect and understand the increasingly complex phenomenon of today’s technology adoption (Wamba and Queiroz, 2020). Hence, integrative models – using more than one theoretical perspective – are often utilized in examining the implementation of technology (Zhu et al., 2006; Martins et al., 2016; Kamble et al., 2020; Wamba and Queiroz, 2020). Hence, this study followed the same strategy in developing the conceptual model for Blockchain implementation in FSC. In this study, innovation and technology are used interchangeably, when referring to the Blockchain technology.

A stage model is often used to examine the implementation of new innovation at the organizational level. Diffusion of Innovation (DOI) theory by Rogers (2003) proposed five phases for diffusing an innovation: knowledge, persuasion, decision, implementation, and confirmation. Recent studies, based on the principles of DOI, often suggested a three-stage model to capture the activities before, during, and after the decision of adopting new technology: Stage 1 Initiation – the organization recognizes a need for the technology, gathers more knowledge, and proposes a plan for the adoption, Stage 2 Adoption – the organization makes the decision of adopting and allocates necessary resources for the adoption, and Stage 3 Implementation – the organization runs a pilot, modifies and deploys the technology at a larger scale, and carries out post-implementation activities (i.e. training, routinizing). Further, prominent theoretical perspectives such as Technology – Organization – Environment (TOE) framework (Tornatzky et al., 1990) and DOI (Rogers, 2003) can outline the determinants to the process of Blockchain implementation. In TOE, technology context refers to the characteristics of the technology being adopted, organization context indicates the descriptive measures (e.g., size and scope) and attributes (e.g., resource and infrastructure) of the adopting unit, and environment context includes external factors such as industry, regulations, market (Hameed et al., 2012; Martins et al., 2016). Lastly, several researchers stress the importance of management in the process of implementing new technology, thus advocating to consider management characteristics as a cluster of determinants with equal standing as technology, organization, and environment characteristics (Damanpour



and Schneider, 2009; Hameed et al., 2012). Drawing from the literature reviewed previously, the conceptual model for Blockchain implementation in FSC was developed as depicted in Figure 1 (Refer to Vu et al., 2021 for more information).



3. Methodology

Qualitative research was conducted, with semi-structured interviews being the main instrument for data collection. The motivation for employing a qualitative approach was to obtain rich and specific insights from industry experts to bridge the literature with the context for an in-depth and explicit understanding of the implementation of Blockchain for FSC.

A total of 13 semi-structured interviews were conducted. First, the authors examined public sources (i.e. news, industry reports, etc.) to develop a list of companies in the food industry, who have initiated/piloted Blockchain. A letter of invitation was sent to individuals from those companies, who have been directly involved with the Blockchain adoption projects. Potential candidates from 45 companies were contacted, and 13 agreed to participate (see Table 1 for generic description), resulting in a 28% rate of response. An interview protocol, with open-ended questions about typical activities of a Blockchain project and associated influential factors, was developed and agreed upon among the authors. Furthermore, the first three interviews also served to validate the relevance and clarity of the questions. Certain insights from these interviews were relevant to answer the research questions, thus the data was included in the analysis. Most participants gave consent to record their interview. One participant did not provide permission, thus the interviewer took notes for the main points of the interview and validated those with the interviewee later. A transcription was automatically created by the online interview platform – Zoom, then was verified with the audio recording for any correction, and finally was used for the data analysis.

Participants (P)	Type of organization	Position	Experience
P1	Fruit producer	Quality manager	15+ years
P2	Blockchain service provider	Business development manager	2+ years
P3	Seafood producer	Sale executive	10+ years
P4	Blockchain service provider	General manager	5+ years
P5	Blockchain service provider	CEO	20+ years
P6	Blockchain service provider	Founder & CEO	20+ years in technology adoption, 4+ years in the food industry
P7	Food regulator	Project manager	5+ years
P8	Blockchain service provider	Project manager	2+ years
P9	Seafood reseller	Founder & CEO	10+ years
P10	Blockchain service provider	Founder & CEO	5+ years
P11	Consulting service	Senior consultant	10+ years
P12	Blockchain and software service	Director of emerging technology	10+ years
P13	Processed food	Founder & CEO	4+ years

Table 1. General information about the participants.



4. Analysis and findings

Coding was the method of choice to analyse qualitative data from the interviews. Nvivo 12 software was used to aid the coding process. First, a segment of the data – often a sentence or a coherent set of statements – is assigned with a relevant concept. Then, related concepts are grouped under a more abstract first-order concept. First-order concepts are subsequently categorized under a relevant context – a second-order theme. Literature on innovation adoption was utilized during the coding process, as the authors went back and forth between extant literature and qualitative data to improve on the concepts used for capturing the meaning of datum, establish the relationships between different concepts, and cluster concepts under a more abstract one (theme and/or categories). Due to the limited length of this conference paper, an example is given to illustrate this coding process. Table 2 illustrates how the specific concept of the organization's innovativeness, part of the organization context, was induced from the qualitative data.

Illustrative quotes	Concept	First-order concept	Second-order theme
We've got a very, very strong R&D investment program because innovation and improvement are critical to our future development. A value of our company is recognizing the importance of investing in innovation – P1.	Strong R&D investment and infrastructure	Innovativeness	Organization
We are always at the forefront of innovation, we always want to be at the top of the heap. We don't want to be at the bottom of the heap – P3.	Actively seeking new ideas		
From the start, [the adopting company] was really thrilled about blockchain... they've already heard about at least bitcoin or blockchain technology before, they're also very keen on experimenting with new idea – P8.	Encouraging trial of new ideas		

Table 2. Example of coding.

Drawing from the interviews, a general view of the step-by-step process for adopting Blockchain and four main categories of determinants to the process are obtained. This process and determinants closely reflect the phenomenon of implementing Blockchain in the specific setting of FSC. The following sections will discuss the findings in detail.

The process of adopting Blockchain in FSC

Similar to what the literature suggested, Blockchain typically unfolds in organizations in FSCs over three main phases: initiation, adoption, and implementation. For the initiation phase, firms typically started with recognizing a need for Blockchain as a potential solution to some persistent challenges in FSCM. P1 recalled, "we want to capture as the product moves through the chain. And then, how do we share that with our chain partners. And then, how do we use the blockchain technology to help us to do that". After deeming Blockchain as a suitable solution, firms determine the scope and the plan for the project. Identifying a specific scope helps the organization to set appropriate objectives and a roadmap for the implementation. P7 recalled, "We start off with workshops to do a bit of brainstorming around the scope of the project... to say what is achievable, what are your burning questions that we want to tackle". On the other hand, planning is to set the stage for Blockchain implementation by analysing the current supply chain and determine important elements such as suitable solutions, parties involved, data point to be captured, etc. P2 described the activity as "to implement any solution in the supply chain, you have to know your supply chain. The first thing we do is we support with the data mapping and the participants mapping. It is important to understand who is involved, who is doing what, when does the ownership of the products change hands, and at what places? So the activity is to map out the supply chain". Following the scoping and planning step, the next activity is conducting a pilot of Blockchain adoption. This finding is interesting since the experts' insights are different than what the literature suggested. In a number of adoption models, a pilot is often found to be included in the implementation phase rather than initiation (Kim and Garrison, 2010; Pichlak, 2015). For the case of Blockchain for FSC, the final decision of using Blockchain comes after the pilot, and subsequently, the results of such pilot can dictate the decision of fully adopting Blockchain.

There are two instances in which the participants successfully integrated Blockchain into their organization and operation. Thus, insights regarding the implementation phase of Blockchain project were acquired. One important finding is the orientation of activities related to diffusing the technology at the individual level. Since Blockchain is an underlying technology added on top of existing IT systems and processes, it brings minimal changes to employees' daily tasks. The targeted end-users in this case are often the end consumers and/ or the direct buyers of the food products, as



organization aims to onboard them with the Blockchain experience. P9, who successfully integrated Blockchain for their business, shared that “for the next step, our focus is on maximizing usability for the end-user (end-consumers). So we spend time to develop user experience such as the mobile APP for tracking our seafood. This will make onboarding others with Blockchain traceability that much easier”. The other main activities for this phase are preparing the solution for large-scale deployment and integrating Blockchain into the organization’s operation and business.

The determinants of the Blockchain implementation process in FSC

Relevant determinants of Blockchain implementation in FSC are found from experts’ insights. These factors can be categorized into four clusters: technology, organization, environment, and management characteristics.

For the technology context, it was found that relative advantages, complexity, compatibility, and cost of Blockchain are relevant to the process of implementing Blockchain. Experts perceived that Blockchain possesses relative advantages over existing IT systems by bringing new values and improving current processes. New values can be interpreted as novel capability/ business enabled by using Blockchain. For instance, P5 successfully deployed a Blockchain solution for a novel financing model, enabling their client to have more capital for expanding their farming. Food recall is often the example that experts mentioned when discussing how Blockchain can improve existing processes. P2 theorized how Blockchain can help with the case of the E.coli outbreak due to Romaine lettuce in the US “for example, the IBM food trust is about having easy access to data on specific shipments. So the famous example with lettuce in the USA, if you have a problem with one, you will not recall everything, because you will know exactly where these problematic containers are coming from”. The complexity of Blockchain is also perceived as an important factor to the implementation. Especially during the pre-adoption activities, participants expressed challenges in choosing the right solution, configuring different parameters of the system to synchronize with current operation, and identifying how to scale the system sustainably for large operations with numerous parties involved. Part of the complexity is because Blockchain is still novel to the food industry and more efforts from early adopters are needed to understand and develop the solution – as P10 said “we have a lot of discussions that are underway. But if I’m asked to put it, I would still view Blockchain as definitely being at education phase. People are still getting their heads around it and trying to figure out”. Compatibility is another aspect that was highlighted by the participants. Firms are keen to embark on the Blockchain journey when they perceive it to be consistent with the existing values and needs. Extant literature also stressed that being able to integrate with the current process and IT infrastructure is a key for a new technology to integrate into an organization successfully (Martins et al., 2016). Lastly, the majority of participants agreed that the cost of Blockchain should factor into the decision of using it. Cost is recognized as an influential factor to innovation adoption (Hameed et al., 2012), and even more so in the food industry setting, as emphasized by P4 “at the end of the day, food industry as a whole, the margins are really tight. So whatever you do, you should not add cost”.

Insights from participants unveiled that resources, readiness, innovativeness, size and position of an organization are influential to the process of Blockchain implementation in FSCs. In terms of resources, both financial and human resources need to be sufficient for the Blockchain project. The importance of finance is self-evident, and human resource is just as important to the implementation process. P5 attributed part of the success of their Blockchain project to having the right personnel from the adopting company involved “All of the staff there were very young, but they were exceedingly talented people, and that was such an advantage”. Readiness can be indicated by having the necessary technological capabilities and experience with using/ adopting IT systems. For instance, with the case of P3, determining the critical data point and having that information ready for their Blockchain-enabled traceability project were straightforward because “traceability for us is nothing new. We’ve had this requirement for many years before by customers”. Innovativeness is an interesting concept that participants brought up when discussing what enables firms to adopt Blockchain smoothly. Innovativeness of a company can be demonstrated by having strong R&D investment and infrastructure, actively seeking new technologies for strengthening their businesses, and having an encouraging attitude towards new ideas. Illustrative datum of this point can be found in Table 2. Finally, the size and position of firms are interesting inputs from experts regarding the determinants of Blockchain implementation. While it is evident that Blockchain has been initiated from companies of various sizes and positions in the FSC, a number of experts expressed the notion that large organization with the power to mandate other entities are likely to be quicker in adopting and diffusing Blockchain in their respective food supply chain. P12 gave an example “the farmer in Africa cannot dictate Nestle to adopt blockchain. It has to be the management of Nestle who will ask the farmer in Africa to be onboarded for traceability and visibility for their consumers. That’s how it works.”

According to the interviews, external influential factors to the implementation of Blockchain can come from regulatory bodies, consumers, and other organizations within the FSC. The influence from regulatory bodies often comes in two forms: encouraging the experiment of Blockchain and tightening rules. Five projects that were discussed by participants, were directly funded by the governments. Further, the majority of the participants predicted that scrutiny of food products will get stricter in the future, and referred to the same example of the FDA in the US. In one of their



recent publications, the FDA expressed the demand for more rigorous food traceability activities and, recommended Blockchain as a potential solution (U.S. Food & Drug Administration, 2021). On the other hand, consumers are also seen to be demanding more traceability and transparency of food products, and willing to pay more for authentic and safety-proven products. P9 stressed on this point that “Consumer demand for trusts. With more and more food recalls becoming more and more frequent, the consumer demand is becoming significant”. Additionally, influential factors to Blockchain adoption in the food industry can come from other organizations in the industry. P7 shared their experience of carrying out a Blockchain pilot funded by the government, in which three companies volunteered to take part. They are competing in the same market, and two of them joined only after knowing that the first company participated in the pilot. Furthermore, in order for a Blockchain initiative to be fruitful, the collaboration and willingness to participate from organizations within the value chain are also crucial. P2 recalled, “we are usually working with two or three connected companies in the supply chain at minimum, and sometimes even more, for an end-to-end solution”.

Lastly, the role of managers to the process of implementing Blockchain is highlighted by the participants. The attitude of top management is regarded as an important factor. Supportive and positive notions towards Blockchain technology from senior managers/ owners of the brand can serve as a great springboard for the projects to progress, as P8 explained “there wasn’t any negativity or concerns from top management. And I think that creates a healthy working environment”. Moreover, the involvement of top management during the projects is meaningful. P5 worked directly with the owner of the adopting organization from the start, and successfully deploy their Blockchain solution for the whole business. P9 and P13 are the CEOs of their companies that operates in the food industry. They both engaged actively with their Blockchain projects since the beginning and achieved fruitful results – large-scale implementation of Blockchain and successful pilot, respectively.

5. Discussion

Combining literature-driven conceptual model with empirical findings, an evidenced-based framework for adopting Blockchain in the food industry was developed, as illustrated in Figure 2.

At a broad level, the process of implementing Blockchain in the FSC is found to be similar to what extant literature has found regarding the adoption process of technology, with three sequential phases of pre-adoption, adoption decision, and post-adoption (Hameed et al., 2012; Martins et al., 2016). The activities at a more granular level are found to have differences, noticeably with the early introduction of the pilot, and the orientation of activities related to diffusing Blockchain for individual users. Furthermore, as extant literature has found a vast number of determinants to the implementation of new technology (for a comprehensive list see Hameed et al., 2012), findings from qualitative data helped to pinpoint the most relevant factors to the context of implementing Blockchain in FSC. For technology context- relative advantage, compatibility, and complexity are highlighted by experts, aligning with DOI theory (Rogers, 2003). Further, as the cost is found to have an impact on certain phases of adopting new technology such as RFID (Hossain et al., 2016), a similar notion is expressed by experts for Blockchain. For the organizational context- resources, readiness, innovativeness, and size and position are highlighted by the experts, consistent with what literature suggested as possible determinants for the assimilation of innovation (Pichlak, 2015). For environmental context- the influence from regulatory bodies, consumers, and other organizations are also found in literature as pertinent factors to the implementation process (Hameed et al., 2012; Martins et al., 2016). Finally, top management attitude and involvement with the new technology, are found to be important for the Blockchain adoption process, consistent with what literature suggested (Damanpour and Schneider, 2009; Hameed et al., 2012).



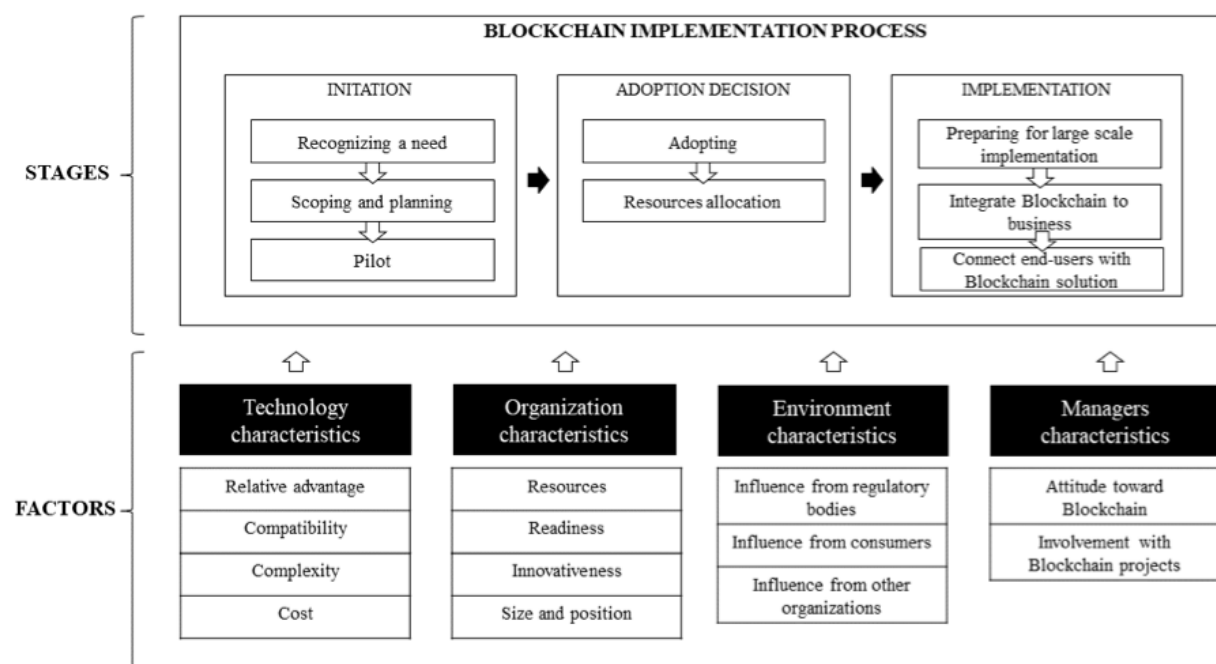


Figure 2. Evidence-based framework for implementing Blockchain in FSC.

6. Conclusion

With the rapid growth of Blockchain in the food industry, there is an evident need to also study the phenomenon and expand the knowledge of Blockchain in supply chain management (SCM) and FSCM. The aspect of implementing Blockchain is particularly important to examine, as a better understanding of the assimilation process can lead to successful adoption and generation of business value. However, since the current stream of research regarding Blockchain implementation in FSC is still in early development, this study proposed to elaborate upon existing theoretical perspective and conceptual models on Blockchain implementation, through the semi-structured interviews with industry experts, to arrive at an evident-based framework for Blockchain implementation in the food industry. The end result is a comprehensive framework with three main phases of adoption, eight typical courses of activities, four main categories of determinants, and 13 relevant influential factors to the process of implementation.

The contribution of this work thus is twofold. First, it expands the current body of knowledge about Blockchain for SCM and FSCM. Further, the framework of implementation proposed in this work can serve as the springboard for future studies to develop robust hypotheses and a research model for quantitative testing. Second, preliminary findings about the Blockchain implementation process in the food industry can serve as an effective reference and guidance for organizations in the food industry when considering Blockchain.

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THE POTENTIAL APPLICATION OF BLOCKCHAIN FOR LEAN AUTOMATION IN SUPPLY CHAIN MANAGEMENT: A SYSTEMATIC LITERATURE REVIEW

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Abstract

The purpose of this study is to evaluate how Blockchain Technology (BCT) can support the implementation of Lean Automation. We conducted a systematic literature review to understand how BCT is being implemented in supply chain management (SCM) field and to evaluate how this technology can be used to reduce inefficiencies in supply chains. Our findings identified the most common BCT-based application themes in SCM and ways that this technology can be used to support future implementation of Blockchain-enabled Lean Automation – B-eLA. The study provides important contributions on the intersection between the BCT, lean production and Industry 4.0 within SCM context and seek to exploit BCT's potentials to improve businesses' efficiency and effectiveness.

Keywords

Blockchain Technology, Lean Automation, Supply Chain Management.

1. Introduction

Although having different approaches, LP and I4.0 are aligned by a shared general objective of reducing inefficiencies in operational processes. On the one hand, LP delivers its impact on supply chains through a systematic and continuous search for waste reduction and improvements (Womack and Jones, 2003). On the other hand, enabling technologies pertaining to I4.0 introduces automation and interconnectivity to streamline activities (Bibby and Dehe et al, 2018). It is evident that these two approaches introduce capabilities that can mitigate existing supply chain inefficiencies and lead firms to much greater performance standards that are much greater than in the past. Thus, scholars and practitioners have begun exploring the integration of both approaches to realise the benefits from both domains (Chiarini and Kumar, 2020). Its successful implementation enables lean automation (LA), which allows firms to achieve higher changeability and shorter information flows to meet future market demands (Kolberg et al, 2017). With the advent of I4.0, the concept of LA has once again interested both practitioners and scholars due to its ability to improve supply chain performance.

Despite academic discourse delineating the potential of combining LP and I4.0 to achieve LA, literature discussing how it can be practically implemented is scarce (Tortorella et al, 2021). A main concern for its applicability refers to the development of a common and unified interface that synergies between LP practices and I4.0 technologies. Although some LA initiatives exist, these tend to treat LP and I4.0 as two distinctive dimensions that must materialise at different stages. This has led to some scholars stating the need for a LA framework that specifically considers the synergies between LP practices and I4.0 technologies. One technology with the potential to facilitate LA is Blockchain technology (BCT), due to its ability to synchronise digital exchanges between distributed systems in a peer-to-peer manner. In the LA context, BCT can serve as a catalyst for interactions between the widely deployed technologies and systems, whilst also serving as a compatible tool for digitising traditional LP practices. In spite of these claims, understanding how BCT can facilitate LA remains unclear.

To alleviate these critical research issues, we first performed a SLR with the aims of understanding how BCT is being implemented in existing SCM studies and how the technology is being thought of to reduce inefficiencies in supply chains. In this sense, we evaluate how BCT can enable LA implementation, in other words B-eLA. Finally, we identified SCM areas which received little attention to help propose a future research agenda.

The rest of the paper is organised as follows: Section 2 provides a research background relating to I4.0, BCT, LP and LA. In this section, we also present a taxonomy for the different types of wastes that can arise in supply chains and a discussion on how BCT can facilitate LA. The SLR protocol is described in Section 3 together with the research questions (RQs) and the study findings appear in Section 4. Section 5 presents a discussion with a future research agenda. Section 6 offers a conclusion with the summary of findings, theoretical and practical implications and research limitations.

2. Background theory



In this section, we conduct a brief overview of the literature on I4.0, BCT, LP and LA. Following thus, we introduce our novel approach coined Blockchain-enabled Lean Automation (B-eLA), by introducing how BCT can facilitate LA implementation. We then present a taxonomy of wastes which was developed based on an extensive literature survey.

2.1 Industry 4.0 and Blockchain technology

I4.0 refers to an online economy consisting of complex, interrelated digital technologies that share data for the provision of delivering value to all supply chain actors (Benitez et al, 2020). In such an environment, traditional supply chains evolve into supply chain ecosystems (Ghobakhloo, 2018). This transforms supply chain relations from one whereby partners interact dyadically to develop solutions, to one where mutually engaged participants communicate and coordinate activities to achieve a common goal (Benitez et al, 2020). Some of the most reported I4.0 enabling technologies are cyber-physical systems (CPS), Radio Frequency Identification (RFID), IoT, AI, Wireless Sensor Network (WSN), Virtual/augmented reality, robots, additive manufacturing (3D printing), Big Data and analytics (BDA), cloud computing and BCT. Among all these I4.0 technologies is BCT, which is receiving increasing attention due to its potential to transform almost all SCM business models, enhance end-to-end supply chain business process and thus improve supply chain performance (Wamba et al, 2020).

Developed by the pseudonym Nakamoto, the BCT gained popularity as the technology behind the bitcoin protocol. In a blockchain system, exchanged data is aggregated in cryptographic blocks and broadcasted across the network (Wu et al, 2021). This creates an endless chain of data blocks that allows transactions to be traced and verified at any moment (Toyoda et al, 2017). A successful verification results in an additional block being added to the chain of blocks (Casino et al, 2020). Once transactions have been recorded and certified within one of the data blocks, it becomes immutable and cannot be modified or tampered with.

2.2 Lean Production and Lean Automation

Originating in Japan in the 1960s with the Toyota Production System (TPS), and later adopted in the Western world in the 1990s under the term lean manufacturing (LM), the LP paradigm has become the major approach for simultaneously creating highly efficient operational processes and enhancing supply chain performance. Following the wide-spread diffusion of LP, many firms have seen positive progress in their financial, operational and environmental performances (Negrao et al, 2017). In its purest form, LP is technology-independent and is not reliant on its application to perform associated activities. Instead, LP utilises decentralised control by giving local autonomy to the people interacting with the system (Buer et al, 2021). In contrast, many traditional technologies function in a centralised manner, typically creating 'a single version of truth' (Buer et al, 2021). This could lead to further problems for two main reasons: (i) the adopted technology could create an inaccurate perception concerning the realities a particular situation, and (ii) due to the complexity and rigidity of traditional technologies it can be extremely difficult to make adjustments to the system in order to continuously improve, which could subsequently encourage workarounds rather than solving the root cause of the problem.

2.3 Towards Blockchain-enabled Lean Automation (B-eLA)

The introduction of CPS and other key I4.0 technologies enable distributed computing that is not typically found in traditional centralised systems. This corresponds with traditional lean production, which because of the resource intensity of operationalisation, should avoid a centralised hierarchy in favour of a linked, decentralised structure (Zuehlke, 2010). Thus, this suggests that both I4.0 and LP are capable of functioning well under decentralised control. As decentralised structures integrate many processes, such a structure relies on interoperability to facilitate communication, cooperation and coordination among these processes (Vernadat, 2007). Therefore, an infrastructure that facilitates such an environment is a critical success factor for high-performing LA.

BCT is a key enabler for decentralisation and its features are proven to enable interoperability between distributed systems. What sets BCT apart from other I4.0 technologies is its ability to provide a digital infrastructure for hitherto disconnected and untrusting agents to communicate in a peer-to-peer manner. Integrity of the network can be secured through a distributed consensus mechanism, which is an advanced cryptographic technique that allows involved participants to reach agreement about the true state of shared data. The transparent nature of the technology allows unrestricted traceability of transactions performed within the LA system. As data is ensured through cryptographic proof, untrusted agents can directly interact with each other in real-time, without the need of a trusted third party. Due to the absence of a trusted third party, associated transaction costs can be reduced or even eliminated.



3. Systematic literature review protocol

The protocol employed to conduct the systematic literature review (SLR) consisted of the following eight steps: (1) planning and formulating the problem; (2) searching the literature; (3) data gathering; (4) quality evaluation; (5) data analysis and synthesis; (6) interpretation; (7) presenting the results; and (8) updating the review (Thomés et al, 2016).

In the planning and formulation phase, we conducted a Rapid Review (RR) to examine the existence of SLR's in this topic to ascertain whether a new review is needed (Thomé et al, 2016; Tranfield et al, 2003) and to delimit the SLR's scope. Following the RR process, the following three research questions were formulated to guide the review:

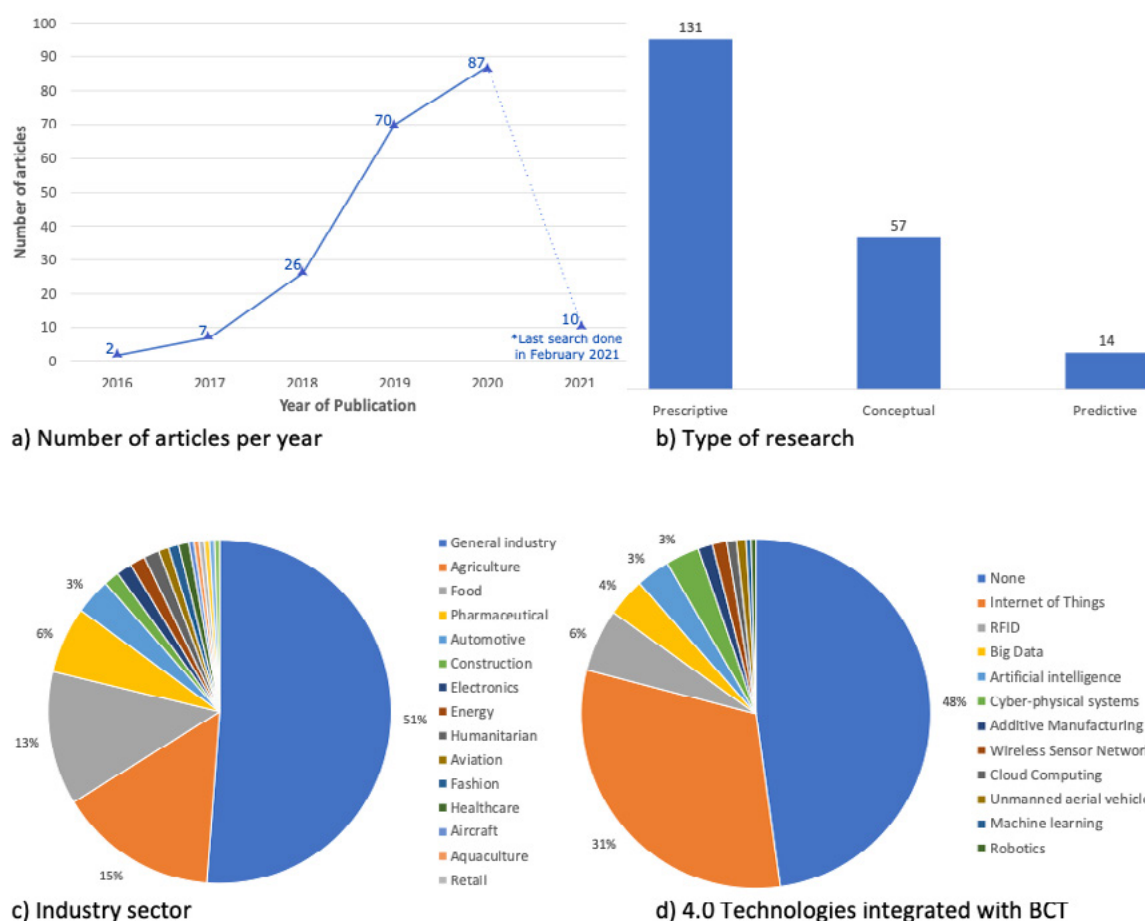
RQ1 – What are the applications of Blockchain technology in supply chain management?

RQ2 – How has Blockchain technology been considered to minimise waste?

RQ3 – What gaps exist in the research, and what may be done to contribute to future research?

3.1 Bibliometric analysis

Figure 1 summarises the bibliometric analysis for the selected articles. Figure 1a illustrates the distribution of publications by year and was performed to assess the trends in the number of studies on the topic. Figure 1b illustrates the categorisation of the literature sample based on the following three research types: (i) prescriptive, (ii) predictive and (iii) conceptual. Referring to the retrieval results found in Figure 1c, half of the articles consider BCT application in generic industrial context and half of them evaluated the technology usage in specific industries.



3.2 Applications of Blockchain technology in SCM

Table 1 is the summary of findings derived from the first round of coding, which was performed inductively. Generally speaking, we can observe various implementation areas concerning the application of BCT in SCM. This suggests that scholars do not question the adoption of BCT per se, but rather their opinions diverge when it comes to its industrial context.

Table 1 – Findings from the inductive content analysis

BCT-based application themes	Characterisation
Factory of the future	The use of BCT to advance production processes.
Tracking and tracing	The application of the BCT to identify past and present location details of a product.
Information and knowledge sharing	The use of BCT to allow information and/or knowledge sharing within and/or across supply chains in a collaborative manner.
Re-inventing trust	The use of BCT as a trust mechanism rather than placing trust in the hands of a traditional intermediary.
Quality control	The use of the BCT to ensure that product quality is maintained or improved.
Fraud and counterfeit prevention	The adoption of the BCT to authenticate transactions and/or products.
Disintermediation	The application of the BCT to replace the role of intermediaries who were previously responsible for coordinating and verifying transactions.
Automatic decision-making	The adoption of the BCT to make independent choices without the need for human intelligence.
Transparency	The use of BCT to better visibility in the supply chain.
Security	The application of the BCT to ensure confidentiality, integrity and availability.
Data recording and storage	The use of BCT as a robust and comprehensive infrastructure that allows for a network that can record and store pertinent information.
Resilience	The adoption of BCT to enhance the supply chain's ability to be prepared for unexpected events and respond and recover quickly to these events.

4.3 B-eLA: Blockchain technology as means to minimise waste in supply chains

Figure 2 illustrates a heatmap to depict the relationship between how BCT is being applied in supply chains and how the technology is being considered to minimise waste.

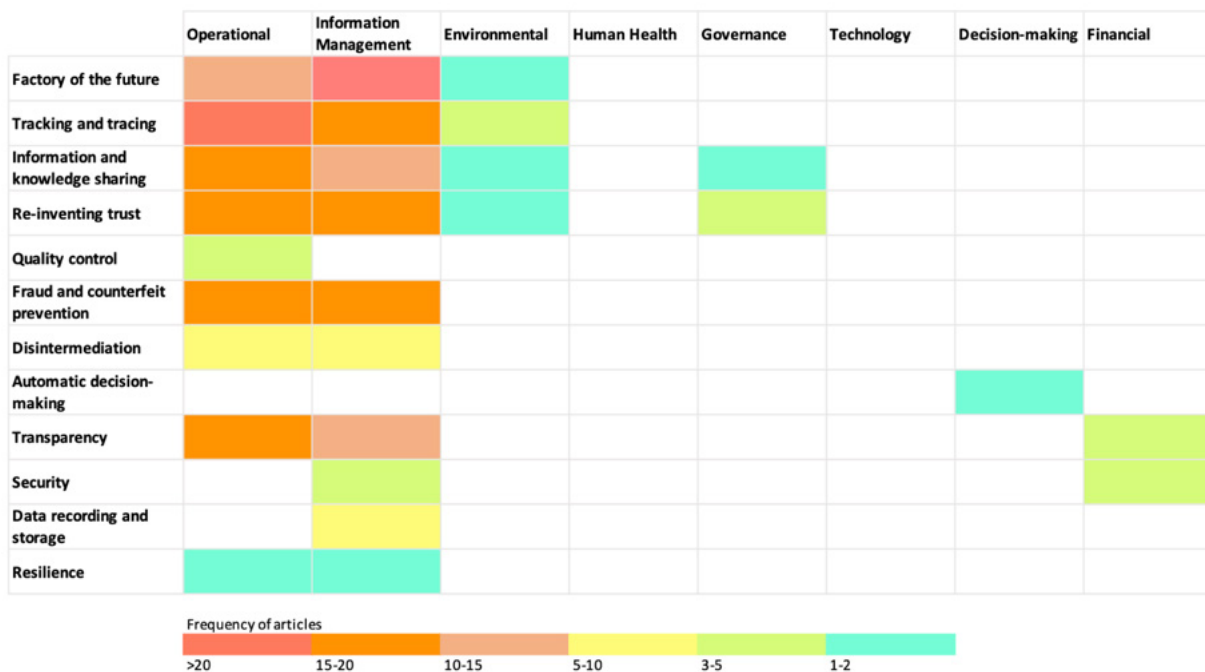


Figure 2 – Heatmap of Blockchain application and waste reduction



4. Conclusion

In this paper we performed a SLR to understand how BCT is being implemented in SCM field and evaluated how this technology can be used to reduce inefficiencies in supply chains. When answering RQ1 in Section 4.2, we identified the most common BCT-based application themes in SCM. Later in Section 4.3, we made links between these themes and the holistic taxonomy of waste, by evaluating how the technology can be considered to minimise waste and therefore supporting future implementation of B-eLA.

In terms of our contributions, one of the key roles of the SLR is to support new theory development, mainly through knowledge-gap mapping (Denyer and Tranfield, 2009). Another theoretical contribution refers to the proposed taxonomy of waste modelled in this research. In practical terms, supply chain managers and fellow practitioners can use this study as a 'first-step' towards objectively supporting effective B-eLA efforts.

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BLOCKCHAIN ADOPTION TO IMPROVE EFFICACY AND TRANSPARENCY WITHIN THE AIRLINE INDUSTRY: AVIATION LEASING SECTOR

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Introduction

The aviation leasing ecosystem involves complex operations and flow of documentation, Figure 1. In many cases, it is hard for any single stakeholder to have a holistic view of this complex ecosystem. The aircraft lifecycle depends on a life span of approximately 30 years and will go through on average of five to eight owners over the asset's life. However, each time the ownership transfers, all documentation of the aircraft's birth must also transfer over to the new owner. In some instances, the critical documentation can be 25+ years old and will have been stored for much of its time. The complexity and timespan of this process often catch leasing companies off-guard. Therefore, the Lessee must understand what difficulties must be dealt with and avoid any time-consuming and costly pitfalls since there is no uniform protocol for engaging aircraft leasing companies.

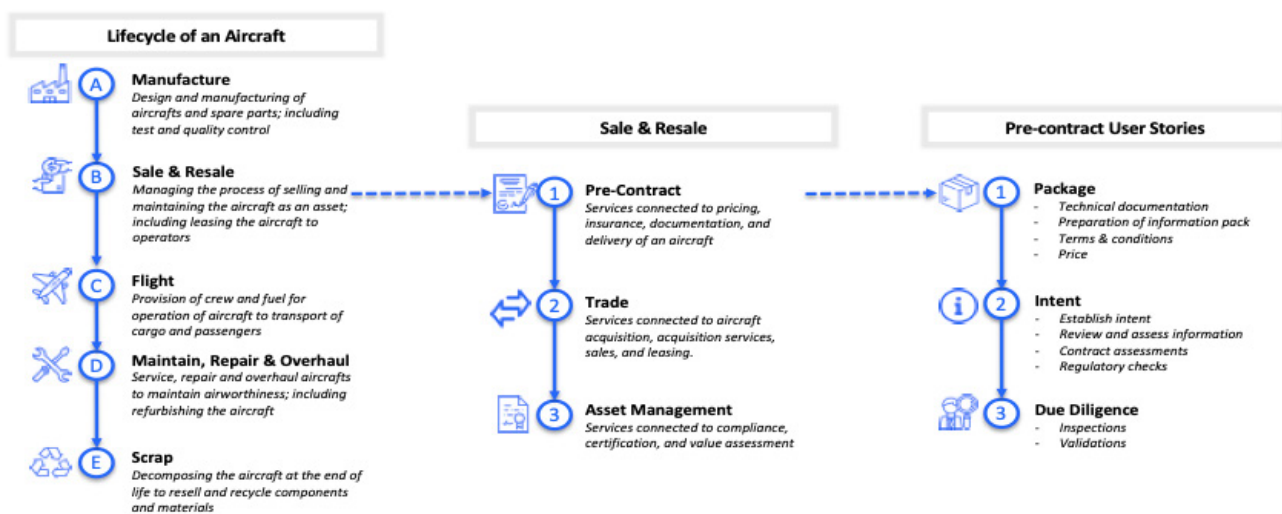


Figure 1 –The lifecycle of aircraft leasing

Like other industries, aviation is being impacted by digitalisation, the advent of advanced technologies such as distributed ledgers, or Blockchains, to big data and artificial intelligence. With the adoption of Blockchains, the aviation leasing industry will be granted a secure exchange of data in a distributed manner. The technology could affect the structure and governance of the business and relationship configurations and information sharing between Aviation actors. If integrated with field-sensing technologies such as the Internet of Things, Blockchain could create permanent, shareable and actionable records of products' digital trackability throughout the entire sector. Such improved visibility would provide trackability, authenticity and legitimacy, all of which are crucial and proven to the food, pharmaceutical and distribution supply chains. Hence, this research aims to investigate aspects and requirements for developing a Blockchain framework for managing the complexity and tracking the transactions in the business processes within the Aviation Leasing Sector. Towards achieving this objective, the paper identifies the most likely disruptions associated with inefficient complex manual paper-based Aviation leasing process. It explores the challenges for blockchain future diffusion in the sector.

Literature Review

Evolution of Blockchain Literature

The evolution of Blockchain literature has been analysed based on a review of 148 research papers published between 2000 and April 2019 (for conformity, grey literature has been excluded from the descriptive analysis). The purpose of the study was twofold: (1) to provide insight regarding current research trends in Blockchain technology and its applications, and (2) to help to visualise the multidisciplinary research approaches developed so far in the scientific literature. It is worth noting that during 2019 the number of publications has significantly increased. Until 2016 just a handful of publications existed related to Blockchain-enabled applications, mainly in supply chain and agri-food. However, since 2010 their number reached almost over 122. Therefore, research has slowly, yet



significantly, picked up in the area of Blockchain-enabled applications during the last three years. This upward trend highlighted the changes arising from adopting Blockchain technologies that impact business and, in particular, the aviation industry and may generate competitive advantage (Hamel & Prahalad, 1994; Hwang & Christensen, 2008; Lui, Ngai, & Lo, 2016). Disruptive technology impacting the market focuses mainly on discontinuing the ordinary course of the current process and the interruption of the current performance trajectories (Christensen, 1997).

Blockchain technology was first introduced with the advent of Bitcoin as its core underlying technology. It took several years for the research community to become fully aware of Blockchain's capabilities and long-term potential and take advantage of its possible uses and applications (Casino et al. 2019). It is evident that a large volume of scientific literature has been published in conference proceedings, with a steady continuing upward trend. Therefore, journal-oriented content relates mainly to Blockchain-enabled applications has been more notably published since 2016 onwards.

Blockchain and Business Process Improvement

Modern business processes become more challenging, and changes are complicated to solve when multiple organisations are involved. Blockchain provides trust that addresses service dynamics and complex interrelationships between stakeholders. However, changes in internal processes can introduce trust issues when such changes may have a cascade and effect on another organisation. Cross-functional organisational processes must be opened by manifesting their business logic across involved parties (De Filippi et al., 2020). To obtain Blockchain benefits for process executions, smart contracts can be employed to encode a business process into smart contract transactions (Garcia et al. 2017). The business logic is closed to the public but open to involved parties. Permission-based Blockchain fits well into this context where the degree of decentralisation varies depending on the number of actors involved.

Blockchain can also play a vital role to guarantee efficient process workflow. It is the single repository for business process descriptions that ensure workflow structure and flow control correctness. This is a relatively straightforward process, as it requires only a particular type of transaction to record static descriptions (Ashraf Uddin et al 2020). After business process workflow is initiated as an instance, process executions will be generated and encoded into a smart contract (Garcia et al. 2017, Lopez et al. 2017), thus guaranteeing operation validity as specified in the workflow descriptions. Since a smart contract code is deployed and truthfully executed by external actors to change the state of a Blockchain ledger, abstracting business process descriptions and instances stored as transactions will directly gain Blockchain benefits.

Methodology

Exploring Blockchain roles to improve complex Aviation business processes is a relatively new topic with limited data availability. The nature of this research is applied research, where the emphasis is on producing relevant practical knowledge (Irani et al. 1999). Hence, a case study is then used as a research strategy to achieve the research objectives (Walliman 2010). Several techniques for data collection are employed, including interviews and historical data for the primary data and multiple sources of data collection for secondary data. Research design and stages have been used. Semi-structured interviews were applied to explore the opportunities of applying Blockchain in the studied sector. A list of the interviewed experts and practitioners from the aviation leasing sector is illustrated in Table 1. The research is designed based on five stages, (1) Building the Technical Platform, define advanced capabilities of Blockchain, map out the existing flows of documentation/requirements gathering and known issues; (2) Aviation Workshop Groups – to explore the potential of Blockchain to make the industry more digitised; (3) Design Interviews – to explore the Practical Capabilities of Blockchain and how they can add value to an existing paper-based enterprise; (4) Merge Practical & Theory Platforms/capability to Produce Aviation Leasing Blockchain platform, to discover best Use Case for potential new Business Model that reduces complexity and time, and (5) Validate and Test – to test use case study with a panel of experts and validate its functionality and use within the industry.



Table 1- experts and practitioners from the aviation leasing sector.

Aviation Leasing Companies SME	Position	Business Interest	Location
1	General Manager	Aircraft Asset Management	Dublin
2	CEO	SME	Dublin
3	Operations Director	Aircraft Leassor	Dublin
4	Snr. Legal Council	Aircraft Leassor	Dublin
5	Snr. Manager	SME	Dublin
6	Manager Educ. & Dev.	Regulator	Dublin
7	Snr. Manager	Foreign Direct Investment	Dublin
8	Corporate Group Treasury	Treasury	Dublin
9	VP Technical	Engine Leasing	Shannon
10	Group VP	Aircraft Leasing	Shannon
11	Head of Customer Relations	Regulator	Dublin
12	CEO	Aircraft Leasing	Dublin
13	Sales & Marketing	Aircraft Leasing	Dublin
14	Director	Finance	Dublin

Given the technical complexities and the embryonic state of Blockchain technology, it was proposed to develop a pre-interview information pack to acquaint the interviewees with essential background information. Due to confidentiality, it was presented as a helpful priming technique. Even for those with IT specialities and sufficiently understood Blockchains, this technique significantly supports the proposed questioning (Eden 2004). The pre-interview information pack contained a background introduction about the research rationale, a useful guide and introduction to what Blockchain is and how it works, a list of piloting schemes observed in practice, and the list of interview questions. All interviews took place between April and June 2020 and lasted between 30 and 60 minutes. In-depth interviews were conducted with 14 Aviation subject matter experts, Table 1. A narrative analysis was deployed as the two main data analysis techniques to aid our understanding and evaluation of the interviewees' cognitive complexity in making sense of Blockchain technology.

Findings and Analysis

The respondents have stated that Blockchain has witnessed continual evaluation in 2019 and 2020 from a capable yet underdeveloped technology into a more refined mature solution poised to deliver on its initial promise to disrupt. The question became no longer "Will Blockchain work?" it's a case of "How can Blockchain work for them and improve their business process?" At this stage, most respondents tended to perceive what the benefits could be of Blockchains to the Aviation sector, what areas of applications are envisaged and how they could potentially be challenged.

The respondents provided a few Use Cases and set the scenarios of how their organisations might respond to the emergence of Blockchain and considered several plausible alternative outcomes, mostly around parts supply, documentation and maintenance records. They frequently referenced that aircraft are being traded a lot more frequently nowadays, primarily because of the sheer volume of aircraft in the market. Yet, the trading system remains antiquated and document-heavy. One particular respondent associated with the finance aspect of aircraft leasing stated that

"When we are working on an aircraft financing transaction, the number of documents compared to any other structured finance deal is second to none."

They went on to state that "If company A wants to sell an aircraft to company B, there is a vast amount of work in terms of the aircraft's records. There have been some minimal advances over the years in document management systems, but they are just document repositories or glorified databases. The documents are still in PDF format," they explain

"You are talking about wading through pages and pages of data – it's time-consuming and labour-intensive".



Benefits of Blockchain

Through analysing, the respondents teased out the potential benefits of Blockchain use, Table 2. A common theme among the subject matter experts was that although some applications would be beneficial, they tended to prefer small-scale applications that would deliver incremental gains rather than radical changes. “Start small and grow a common platform for all to use”. This common approach is intended to utilise the technology first before embarking on more ambitious platform adoptions. Several respondents believed that trust and security were essential, and many had a different perspective on what security means when it was defined. Many viewed this as a positive step and felt that security enhancements, currently enjoyed by others using Blockchain, would protect trade and offer strategic benefits to the aviation sector. Several stated that integrating Blockchain at a global level would push the boundaries of real-time visibility relating to contractual agreements between parties on a need to know basis. The listed the Blockchain benefits according to their best preferences and importance to the respondents, Table 3.

Table 2 – Benefits of Blockchain to the Aviation leasing sector.

Benefits of blockchain to the Aviation Sector	Explanation	Referenced by Interviewee
Improves Visibility	Centralised Platform (one that all companies can use) - Digitisation	1,3,4,5,6,7,8,9,10,11,12,13,14 (13)
	Reduces the time to process transactions	1,2,4,5,6,8,9,10,11,12,13,14 (12)
	Cost, understanding the technology and industry will wait for others to make the move first.	1,2,3,4,5,6,7,8,9,10,11,12,13,14 (14)
	Better documentation (Quality of Paperwork)	2,4,6,10 (4)
	Realtime Visibility of Assets / Documentation	2,3,6,9 (4)
	Openness and Transparency	4,5 (2)
	Industry already engaged , however very early stage work is been conducted.	1,2,5,6,7,11 (6)
Security	Trust in Documentation / Immutable	1,2,3,4,5,6,8,9,10,11 (10)
	Trust within the Industry (partners)	1,3,5,8,11 (5)
	Awareness / Governance	1,5,6,8,11,14 (6)
Disruption	First Time Movers	1,2,3,4,5,6,7,9,10,11,12,14 (12)
	Improvements	1,2,4,5,6,9 (6)
	Speed to transact	2,3,4,5,7,8,9,10,11,12,14 (11)

Table 3: Order of Blockchain Benefits according to respondents preferences

Order for preference/Importance	1	2	3	4
Blockchain Benefit	Cost-Benefit Analysis	Common/Central Platform	Speed Process Transaction	Trust in Documentation

Preference 1: Cost-Benefit Analysis of Blockchain: The market is controlled by intermediaries who assist in transactions of assets via lessor to lessor with additional built-in hidden costs. These costs are then pushed downstream to the customers. Intermediaries handle any touchpoint in the selling process, such as Legal, Finance, Agents, Maintenance, Regulators, Government. The more complex the transaction, the more intermediaries may be involved. Blockchain can be effective in resolving some of the leasing intermediaries related issues effectively. The use of Blockchain can help improve asset management and reduce costly potential data errors. Enabling the digitisation of leased aircraft documentation in an immutable format when disputes occur are common. It prevents delays in transferring contracts and shortening resolution time. Aircraft lessors (sellers) would also have the ability to accurately track assets and costs, estimate delivery times for multiple aircraft, and make smarter decisions overall. Several Interviewees raised the concern about the time it took to complete a transaction and stated that “Time Kills Deals”. In an ideal world, when lessors decide to sell an asset, they want that asset off the books as a priority so that the capital can be redeployed into the business or a new set of assets. It is also seen as a saving in the cost of capital available.

Preference 2: Common/Central Platform: A key second benefit of Blockchain technology is its ability to have multi-enterprise applications. These can work across multiple organisations

“locking data immutably into the Blockchain rather than having individual applications running separately and exchanging data on a case-by-case basis”.



Thirteen of the respondents believe that the technology could assist them with the transfer of assets between lessors. A common platform was seen as a positive approach to provide lessors with a complete platform—hardware, software, and infrastructure—for developing, running, and managing applications without the cost, complexity, and inflexibility of building and maintaining that platform on-premises or individually as a company.

Preference 3: Speed Process Transaction: In comparison to traditional financial services, Blockchain facilitates faster transactions by allowing person-to-person (P2P) cross-border transfers with a digital signature. Proper governance processes are made more efficient with a unified system of ownership records and smart contracts that would automate lease agreements. It was also cautioned that resistance from existing intermediaries and or actors could occur, which could pose a significant challenge/barrier to Blockchains' further diffusion within the Aviation Leasing sector.

Preference 4: Trust in Documentation: Eleven respondents viewed trust as an issue and more so the potential to misplace critical documentation of the asset in question. In the case of one respondent, they questioned the retrospective documents, documents that cannot be found and replaced after the event. The critical point made was that the document was true and correct, and easily accessible. Several Lessors stated that this was a time-consuming process having to physically go through multiple archived file boxes (20+) per aircraft, not knowing where and how they are stored. They stated that this was a significant time-consuming task that needed to be done to close out the due diligence aspect of the process. They noted that the sale process is also time-bound that they usually only had 14 days to complete this task. Several respondents stated that this could also become a negotiation stumbling block should specific papers not be available and can drive down the asset's cost. With the Blockchain ledger, each time exchange of goods is recorded on a Blockchain.

Application of Blockchain

The research examined potential use cases where Blockchain technology may penetrate the aviation leasing sector. These business cases included maintenance transparency, documentation management, flight data management, aircraft lease administration, and streamlining digital travel systems. The respondents showed that the implementation of Blockchain in these use cases must rely on the pillars illustrated in Table 4

Table 4 Aviation areas where Blockchain might penetrate.

Aviation sector areas where blockchain might penetrate.	Explanation	Number of SME's by response
Visibility and traceability	Improve visibility of documentation	1,2,3,4,5,6,7,8,9,10,11,12,13,14 (14)
	Scaleability of implemented solution	
	Information availability	
	Real time access	
Standard simplification of process	Standard Platform	1,2,3,4,6,7,9,10,11,12,13,14 (12)
	Standard Global documentation / system	
Smart contracts	All information pertaining to an asset is centralised and assigned to that asset	1,2,3,4,5,6,7,8,9,10,11,12,13,14 (14)
	Validation and instant communication	
Trust	One version of the truth	2,3,4,5,6,8,9,10,14 (9)
	Tracability	
	Single location for all documentation	
Disintermediation	Eliminates corruption	1 (1)
	Intermediaries	
	Loss of certain skills	
	Re-assignment of existing resources	
Deployment	Job losses	2,3,4,5,6,7,8,9,10,11,12,13,14 (13)
	Allow for new intermediaries to emerge	
	Suitable non production environment	
	Prove concept prior to scale	
	Include all stakeholders at initiation stage	
	Look at 6 month ROI for pilot (low hanging fruit project)	

Respondents emphasised the high value of Smart Contracts and Visibility/Tractability elements as primary enablers for Blockchain applications. Deployment has been seen as the next most increased support of Blockchain applications. However, many respondents provided much caution and stated that it needs to start small and build. Others highlighted the fact that all stakeholders need to participate in the establishment of Blockchain within the industry. Many respondents agreed that standardisation and simplification of the process



were also crucial. Following standardisation and simplification, trust was identified as a potential challenge. Subsequently, creating the industry standards would be a significant step in helping the industry advance, removing barriers to entry (lack of standards is a barrier). Reducing the risk of locking into non-standard approaches aids the assessment of Blockchain quality for service providers, increasing trust and reputation.

Challenges of Blockchain Implementation

Blockchain technology carries a unique set of challenges contributing significantly to its slow-moving adoption, Table 5. A significant challenge of Blockchain networks is related to the network's technical scalability, which can put a strain on the adoption process, especially for public Blockchains. In contrast, legacy transaction networks are known for their ability to process thousands of transactions per second. However, the information provided is consistent across the respondents and predominately relates to cost, legal, security and privacy and Information sharing.

Table 5 - Perceived challenges of Blockchain usage in Aviation Leasing.

Perceived challenges of blockchain usage in Aviation Leasing.	Explanation	Number of SME's by response
Confidence and related necessary issues	Organisations still do not understand the full extent of the technology	1,4,5,7,11,14 (6)
	Technology still at early stages of development	
	Still uncertainty about blockchain as a solution / common platform	
	Technology viewed as complex	
Governance / Collaboration	The high number of stakeholders involved	1,2,3,4,5,6,8,9,10,11,12,13,14 (13)
	Changing the mindset	
	Intermediaries may hinder potential opportunities	
	Data ownership - who would own the data.	
Information sharing	Integrity of data input	1,2,3,4,5,6,7,8,9,10,11,12,13,14 (14)
	Common Platform that is independent from competition (Independent aggregator)	
	Data integrity / retrospective data challenge	
	Obtaining data as a starting point	
Technology & Information issues	Disruption to existing model / process	3,4,5,6,8,9,10,11,12,13 (10)
	The lack of standards across the industry	
	How the smaller operators participate	
Cost, Legal, Security and Privacy	Cost of implementation	1,2,3,4,5,6,7,8,9,10,11,12,13,14 (14)
	Resistance to and transparency among the Aviation Sector	
	Sensitive information been made available to competition	
	Regulatory uncertainty	
	Reputable damage should system be hacked	

With any significant change in process and with the transfer to a digitised technology, utilising a common platform is substantial. The discussion soon moved to how this may play out, with respondents recommend that incorporating an Independent aggregator who would be agnostic to the Aviation Industry could suffice. This recommendation was seen as a plausible option and was open to further exploration. However, concern soon passed to security, integrity and data ownership. The industry is looking for an independent aggregator or organisation that they can trust that does not report back through a management line supporting the competition. Governance / Collaboration was also a concern; however, introducing an independent aggregator was seen as a positive and one that the industry would embrace. Individual contributors wanted to maintain ownership of the data.

Conclusion

The research analysis highlights the potential of Blockchain and its inbuilt capabilities, including security, visibility, trust and more importantly, it identifies many applications. Particular emphasis was set aside on how "Time Kills Deals" as a Use Case example from the information received from the respondents and as a priority area for the industry. The evolution of the aviation sector requires a methodology that analyses the various dimensions of the business framework models. These dimensions include:

- The complex actions incorporated into the business framework model
- The types of transactions aviation companies conduct
- The actors that are involved in the processes and transactions

The blockchain-based business framework model needs to be continually deployed (or redeployed), managed and evolved according to the morphing strategy of the aviation sector.



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AN INVESTIGATION OF BLOCKCHAIN INITIATIVE AND OPERATIONAL EFFICIENCY

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Introduction

To echo the consistent concern of improving efficiency in operations, researchers have pointed out the critical role of adopting new technologies (Bruque-Cámara et al., 2016; Zelbst et al., 2012). In recent years, an increasing interest is currently shown in using blockchain to address operational challenges (Jabbar & Dani, 2020). Blockchain is defined as “a decentralized, distributed, shared, and immutable database ledger that stores registry of assets and transactions across a peer-to-peer network” (Khan & Salah, 2018, pp.405). Generally, blockchain is expected to benefit in many aspects, such as reducing cost, enhancing productivity and alleviating paper-trail inefficiencies (Chod et al., 2020; van Hoek, 2019).

In terms of organisational learning, there are two different patterns that determine how firms leverage resources and capabilities - exploitation and exploration (Levinthal and March, 1993). As Subramani (2004) notes, different patterns of information technology use can lead to different outcomes. Thus, in order to investigate the effect of blockchain initiative, it is necessary to consider two distinct dimensions, namely exploitation and exploration. Since the application of blockchain is still at an early stage, the way in which blockchain can help firms with value creation needs more examination. Although some studies have explored how blockchain can affect firms' operations, empirical evidence is relatively lacking. To date, a large proportion of the studies have employed qualitative research methods. This research attempts to address this by investigating quantitatively the impact of blockchain initiative on firms' operational efficiency, from the perspective of organisational ambidexterity.

The remainder of this research is structured as follows. Section 2 outlines the relevant literature and develops the research hypotheses. Section 3 describes the methodology adopted in this paper. The empirical results are given in the next Section. In Section 5, a general conclusion of this study is provided.

Literature review and hypothesis development

Organizational ambidexterity

Exploitation implies refinement and utilisation of firms' existing knowledge, competences, and opportunities, while exploration denotes the establishment of completely new knowledge, competences, and opportunities (Uotila, 2017). Scholars have devoted substantial attention to addressing the influence of exploitation and exploration on organisational performance. For example, Auh and Menguc (2005) suggested that exploration and exploitation were oppositional in relation to a firm's efficiency and effectiveness. Although exploration and exploitation have different underlying logic, and tensions arise between them as they compete for scarce resources within a firm, synergy also exists and balance needs to be achieved to ensure better firm performance (March, 1991; He and Wong, 2004). An exclusive engagement in exploration means that firms lose out by not gaining from existing knowledge. At the other extreme, exclusive involvement in exploitation will trap a firm in obsolescence (Levinthal and March, 1993). Thus, an optimal solution would be an ambidextrous organisation able to simultaneously pursue exploitation and exploration (Tushman and O'Reilly, 1996). In summary, organisational ambidexterity means sufficient exploitation is mastered to assure a firm's current viability, accompanied by a simultaneous effort in exploration to ensure future viability (Levinthal and March, 1993).

Generally, two dimensions of organisational ambidexterity are considered (i.e. complementary and balanced). A complementary perspective interprets ambidexterity as the ability to simultaneously manage exploration and exploitation, indicating that they can be mutually supportive. In addition, the balanced perspective highlights an equal emphasis on exploration and exploitation; in other words, the fit between magnitude (Tai et al., 2019; Chandrasekaran et al., 2012). Although the combined effect of exploitation and exploration is based on a balanced perspective, the best scenario would be to achieve high levels of both exploration and exploitation (Junni et al., 2013).



Blockchain initiative

Basically, blockchain initiative in this study refers to a firm's use of blockchain. Beyond primary applications in finance, blockchain has been extensively applied in areas such as food, insurance, government, healthcare, energy, education, and supply chains (Casino et al., 2019; Wang et al., 2019). In addition, because of the benefits of real-time transparency and cost savings, blockchain is appealing across a range of industries, with manufacturing and OM perceived as the most promising domains for blockchain initiatives (Lohmer and Lasch, 2020). For instance, blockchain platforms facilitate connections between factories and machines, enabling automated value-added manufacturing processes. Combined with big data analysis, connected parties can further derive more in-depth insights, thus improving quality and risk management (Lohmer and Lasch, 2020). From the perspective of supply chain management, blockchain can facilitate many supply chain stages and reconfigure traditional supply chain relationships, as it provides data across supply chains and removes intermediaries via smart contracts (Queiroz et al., 2019). In addition, a general application of blockchain is to provide a visible and superordinate ledger for the movement of goods along supply chains to facilitate traceability (Tönnissen and Teuteberg, 2020).

Previous studies have focused on demonstrating the benefits of blockchain initiatives, such as cost savings and performance improvements. However, as pointed by Hughes et al. (2019b), in addition to prototypes and feasibility studies, few studies have deployed an empirical approach to analyse the impact of blockchain initiatives. Furthermore, the linkage between different patterns of blockchain use and firms' performance are yet to be investigated.

Exploitative/Exploratory blockchain initiative and firm's operational efficiency

This study argues that blockchain initiatives are positively related to a firm's operational efficiency. Operational efficiency is generally referred to as a firm's managerial competence at transforming diverse inputs into value-added outputs in the process of production (Kwon and Lee, 2019). Following the basic conceptual distinctions of exploration and exploitation, scholars have developed unique definitions to explain patterns of technology use. Similarly, based on the definition provided by March (1991), firms' use of blockchain can be categorised as exploratory or exploitative. By adapting the previous definitions, the current study developed concepts of exploitative blockchain initiative (EiBI) and exploratory blockchain initiative (ErBI). EiBI refers to the use of blockchain in the refinement of existing products or processes, leading to incremental improvements in capabilities and expected short-term benefits. ErBI mainly focuses on the use of blockchain in research and development innovations to create new competencies, find novel solutions and discover new opportunities.

On the one hand, the use of blockchain can "enhance, optimise, secure and streamline many existing business and industrial processes" (Al-Jaroodi and Mohamed, 2019, pp.36500), conforming to the concept of EiBI in this research. Specifically, in the era of Industry 4.0, industrial internet-based blockchain adoption can facilitate the operational processes involved in smart manufacturing (Lee et al., 2020). Blockchain can offer a secure payment transaction environment, and a fast payment process for the parties involved in transactions by ensuring transparency and removing intermediaries (Hughes et al., 2019a). Using data from blockchain, smart contracts are designed to confirm whether contractual obligations have been fulfilled and automatically take appropriate action (such as issuing a payment, or making records) (Gaur and Gaiha, 2020). In such cases, increased efficiency is anticipated as a result of these simplified transaction processes and reduced transaction costs (Tönnissen and Teuteberg, 2020). The analysis of real-life data in a case study by Martinez et al. (2019) found that using blockchain can reduce the number of operations in addition to human processing to achieve efficiency gains in customer order management. Furthermore, a manufacturing firm can apply blockchain to verify, store and audit logistics processes to derive corresponding benefit from reduced time delays, management costs, and human errors (Al-Jaroodi and Mohamed, 2019). Manufacturing firms with complex supply chains often face the challenge of long unpredictable lead times and a lack of visibility; blockchain can provide visible inventory flows across companies rendering lead times more predictable (Gaur and Gaiha, 2020). Thus, we propose H1 as follows:

H1: Exploitative blockchain initiative is positively related to firm's operational efficiency.

In addition to the improvement of existing business, blockchain has also been adopted to create new business opportunities, new processes and to develop new products (Viriyasitavat et al., 2019), which constitute ErBI. On a physical level, blockchain can act as a key element of a new process or product, such as blockchain-integrated additive manufacturing, a blockchain-enabled trade platform, or blockchain-powered global online marketplace (Yang, 2019; Tönnissen and Teuteberg, 2020). For instance, a blockchain-based supply chain management platform can realise the integration of commodity flows, logistics, capital flows and information flows by connecting supply chain partners, thus reducing operational costs and improving operating quality (Pan et al., 2020). At the information level, blockchain can be adopted to build a unified database to address issues involved in security, traceability, and the reliability of contracts between manufacturing supply chain participants, which meets the challenges of information integration in new product



design (Benzidia et al., 2021; Leng et al., 2020). Therefore, when developing a new product, blockchain allows untrusted manufacturers to freely exchange capabilities and requirements, providing a more efficient way to establish a closer link with partners (Leng et al., 2020). Benzidia et al. (2021) also noted that one contribution blockchain makes to innovation is improving the efficiency in the process of new product development. Furthermore, innovated processes can lead to enhanced efficiency by helping firms to reduce their process costs and time (Laforet, 2011); a blockchain-driven innovation in process also shows a similar effect (Fosso and Guthrie, 2020). Since using data stored in blockchain represents “faster and cheaper, more efficient and reliable traceable operations” (Martinez et al., 2019, pp.1016), combining blockchain consensus mechanisms with other digital technologies such as big data makes it easier for firms to cope with complicated information and develop more effective operational processes (Pan et al., 2020). Thus, we propose the following hypothesis:

H2: Exploratory blockchain initiative is positively related to firm’s operational efficiency.

Ambidextrous blockchain initiative and firm’s operational efficiency

In line with the literature on organisational ambidexterity (e.g., He and Wong, 2004), a firm can achieve ambidextrous blockchain initiative in two ways. Firstly, a complementary blockchain initiative refers to a situation in which firms score highly on both EiBI and ErBI, whilst a balanced blockchain initiative refers to a situation in which firms have a relatively equal emphasis on the two dimensions.

Organisational ambidexterity theory supports a complementary effect, which indicates that exploitation and exploration can interact with and complement each other and produce more favourable results than when implemented separately (Tushman and O’Reilly, 1996; Wong et al., 2013). Firms that successfully achieve a dual orientation of exploration and exploitation are more attuned to the important opportunities of promoting their operational efficiency (Gedajlovic et al., 2012). The complementary effect of exploitative and exploratory blockchain initiatives can be explained as follows. Firstly, leveraging existing knowledge can help the absorption and creation of new knowledge, which is essential to the development of a valuable new product or services (Smith et al, 2005). By leveraging existing blockchain-related knowledge to improve existing products and process, firms can foster a deeper understanding of functionality of existing knowledge, as well as learning and accumulating corresponding experience in the application of blockchain technology. On one hand, a deeper understanding is likely to enable reconfigurations of existing knowledge and resources to build capabilities of relevance to new product discovery (Cao et al., 2009). On the other hand, accumulated experience enables firms to realise the potential extension and spillover of knowledge, and thus allows firms to develop a new application based on existing processes (Azadegan and Wagner, 2011). Therefore, it lays a foundation for a deeper integration of blockchain in developing a new process or product, thus facilitating efficient implementation and enhancing the success rate. In other words, EiBI is likely to reinforce the positive influence of ErBI. In addition, the created new knowledge is then transformed into existing knowledge in the form of new products and services (Smith et al, 2005). It indicates that the new knowledge generated by ErBI is then used to expand the valuable knowledge base of exploitation. Based on discussion above, we have the following hypothesis:

H3: Complementary blockchain initiative is positively related to firm’s operational efficiency.

Furthermore, scholars have also recognised the risks of overemphasising one dimension at the expense of another. As noted by Guo et al. (2020), when firms fail to maintain a high level of balanced ambidexterity of technological learning routines, they are exposed to the risk of organisation inertia or inadequate technological capabilities. Firms with an extreme focus on EiBI perform well at employing existing knowledge and resources to secure firms’ short-term viability, but fail to seize new opportunities that arise from the dynamic market. Too little focus on ErBI means that a firm is likely to lose the chance to develop new processes or product that can promote operational efficiency. In contrast, firms that overemphasise exploratory blockchain initiative neglect the chance of fully employing existing resources to eliminate inefficiency in operations. Wong et al. (2013) also indicate that a balanced combination is concerned with devoting matching resources for sake of operational efficiency. Thus, the current study proposes that maintaining a balance between exploitative and exploratory blockchain initiative helps a firm to fully utilise the chances to improve its operations.

H4: Balanced blockchain initiative is positively related to firm’s operational efficiency.

Methods

Data collection

Secondary panel data were collected from multiple data sources to test the proposed hypotheses. For the independent variable, information was derived from firms’ official announcements of their blockchain initiative. Compared with newspaper reports, official announcements are the most authoritative source of information (Liu et al., 2020). In addition, operational data were collected from the China Stock Market & Accounting Research (CSMAR) Database to measure other research variables. The sample collected in this study was limited to publicly listed manufacturing firms in China. In the first step, a



list of Chinese manufacturing firms (two-digit CSRC codes C13–C43) was obtained from the CSMAR Database. Secondly, a manual search for whether each firm has made any official announcements containing the keyword “blockchain” was carried out. In this step, 1,490 blockchain-relevant official announcements from 302 firms were screened. Lastly, by reading through all the announcements, the blockchain initiatives of sample firms were identified. Announcements involving no blockchain initiatives (e.g. senior executive resumes, industry introductions and policy analysis) were eliminated. Repeated initiatives revealed in different announcements were also excluded to avoid duplicate counting. Finally, 141 listed Chinese manufacturing firms with at least one blockchain initiative between 2015 and 2020 were coded. Next, in order to measure other research variables, panel data on the 141 sample firms were collected from the CSMAR database for the years 2015 to 2020. Due to the missing data, the final sample consisted of 395 firm-year observations.

Variable measurements

Ambidextrous blockchain initiative. This study adopted the content analysis method to measure exploration and exploitation. Based on the definition proposed above, after carefully reading through the blockchain-relevant announcements, exploratory and exploitative blockchain initiatives were identified. Using Lam et al. (2016) as a reference, the numbers of two types of initiative were counted to quantify exploratory and exploitative blockchain initiatives. In line with prior studies (He and Wong, 2004; Wong et al., 2013), two ambidextrous blockchain initiatives were measured: 1) complementary blockchain initiative: the interaction of exploration and exploitation; 2) balanced blockchain initiative: the absolute difference between exploration and exploitation, which was reversed to facilitate interpretation.

Operational Efficiency. In line with prior studies (Lam et al., 2016; Li et al., 2010), Stochastic Frontier Estimation (SFE) methodology was adopted to measure firms’ operational efficiency. Using the SFE approach, an efficiency score for each sample firm in each year was calculated. The score ranges from 0 to 1, reflecting the firm’s relative capacity in transforming operational inputs into outputs.

Control Variables. Four control variables, namely firm size, firm age, firm profitability and firm cash-to-cash cycle were included on the grounds that they might influence operational efficiency (Lam et al., 2016; Kortmann et al., 2014). Firm size was measured as the natural logarithm of a firm’s sales. Firm profitability was operationalised as firm’s return on assets. Firm age was generated as years since firm’s incorporation. In line with Kevin et al. (2009), firm cash-to-cash cycle was calculated. Each firm’s cash-to-cash cycle was also standardised based on its industry. In addition, year dummies were also controlled in consideration of unobserved time-specific effects.

Table 1 Correlation and statistics result of the variables examined

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.Operational efficiency	1								
2.Complementary blockchain initiative	0.042	1							
3.Balanced blockchain initiative	0.073	-0.122**	1						
4.Exploitative blockchain initiative	-0.120**	0.487***	-0.346***	1					
5.Exploratory blockchain initiative	0.007	0.460***	-0.862***	0.318***	1				
6.Firm age	0.039	-0.038	0.007	-0.073	-0.023	1			
7.Firm size	0.197***	0.027	-0.049	-0.01	0.079	0.172***	1		
8.Firm profitability	0.396***	-0.135***	0.198***	-0.145***	-0.147***	-0.048	0.132***	1	
9.Firm cash-to-cash cycle	-0.088*	0.029	-0.049	0.0240	0.067	0.050	0.197***	-0.000	1
Mean	0.425	0.037	2.813	0.061	0.187	16.5	21.53	0.033	-0.032
Standard deviation	0.158	0.256	0.445	0.239	0.484	4.803	1.530	0.072	1.097

Notes: *p<0.1, **p<0.05, and ***p<0.01 (two-tailed tests)

Table 2 The impact of blockchain initiative on operational efficiency

Variables	Model (1)	Model (2)	Model (3)	Model (4)
Exploitative blockchain initiative		-0.040 (-1.286)	-0.076** (-2.607)	-0.034 (-1.144)
Exploratory blockchain initiative		0.034* (1.817)	0.018 (0.922)	0.077*** (2.960)
Complementary blockchain initiative			0.087*** (3.199)	
Balanced blockchain initiative				0.057** (2.113)
Firm age	0.001 (0.581)	0.001 (0.616)	0.001 (0.584)	0.001 (0.632)
Firm size	0.019** (2.346)	0.018** (2.293)	0.017** (2.232)	0.018** (2.235)
Firm profitability	0.807*** (4.579)	0.817*** (4.757)	0.834*** (4.860)	0.797*** (4.641)
Firm cash-to-cash cycle	-0.018*** (-3.052)	-0.019*** (-3.135)	-0.018*** (-3.083)	-0.019*** (-3.152)
Year dummies	Yes	Yes	Yes	Yes
cons	-0.022 (-0.128)	-0.011 (-0.067)	-0.007 (-0.040)	-0.176 (-0.987)
F	4.786	4.770	5.352	5.424
VIF	1.04-1.54	1.09-1.60	1.05-1.62	1.09-4.11

Notes:(1) *p<0.1, **p<0.05, and ***p<0.01 (two-tailed tests); (2) t-statistics are in parentheses.



Results

The correlations, means, and standard deviations of all variables are shown in Table 1. Sample data manifest a short and unbalanced panel, in which case pooled regression is applicable and more likely to provide reliable results (Ben-Jebara and Modi, 2021). To exclude the potential influence of multicollinearity, variance inflation factor (VIF) for each regression model was calculated and shown in Table 2. The results show that the VIF values of all the models are all smaller than 10, indicating that multicollinearity is not a problem for interpreting the results. To reflect the causal relationship, all independent variables and control variables were lagged by one year from the dependent variable.

Table 2 presents the pooled regression outcomes. In the first column of Table 2, Model (1) is the base model and only includes control variables and year dummies. The main effect of exploitative and exploratory blockchain initiative was then added in Model (2). The results show that the two patterns of blockchain use have no significant direct impact on operational efficiency. H1 and H2 are not supported. To test H3 and H4, following He and Wong (2004), the effects of alternate ambidextrous blockchain initiative were analysed using separate models, with only one of the two ambidexterity dimensions included. The coefficient of complementary ($=0.087$, $p<0.01$) and balanced blockchain initiative ($=0.057$, $p<0.05$) are both positively significant. The results suggest that a firm's ambidextrous blockchain initiative, either complementary or balanced, improves its operational efficiency. Thus, H3 and H4 are supported.

Conclusion

The use of blockchain can help firms to reduce costs and eliminate the risk of human process errors and other functions. Therefore, blockchain can provide firms with the opportunity to improve operational efficiency. The results of the analysis of data from 141 Chinese listed manufacturing firms show that separate pattern of blockchain initiative has no significant impact on a firm's operational efficiency. However, firms that achieve ambidextrous blockchain initiatives, either complementary or balanced, will see an improvement in their operational efficiency.

This paper examined the impact of blockchain initiative, an emerging digital technology, on firms' operational performance (i.e. operational efficiency) using a quantitative approach. The inclusion of the organisational ambidexterity perspective provides a theoretical perspective on the benefit of adopting blockchain and helps to extend knowledge in this area. From a managerial perspective, the empirical results provide practitioners with evidence that blockchain can have a positive impact on operational efficiency. Therefore, it is suggested that managers stay highly focused on the use of blockchain. However, they also need to recognise that the single pattern of blockchain use may not have a significant impact on operational efficiency. To achieve a favourable outcome, it is important to develop both exploitative and exploratory blockchain initiatives.

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E-COMMERCE LOGISTICS AND PEOPLE IN LOGISTICS AND SUPPLY CHAIN



REVERSE LOGISTICS IN E-COMMERCE: A SYSTEMATIC LITERATURE REVIEW

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1. Introduction

E-commerce has been growing rapidly over the last decade. Customers can now place an order simply by clicking on their phone or laptop without the necessity to visit a brick-and-mortar store. Meanwhile, more and more retailers are developing their online businesses as the threshold and investment needed to open an online store is relatively low compared to a brick-and-mortar store. Though e-commerce brings many benefits to customers and retailers, issues like product returns appear to be more frequent compared to conventional businesses (de Araújo et al., 2018). In 2022, the retail e-commerce sales worldwide will reach \$6,543 billion, almost five times the value of 2014. However, as more than 30% of the products are returned in e-commerce (Saleh, 2016), more than \$1,963 billions are involved in the returns, not accounting for the associated operational costs. Therefore, good knowledge and understanding of reverse logistics becomes increasingly significant and necessary for managing product returns. That is why, this paper reviews recent theoretical and empirical research on reverse logistics using the Systematic Literature Review methodology (Tranfield et al., 2003) to inform the much-needed reverse logistics management practice.

Reverse logistics is the counterpart of forward logistics. The early definition was focused on the recovery of products. Later on, the scope has been widened, bringing different perspectives including reverse product flow and information flow (Prajapati, 2019). The most widely accepted definition of reverse logistics was written by Rogers & Tibben-Lembke (1999) as: "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". In short, reverse logistics can be summarised as product return, reuse, repair or remanufacture activities from the downstream of a supply chain to its members in the upstream. Product return management is not the same as reverse logistics. Product return management is a broader concept including the management of marketing, logistics, operations, financial and accounting functions associated with product return activities (Mollenkopf et al., 2011). Rogers et al. (2002) defined return management as: "The supply chain management process by which activities associated with returns, reverse logistics, gatekeeping, and avoidance are managed within the firm and across key members of the supply chain". Hence, it should be clearly stated that the selected studies in this review are focused on reverse logistics in e-commerce rather than other areas of return management.

In a typical e-commerce product return process, the activities involved are return requesting, returns collection, returns inspection, returns reselling, remanufacturing, or disposal. Since the nature of e-commerce selling mainly happening between e-tailers and customers, problems and processes around these two stakeholders have received more research attention compared to other stakeholders. As e-commerce product return activities are unpredictable with growing quantity and high variety of products, hurting companies' profitability, efficient reverse logistics management has become an essential part of running a successful and sustainable e-commerce business.

Over the last five years, many exciting findings were proposed by researchers in e-commerce reverse logistics sector. Also, as managing returns is still a major challenge causing adverse impact on e-commerce businesses (Nel & Badenhorst, 2020), a systematic literature review in this field at this point is meaningful to provide organised information for both practitioners and scholars in e-commerce reverse logistics and return management. Therefore, the objective of this paper is to present a systematic review of reverse logistics and return management in e-commerce businesses, identifying the research gaps and suggesting future research directions. The review questions are:

- 1) What are the reasons resulting in product returns?
- 2) What are the methodologies used in e-commerce reverse logistics research?
- 3) How can an efficient, sustainable return process be designed and implemented?
- 4) What are the barriers that hinder the implementation of efficient reverse logistics in e-commerce?

The rest of this paper is organised as follows. Section 2 introduces the methodology used. Section 3 presents the findings and the results of the content analysis. Section 4 discusses the results, highlighting the research gaps and provides directions for future studies. Section 5 is the conclusion.



2. Research Methodology

A 5-stage systematic literature review (Figure 1) was conducted with content analysis adapted from Prajapati (2019) and Seuring (2008).

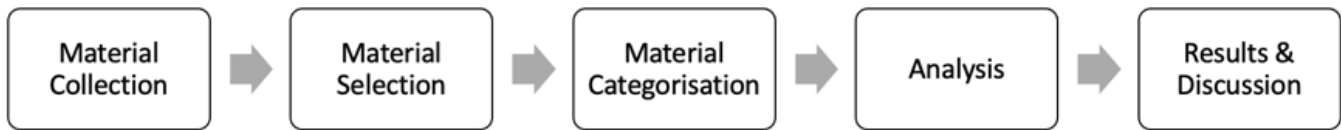


Figure 1: Research Methodology Flow Chart

2.1 Material Collection

This study used Scopus as the search database. Scopus is the largest peer-reviewed article database with over 5000 publishers and 70 million articles (Scopus, 2021). Thus, it was assumed that most of the relevant articles in e-commerce reverse logistics and return management were selected in this review. We queried the database on 23rd December 2020 and confined the search terms as “reverse logistics” or “return” and “e-commerce” in only title, abstract and keywords. The search result in this stage was 684 papers.

2.2 Material Selection

The second stage was material selection through three filters (Figure 2). The first filter was to exclude document type that was a book chapter, a conference review, a review, a note, a short survey or a book. The second filter was to exclude source types including book series and conference proceedings. The third filter was to restrict the language to English only, with 328 papers remaining. Next was abstract analysis to exclude papers that is within the search criteria but not in the field of this review such as papers containing the term “return a profit”. Also, judgement calls were made on whether papers are highly relevant in e-commerce reverse logistics and return management based on the abstract. Those with low relevance were removed. Finally, 74 papers were selected for this review.

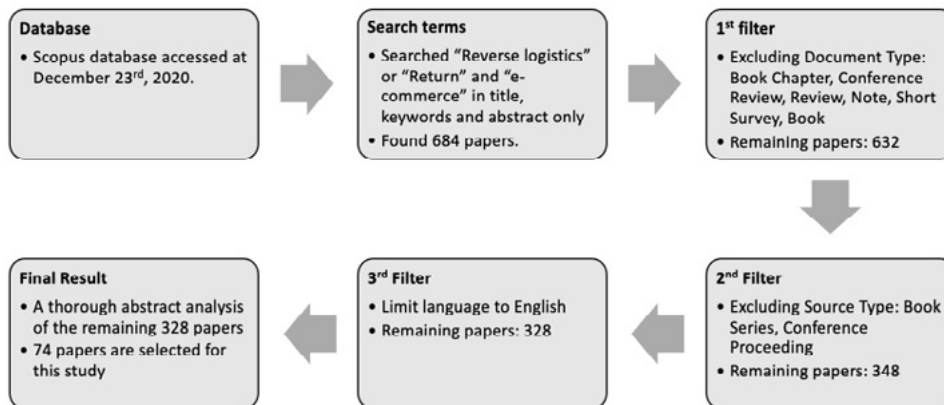


Figure 2: Selection Process Flow Chart

2.3 Material Categorisation

The next stage was to classify the selected materials by predefined categories including research design and research methodology. The research design was segregated into theoretical and empirical studies with both qualitative and quantitative analysis under each category. The research methodology was further divided based on the research design (Figure 3).



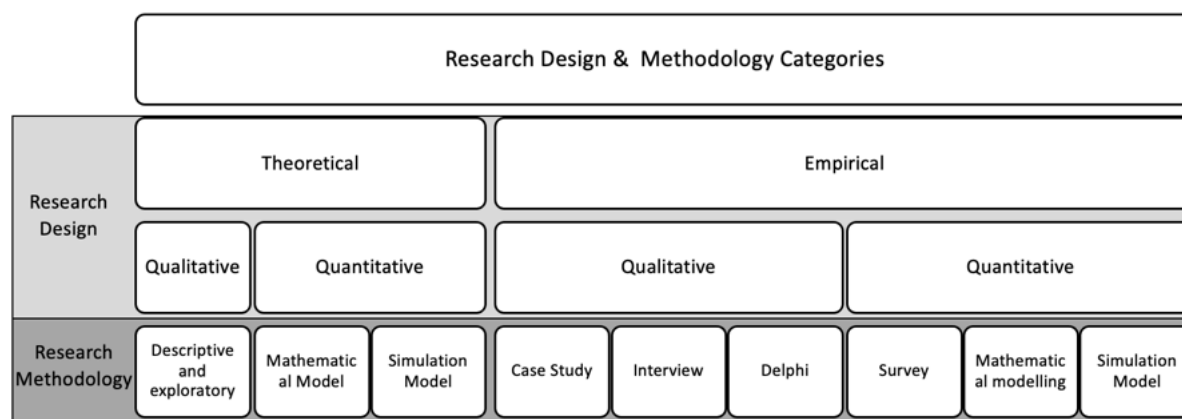


Figure 3: Research Design and Methodology Categorisation

2.4 Analysis

After the categorisation, the next stage was the analysis of the selected materials including two parts. The first part was categorical analysis with the research design and research methodology. The second part was an analysis and synthesis of the content, including the reasons for product return, e-commerce reverse logistics implementation barriers and the objectives in network studies.

2.5 Results and Discussion

The last stage was a discussion of the findings. The implications on e-tailers and customers and the implications on the environment was provided. The directions for future studies were proposed including manufacturer, supplier, and warehousing studies in e-commerce reverse logistics.

3. Findings

3.1 Research Design

In the research design category, we separated the studies as theoretical studies i.e., those without any case study, survey or interview and empirical studies i.e., those with case study, survey, interview or Delphi method, collecting data from the real world. It can be concluded that studies in e-commerce reverse logistics have almost the same number of papers in terms of theoretical and empirical category (Table 1).

Table 1: Category of Research Design

Table 1: Category of Research Design					
Main Categories	Subcategories 1	Subcategories 2	Number of papers	Total	Percentage
Research Design	Theoretical	Theoretical qualitative	5	38	51%
		Theoretical quantitative	33		
	Empirical	Empirical qualitative	5	36	49%
		Empirical quantitative	31		

3.2 Research Methodology

The papers were categorised as qualitative and quantitative research and further classified into seven subcategories. Since many papers use more than one research method, the total number of papers in Table 2 is above 74. From the results, it is evident that the most popular research methodology is mathematical modelling. 73% (54/74) of the papers use mathematical models, indicating that the quantitative methods are more favourable among scholars in e-commerce reverse logistics.



Table 2: Category of Research Methodology

Table 2: Category of Research Methodology			
Main Category	Subcategory 1	Subcategory 2	Number of papers
Research Methodology	Qualitative	Descriptive and exploratory	6
		Case study	22
		Interview	5
		Delphi	3
	Quantitative	Survey	9
		Mathematical modelling	54
		Simulation	39

3.3 Product Return Reasons

Customer studies are one of the popular topics in e-commerce reverse logistics. One reason is that the returns are originated from customers, hence, studies on the factors that affect customers' return decisions are concentrated in studies on return reasons (Table 4). The most common reasons identified by scholars are 1) Customer receives defects, damaged or wrong products and thus results in product return; 2) Impulsive purchasing behaviour leads to too much purchasing or regret buying, which eventually leads to the return.

Table 4: Product return reasons

Table 4: Product return reasons		
Category	Subcategory	Source Papers
Product Information	Customers lack physical contact/product does not fit	(Nel & Badenhorst, 2020; Pei & Paswan, 2018)
	The product does not match website description	(Nel & Badenhorst, 2020; Rabinovich, 2011; Saarijärvi et al., 2017)
	Website information outdated	(Nel & Badenhorst, 2020)
Operation Process	Defect products/damaged products/wrong products delivered	(Nel & Badenhorst, 2020; Pei & Paswan, 2018; Rabinovich, 2011; Saarijärvi et al., 2017)
	Unpleasant logistics service/late arrival	(Lin et al., 2020; Nel & Badenhorst, 2020; Rabinovich, 2011; Saarijärvi et al., 2017)
	Unsatisfied online shopping service	(Lin et al., 2020)
Customer Behaviour	Impulsive buying/regret buying	(Nel & Badenhorst, 2020; Pei & Paswan, 2018; Rabinovich, 2011; Saarijärvi et al., 2017)
	Unethical/fraudulent behaviour	(Nel & Badenhorst, 2020; Saarijärvi et al., 2017)
	Ordering many but only keeping one	(Saarijärvi et al., 2017)
	Found at a cheaper price/the need has faded away	(Pei & Paswan, 2018; Saarijärvi et al., 2017)
Seasonal/Event Reason	Holiday reasons return/gift return	(Nel & Badenhorst, 2020; Rabinovich, 2011)
	Only use/wear in an event	(Pei & Paswan, 2018)



3.4 Barriers Implementing E-commerce Reverse Logistics

Several papers have identified the issues and barriers practising reverse logistics in e-commerce businesses (Table 5). The most common barriers identified are 1) Companies lack investment to implement reverse logistics; 2) The complexities in the return process and the time spent in the return process hinder the implementation; 3) Companies lack supporting technology or available data in the reverse logistics sector.

Table 5: Barriers implementing reverse logistics in e-commerce

Table 5: Barriers implementing reverse logistics in e-commerce

Category	Subcategory	Source Papers
Financial	Lack of investment	(Frei et al., 2020; Lamba et al., 2020; Nel & Badenhorst, 2020; Thiyagarajan & Ali, 2016)
	Unable to achieve economies of scale due to return uncertainty	(Lamba et al., 2020; Nel & Badenhorst, 2020; Thiyagarajan & Ali, 2016)
Knowledge	Lack of training and education/Lack of understanding of the best practice	(Lamba et al., 2020; Thiyagarajan & Ali, 2016)
	Lack of procedures for returns/Lack of reverse logistics performance measurement	(Lamba et al., 2020)
	Lack of understanding of the importance of reverse logistics	(Frei et al., 2020)
Management	Lack of government supportive policy	(Lamba et al., 2020; Thiyagarajan & Ali, 2016)
	Lack of top management support	(Lamba et al., 2020)
	Lack of logistics integration/lack of support from logistics partners	(Lamba et al., 2020)
	Long cycle time and complexities of the return process	(Frei et al., 2020; Lamba et al., 2020; Nel & Badenhorst, 2020; Thiyagarajan & Ali, 2016)
	Customer behaviour unpredictability/return quantity unpredictability	(Frei et al., 2020; Nel & Badenhorst, 2020)
	Lack of supporting technology	(Frei et al., 2020; Lamba et al., 2020; Nel & Badenhorst, 2020; Thiyagarajan & Ali, 2016)
Technology and facilities	Lack of infrastructure facility	(Lamba et al., 2020)
	Pool data management/lack of data	(Frei et al., 2020; Thiyagarajan & Ali, 2016)

3.5 Network design studies

The cost of returns handling depends heavily on the reverse logistics network efficiency considering the time and stakeholders involved, especially retailers now use more than one channel to sell products and also sometimes multiple channels to handle product returns (Guerrero-Lorente et al., 2020). The network design problem is the most explored area in network-related studies. One paper used weighted goal programming to minimise both economic and environmental cost while optimising social benefit (Dutta et al., 2020). Other papers are single objective on the minimisation of cost, which generally includes transportation cost, facility construction cost, return processing cost and warehousing cost (Table.9).

Table.9. Optimisation models objectives



Table.9. Optimisation models objectives

Model	Transportation cost	Facility construction cost	Return processing cost	Warehousing cost	Environmental impact	Production cost	Social impact	Paper
MILP	✓		✓	✓				(Das et al., 2020)
WGP	✓	✓	✓		✓		✓	(Dutta et al., 2020)
MIP	✓	✓	✓					(Guerrero-Lorente et al., 2020)
MINLP	✓	✓	✓	✓				(H. Guo et al., 2020)
MIP	✓	✓	✓			✓		(Prakash et al., 2020)
MINLP	✓							(Zhang et al., 2020)
MIP	✓	✓			✓			(J. Guo et al., 2017)
ILP				✓				(Schrotenboer, 2017)
MIP	✓	✓		✓				(Deng et al., 2016)
MIP	✓	✓	✓	✓				(B. Liu et al., 2015)
MINLP	✓	✓	✓	✓				(Li et al., 2014)
MIP	✓	✓						(D. Liu, 2014)
MINLP	✓	✓		✓				(Zaarour et al., 2014)
MIP	✓	✓	✓	✓				(Li et al., 2013)
MILP	✓	✓						(XiaoYan et al., 2012)

Abbreviations: Mixed Integer Programming (MIP), Mixed Integer Linear Programming (MILP), Mixed Integer Non-linear Programming (MINLP), Integer Linear Programming (ILP), Weighted Goal Programming (WGP)



4. Discussion

4.1 Customers and E-tailers Implications

Figure.3 summarised the studies on customers and e-tailers. The number in the brackets is the number of papers identified under each topic. Going through the return process from supply chain downstream to upstream, the origin of returns is customers. Though factors such as customer behaviour and customer satisfaction have been paid due attention on the reasons resulting in product returns, methods to prevent product return were seldom researched (Walsh & Möhring, 2017). Further, since e-tailer can change their return policy to attract and keep customers, many scholars studied the impact of return policy on customer purchase intention, loyalty and satisfaction (Mollenkopf et al., 2007; Pei et al., 2014). In general, a strict return policy can reduce the quantity of returned products, however, customer satisfaction level will also decrease. One research gap identified in customer behaviour studies is the prevention method for product return activities under different customer satisfaction levels. Returned products quantity and variety is uncertain in practice and thus often risk is involved in predicting the product return activity. Vilar-Zanón et al. (2017) studied the risk management in return handling through analysing the product pricing strategy considering future cost of product returns and the reserve capital for an e-tailer to cover the cost of returns handling in a period. Since product return activities can hardly be predicted, studying the risk in reverse logistics is necessary.

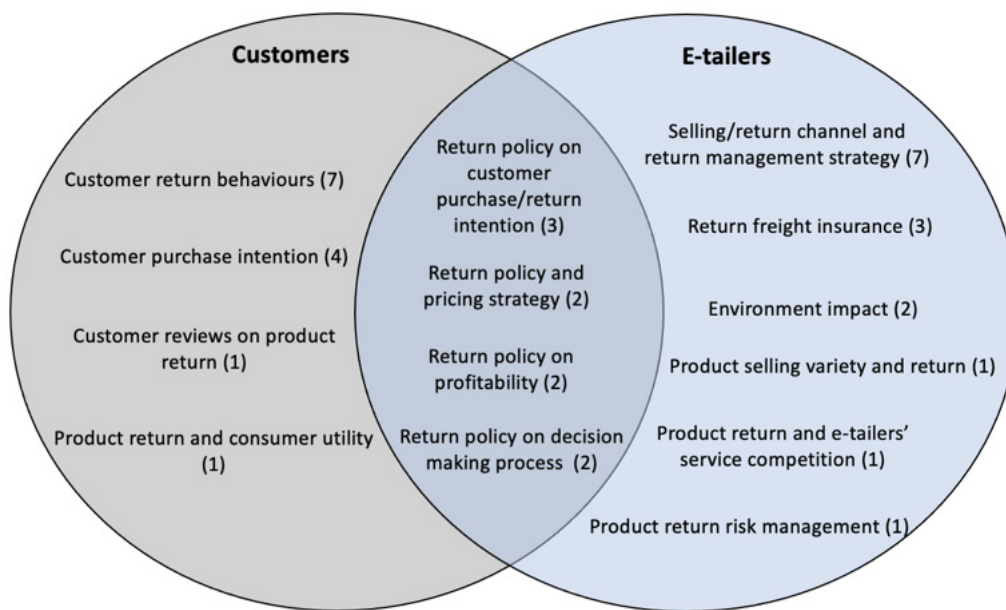


Figure.3. Category of Studies on E-tailers and Customers, Source: Author

4.2 Environmental Implications

Since the product returns is more frequent in e-commerce compared to conventional retail, a well performed reverse logistics operation offers more environmental benefits in e-commerce than in traditional business. Four papers were identified studying the environmental implications in e-commerce reverse logistics. Bertram & Chi (2018) compared the environment sustainability in apparel e-tailing and in conventional retail. They found that e-tailing has less environmental damage compared to traditional retailing under most situations. But some factors such as excessive packaging and more frequent product return activities in e-commerce lead to more carbon footprint than traditional retail. Matthews et al. (2001) also compared the environmental impact of e-commerce and traditional retail and found that with 35% of return rate in the book industry, e-commerce is more environment friendly. Zhao et al. (2019) identified that the carbon emission for conventional retail is mainly from the buildings and consumer trips. While for e-commerce, the carbon emission is mainly from the packaging rather than from the returned product transportation. Bazan et al. (2015) used a mathematical model to analyse the cost of environmental implications in reverse logistics under the manufacturing and remanufacturing context. The model calculated the batch size and the number of batches in manufacturing and remanufacturing and concluded that models taking environmental cost into account promote less remanufacturing. The reverse logistics has benefits on the environment as it generates less carbon emission and waste compared to conventional retail; however, the links between each procedure and function in reverse logistics operation and the environmental benefits are not clearly identified. To implement a sustainable reverse logistics, factors impacting the environment should be clearly identified with weightage and those with high impact such as the impact of packaging on the environment should be further researched.



4.3 Future Research Directions

The research on remanufacturing and warehousing were paid less attention than other functions such as retailing in e-commerce reverse logistics, indicating that the studies were more concentrated on the downstream of the supply chain, which could be the reason that the nature of e-commerce businesses happening mostly between e-tailers and customers. However, as companies are more aware of the benefit of reverse logistics and the regulations established from the government demanding cleaner production and operation (Genchev, 2009), the practice of reverse logistics in e-commerce will become the norm for many companies in the future. Hence, research is needed on warehousing and remanufacturing in e-commerce reverse logistics.

1. Warehousing – The warehousing sector is crucial for reverse logistics. Once a return request is approved by e-tailers, products need to be shipped to a warehouse, where inspection is conducted for further instructions. Returned products in e-commerce have a wide range of variety and demand uncertainty and thus add more complexities to the warehouse operation than conventional product storage and handling operation. Hence, the research direction for warehousing is to incorporate and to adjust existing warehouse operation procedures for reverse logistics and further to integrate warehousing for forward and reverse logistics. The research in e-commerce reverse logistics warehousing should work on the modelling towards the dynamic storage and equipment configuration under stochastic demand context to better simulate the real-world product return situation and to improve the flexibility in warehousing operation.

2. Remanufacturing – The remanufacturing process is time consuming as products need to be shipped from an inspection warehouse to the remanufacturing facility or a disposal facility. If remanufactured, the products need to be shipped to a distribution warehouse or directly to customers. This process can be studied along with the warehouse operations to reduce the non-value adding travel of returned products in remanufacturing. For example, some minor rework can be finished inside the inspection warehouse. Future research can also work on this problem to redesign the process for remanufacturing. This requires more process integration studies in terms of product transportation, remanufacture, and information sharing mechanisms. Moreover, circular economy procedures can be considered in the remanufacturing process as product value scraping, reuse of packaging or certain parts of the product are common practice in the remanufacturing process.

5. Conclusion

The academic attention to e-commerce reverse logistics has seen a surge in the last five years. This could be attributed to the benefit of reverse logistics on the supply chain, the increasing quantity of returned products generated from e-commerce businesses and the growing awareness of their environmental impact. This paper has identified 74 papers in e-commerce reverse logistics and further categorised them based on research design and research methodology. Further, contents such as product return reasons, barriers to implementing reverse logistics in e-commerce and objectives in network design studies were synthesised. Many exciting areas in e-commerce reverse logistics require research attention, some of which were provided in this paper. From the synthesised content, managers can identify the reasons for returns and acknowledge the barriers of reverse logistics implementation while scholars can identify the hot topics and research gaps in e-commerce reverse logistics. The limitation of this study is the search database selection. Considering other databases such as EBSCO and ABI/Inform may contain papers that are not in Scopus, some qualified research works were inevitably not included in this study.

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HUMANITARIAN LOGISTICS AND SUPPLY CHAIN MANAGEMENT



A RESEARCH ON RISK MANAGEMENT IN EMERGENCY SUPPLY CHAINS

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Purpose

In response to a disaster, emergency supply chains (ESCs) are developed swiftly to respond to the needs of the vulnerable population. Irrespective of context, risk is inherent practically in all processes of supply chain management. Economic systems are ever more prone to complexity and uncertainty. Therefore, making informed decisions requires effective risk management. The purpose of this paper is to present a conceptual risk management framework for ESC applications. The framework is developed to deepen the understanding of emergency supply chain management and its characteristic risks.

Research Approach

The study conducts a synthesis of literature review and based on findings, a conceptual framework is developed.

Findings

The study reveals that the adoption of best practices from the conventional setting is not directly applicable due to the unique features of ESCs.

Research Impact

This study will be able to provide sufficient awareness into how emergency supply chain risks functions and how relief organisations involved in emergency response operations can effectively process and manage these risks. The study makes available groundwork for conducting empirical studies that will support an integrated resource effective and time-efficient decision-making model in emergency supply chain risk management (ESCRM).

Practical Impact

Synchronising ESC operations with risk management is essential. The proposed ESCRM framework will deliver a profile for risks that will support emergency managers in understanding, anticipating and dealing with potential risks in the system proactively.

Keywords

Disasters, Emergency supply chains, Risk management, Emergency supply chain risk management.

1. Introduction

The presence of diverse and severe disasters around the globe is continuously increasing. Disaster impacts involves the disruptions of the functioning of the society, which leads to loss of lives, economic losses and damage to the environment. For example, in 2020, the COVID-19 pandemic resulted in all countries around the globe to enforce a total lockdown, restricting the free movement of people and goods, which led to huge economic losses, millions of deaths and still counting. Following the occurrence of a disaster, disaster relief operation (DRO) must be swiftly initiated to mitigate or ensure minimum effects on the vulnerable population and damages to the society. Contrary to the commercial supply chain, the emergency supply chains are set up immediately following the occurrence of the disaster with little or no prior preparation.

All supply chains face the risk of disruptions that result from diverse causes and may take various forms (Snyder et al., 2006). Accounting for these risks prior or during the design of the supply chain networks is imperative to allow the supply chains perform well even after the risk event has taken place. To improve the effectiveness and efficiency of the ESCs, risk management (RM) is a fundamental step. The topic of supply chain risk management (SCRM) that encompasses the identification, assessment and mitigation of risks was developed for the commercial supply chain. ESCs are unique from their commercial counterpart (Dubey & Gunasekaran, 2016). However, the application of commercial concepts, models and tools to the emergency context is acceptable but not directly transferrable (Van Wassenhove, 2006; Maon et al., 2009; Day et al., 2012). Existing literature shows that academicians in various context have proposed many frameworks, such as, disaster relief logistics (Kovács & Spens, 2007); Emergency logistics preparedness (Jahre et al., 2016); Triple- A framework (Dubey & Gunasekaran, 2016), etc. SCRM is vast expanding and there is no single framework for managing supply chain risks in all context. In ESCM, there is no comprehensive framework for risk management. Existing SCRM frameworks in the business setting is inadequate in the ESC context. Balcik et al., (2010) underlined that where proven SCM practices are adopted in the ESC context, satisfactory performance outcome has remained elusive. This creates a gap with the opportunity of providing knowledge of the presence of risk and its effects in ESCs. In this study, a conceptual framework for assessing and managing risk in ESCs is proposed. The framework



adds an initial understanding of ESCs and the processes and management of the characteristic risks to contribute to the advancement of knowledge in the ESC setting. The study is structured as follows Section 2 presents a brief literature review including ESCs and RM. Section 3 presents the conceptual framework. Section 4 concludes the study.

2. Literature Review

2.1 Emergency Supply Chains

Rapid and appropriate response to mitigate the effects of disasters (Besiou et al., 2011) and provision of necessary support to the vulnerable population for the prevention and alleviation of suffering are the fundamental task of the emergency supply chains (Blecken, 2010). A typical ESC diagram is illustrated in Fig. 1. According to Beamon and Balcik, (2008), the presence of minimal or zero lead-time, demand unpredictability, uncertainty, inadequate resources and other dynamic influences define the activities of emergency supply chains. The question of “what is required”, “when” and “where” are key attributes associated in the emergency context. These attributes differentiate the ESC from its commercial counterpart. Maon et al. (2009) underlines that commercial and emergency SCM mark some significant similarities, such as the critical theories related to the flows of goods, information and finances. In addition, the primary SCM practices; demand management, supply management and fulfilment management also remain unchanged (Ernst, 2003).



Fig 1. A typical ESC diagram

Source: (Oloruntoba & Gray, 2006)

According to Overstreet et al., (2011), the emergency supply chain is spontaneous, and the demand is not limited to commodities but also includes human resources and services (Blecken et al., 2009). Van Wassenhove, (2006) highlighted how the emergency supply chain has remained 15 years behind its commercial counterpart in terms of applied methods. Due to the distinctive characteristics of ESC, Taylor and Pettit, (2009) underlined that there is a challenge of direct adaptability of methods and techniques from the commercial supply chain to the emergency supply chains. However, they can be adjusted to fit. Day et al., (2012) posited that emergency supply chains operates in environments that would critically challenge experienced supply chain managers only familiar with commercial settings.

2.1.1 Actors in Emergency supply chains

Governments and Non-governmental organisations are the main actors in ESC that hold the main power to control over political and economical conditions. The decisions they make fundamentally affect the activities of the ESC. Kovács and Spens, (2007) list donors, aid agencies, logistics service providers, the military and suppliers as actors in the ESC. Figure 2 show the actors of the supply network of the ESC. Donors have become particularly influential in prompting emergency organisations to think in terms of greater donor accountability. For example, donors often request the funds raised be directed towards procurement of food and relief for affected people or even towards a particular disaster-hit location. Thus, the delivery of relief to disaster-affected people to alleviate suffering is not the sole goal of emergency supply chain management, there is also a need to be accountable to the stakeholders in the chain. Van Wassenhove, (2006) highlighted that the media is also a critical stakeholder in the ESCs. The presence of numerous numbers of actors present in a particular disaster relief operations results in diverse objectives, thus, increased complexity (Oloruntoba & Gray, 2006; Tatham et al., 2009).

2.1.2 Stages of emergency supply chains

Disaster management is often described as a process with several stages (Kovács & Spens, 2007). Goldschmidt and Kumar, (2016) suggests that the disaster relief operations consists of two phases; relief and development and four activities; mitigation, preparedness, response and recovery. ESCs encompasses all phases and activities of the disaster management life cycle (see Fig 3). The relief phase includes the response and recovery activities and the development phase includes the mitigation and preparedness activities. Mitigation is the application of measures that will either the prevent onset of disaster or reduce the impacts should one occur. Preparedness activities prepare the community when a disaster occurs. Response is the employment of resources and emergency procedures as guided by plans to preserve life, property, the environment and the social, economic and political structure of the community.



Recovery involves the action taken in the long term after the immediate impact of the disaster has passed to stabilise the community and to restore the semblance of normalcy (Altay & Green, 2006). Pettit and Beresford, (2005) discussed that the phases of disaster relief operation is viewed as a cycle that links recovery back to the mitigation phase.

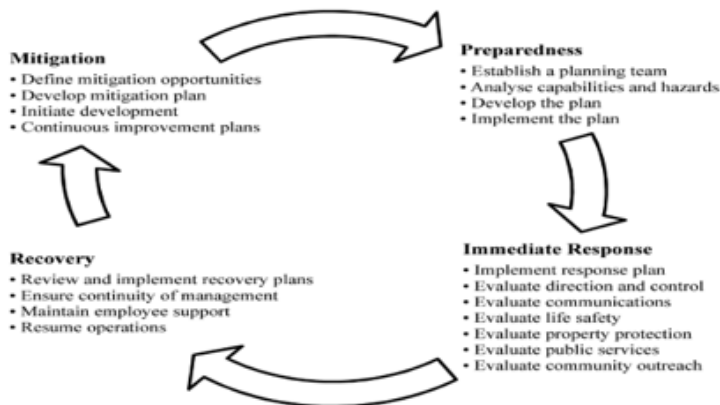


Figure 2. Disaster management process
Source: (Scholten et al., 2014)

2.2 Risk management

Supply chains face challenges (unexpected changes in information or material flows) that result in risks. Dealing with risks in today's contemporary setting is becoming increasingly challenging due to uncertainties in demand, supply, global outsourcing, and short life cycles. The disaster response-operating environment is influenced by unpredictability and uncertainty of demand and supply, destabilized local infrastructure, fragmented information, etc., thus relief agencies struggle with their operational efficiency, which leads relief organisations to the adoption of new ways to conduct their activities (Stefanovic et al., 2009). However, ESCs are more vulnerable to risks than ever before due to internal and external disruptions. Jüttner et al., (2003) defined supply chain risk as the influence of mismatch between supply and demand. Risk management is becoming an integral part of a holistic supply chain design (Christopher & Lee, 2004). SCRM is a complex concept, thus, several researchers have offered diverse definitions (Tang, 2006; Goh et al., 2007; Thun and Hoenig, 2011; Ho et al., 2015; Fan and Stevenson, 2018). Tang (2006) defined SCRM as the management of supply chain risks through the coordination or collaboration among the supply chain partners to ensure profitability and continuity. In the commercial SCRM literature, several authors have presented diverse supply chain risk types and classification (Christopher and Peck, 2004; Samvedi et al., 2013; Tang and Musa, 2011). Christopher and Peck (2004) presented three classes of supply chain risks: external to the network (environmental risk), external to the firm but internal to the supply chain (demand and supply risk) and internal to the firm (process and control risks). The ESCs operate in uncertain and dynamic environments in contrast to the demand-driven, steady state supply chains found in the business sector. Demand is not the primary source of uncertainty; a number of other uncertainties; logistical, authority, policy, socio-economic and financial issues (Day, 2014; Overstreet et al., 2011) may arise as the critical drivers of action and outshine uncertainty related to the required relief capacity (Thévenaz & Resodihardjo, 2010). Identification of supply chain risk types and classification helps in providing strategies for mitigating and managing supply chains risks. Jahre, (2017) highlighted that SCRM frameworks group management strategies based on diverse dimensions, including sharing and transferring (Ghadge et al., 2013) monitoring vs collaboration (Hajmohammad & Vachon, 2016), etc. Various strategies have been identified in literature; collaboration (lavastre et al. 2014), agility (Talluri et al. 2013), postponement (Ghadge et al. 2013), etc. Managing risks in ESCs help to mitigate further disruptions in disaster relief operations (Natarajarathinam et al., 2009). McLachlin et al., (2009) discussed that the relevance of managing risk in ESCs is undoubtable for two reasons: a disruption to the ESCs can increase the effects of the disaster and the ESCs often face by multiple risks (Jahre 2017). A SCRM framework regardless of the context depicts an integrated process that takes place across a number of settings before a turbulent disruption occurs (Ritchie & Brindley, 2007; C. Tang & Tomlin, 2008). Risk can be perceived as a series of essentially unforeseeable events that can result in harm. Ritchie and Brindley, (2007) proposed a generic framework that included five major components (risk context and drivers, risk management influencers, decision makers, risk management responses and performance outcomes), for managing risk in supply chains applicable in diverse settings. These components included a number of elements respectively. This study adapts the five major components from this generic framework for the development of the conceptual framework in the next section.



3. A Conceptual Framework for Risk Management in ESCs

Effective management of risk has become the principal interest of relevant actors and decision makers in emergency relief operations for survival and efficiently thrive in the uncertain and dynamic environments disasters present. Accordingly, risk management has emerged as a natural extension of emergency supply chain management with primary objective of identifying the potential risk sources and proffering suitable action strategies to mitigate the risk. Figure 4 illustrates the proposed framework for managing risk in ESC consisting on five components including risk context and drivers, risk management influencers, decision makers, risk management process and performance outcomes. Dynamic in nature, repetitive, continuous and centered around by the risk management process (risk identification, risk analysis, risk awareness and risk mitigation), the conceptual framework follows a sequential process, with each component depending on the other. To achieve the purpose of any risk management process, one must initially recognize the context from which the risk source emanates from. The risk sources influence and supports the risk management principles. Risk awareness is dependent on the actors that are involved in the supply chain. How risks are been perceived, being aware of the presence of risk covers the whole risk management framework and involves the actor's action in reacting to risk and improve the risk position. The perception and experience of decision makers influence the attitude towards risk. Actors must have the capacity to manage risks (internal or external). In most cases, the presence of external risk influences the internal risks, which leads to complex situations. The decision makers must respond to these risks, but there are many substitute techniques (risk taking, avoidance, mitigation and monitoring) to implement the process. The framework reflects the significance of the implementation of diverse mitigation strategies in relation to risk in various context and the actors that make decisions. Different emergency supply chains exhibit distinct characteristics and challenges. Hence, they require specific and tailored strategies to maximize efficiency. Performance measures vary widely and these measures relief the effectiveness of activities, regardless of the setting. As against profitability, rapid distribution of relief and minimized effects of human suffering reflects the effectiveness of ESCs.

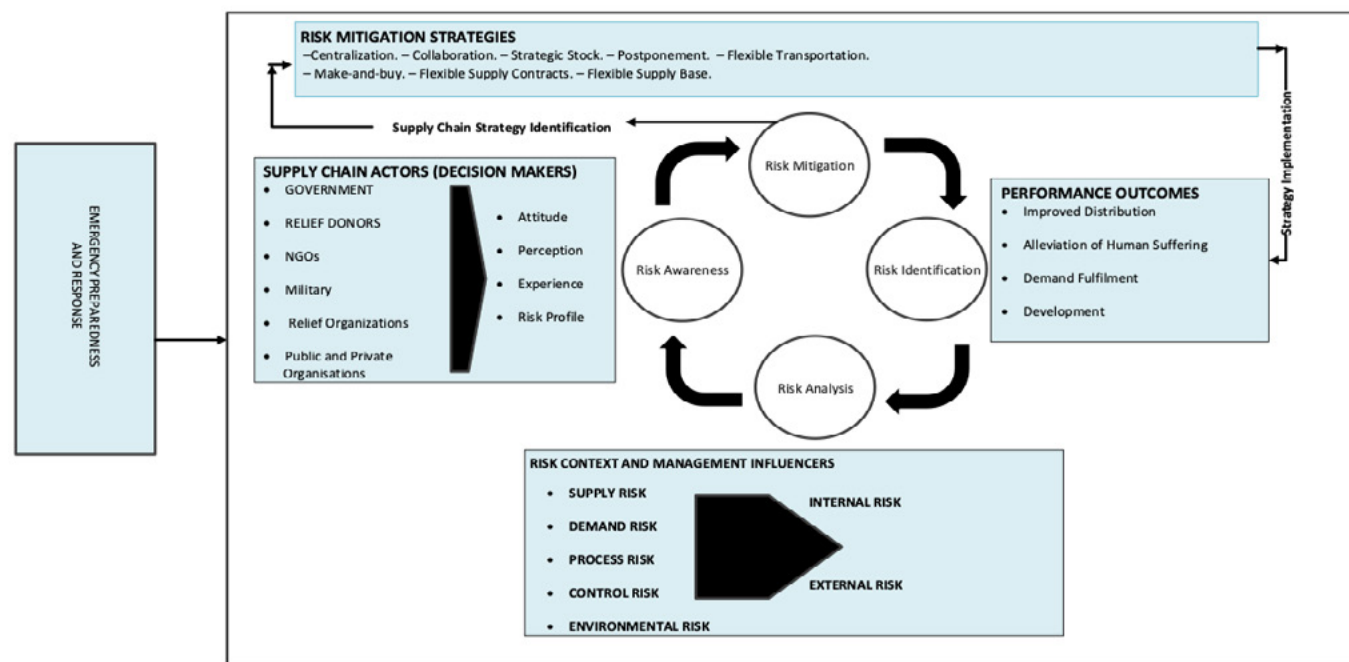


Fig 4. A conceptual framework for risk management in ESCs

4. Conclusions

ESCs is a relatively new research field that continues to grow. This growth is not only dependent on the continuous increase in the number and impact of disasters but also the ESCs is considered the most agile and flexible supply chains that exist. Detailed conceptual and empirical studies are necessary to advance ESCs. The purpose underlying the research study and the paper is to deepen the understanding of the ESCs and its characteristic risks. ESCs are unique and the direct transfer of best practices from the commercial supply chains is difficult. The study reveals that risk management is an integral part of supply chain

design and similar to any supply chain, the ESC possess risk factors that can disrupt its effective operations. Synthesising literature, the study develops a conceptual framework for managing risk factors in ESCs. The study provides initial understanding for actors participating in the relief operations to proactively and responsively, deal with potential risk factors that can disrupt or hamper their supply chain activities. The conceptual framework is generic and can be applied in most sudden-onset disasters that occur with no prior notice and require immediate response with little or no detail. Further empirical research is necessary to support the integration of an analytical decision-making model. Furthermore, the framework could be tested where applicable, by various relief organisations operating in diverse geographical locations.

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EVALUATION OF THE SUCCESS FACTORS OF A FOOD ACCESS PROGRAMME FOR COVID-19 RISK-GROUPS IN A EUROPEAN CONTEXT

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Introduction

The Covid-19 pandemic has turned the world upside down since early 2020, and there have been countless endeavours from all around the world to try and make life in lockdown easier for citizens. In this study we explore a food delivery programme in Helsinki, Finland organised by the City of Helsinki and the Church in Helsinki, along with multiple partners from the private and public sectors. We consider this programme to be in the sphere of humanitarian food aid, even though the circumstances are somewhat unique.

What makes this case interesting in the context of food aid is the premise, which does not derive from poverty, but rather a national mandate to remain at home. This can be viewed as a sudden on-set disaster (Van Wassenhove, 2006), particularly affecting the elderly, for whom the virus was considered especially dangerous. We approach the case from a humanitarian performance management perspective, as the supply chain in this case aims to promote a dignified life for those affected by disaster (Haavisto and Goentzel, 2015).

The paper is structured as follows: we first consider streams of literature regarding humanitarian supply chain management (HSCM) and the performance management thereof. We then provide a brief overview of literature regarding food aid and access, and how they relate to a rapid onset disaster in the Global North. We also discuss social issues in the supply chain, with a focus on humanitarian supply chains (HSC) and inclusion of vulnerable communities. Literature is followed by a brief foray into the research design. The case description introduces the programme in more detail, and the discussion section relates the data back to the literature and presents a framework for determining success factors. The paper is finished with a conclusion section and future research avenues presented here.

Literature

The programme in this study takes place within the public sector sphere, with contributing organizations from private and NGO sectors as well. We will examine the case from humanitarian logistics performance management perspective, as the programme follows the ethos of humanitarian operations at its core, promoting dignity and wellbeing for those affected by a disaster (Haavisto and Goentzel, 2015).

Measuring HSCM performance continues to be challenging, despite progress made in research and practice in the area (Najjar et al., 2019). HSCs are by definition unpredictable and uncertain (Tatham and Kovács, 2010). They often deal with non-financial measures, which is the main difference between HSCM and corporate SCM (Schiffeling and Piecyk, 2014). Schiffeling and Piecyk (2014) continue to highlight that while financial flows are indeed relevant in the humanitarian context as well, the benefits lie outside of economic value and present a more diverse and complex stakeholder environment. Najjar et al. (2019) identify several different streams of literature on HSC performance management. First, logistics efficiency is examined through for example resource allocation and better distribution management. Second, metrics, such as lead times, inventory holding costs, and volumes delivered, are useful in determining performance levels. Last, communication, information sharing, and cultural issues are important to consider, as the stakeholders involved in HSCs can be extremely diverse (Schiffeling and Piecyk, 2014; Najjar et al., 2019). Furthermore, HSCM performance literature can be divided into four phases: mitigation, preparedness, response and recovery (Banomyong et al., 2019).

Haavisto and Goentzel (2015) discuss the importance of goal setting for humanitarian organizations. They lean on the assumptions that goals must be set in order for organizations to orientate their actions and achievements, and those actions must be measured to determine their impact. Measuring efficiency has largely relied on financial and time indicators, which may overlook issues such as equity and sustainability (Haavisto and Goentzel, 2015). In sudden onset disasters efficiency in terms of time as well as funds available can save lives, and is therefore still an important indicator (Van Wassenhove, 2006). Efficiency must however not be achieved at the expense of transparency or accountability to stakeholders, donors and beneficiaries (Haavisto and Goentzel, 2015). When there are multiple organisations from different sectors involved, it



Food aid in Finland has mostly been studied from a poverty perspective (e.g. Ohisalo, 2017). Food aid consists of 'bread lines', usually organized by churches or charities where people would need to queue up on a certain day to receive a donated bag of food. This approach has to do with financial access, whereas spatial and physical access is not a significant factor. In an urban context particularly, the fundamental availability of food is generally not the issue, whereas households and individuals have different financial and spatial entitlements (Morgan, 2014).

In the Global North, food deserts have been studied as food insecure areas of cities, where access to nutritional food, such as fresh produce, is limited (Wang et al., 2018). Wang et al. (2018) also consider situations such as people with low mobility or who are otherwise unable to for example drive to supermarkets. These restrictions also stem from larger societal structures, such as large retail chains favouring wealthier neighbourhoods and/or small shops located in more convenient locations being pushed out of business by large supermarkets.

Including marginalised or vulnerable communities in supply chains is an important aspect of sustainable supply chain management (SSCM). The social aspects of sustainability in supply chains are less explored than its environmental or economic counterparts (Yawar and Seuring, 2017). Ensuring food access for vulnerable groups can indeed yield economic benefits for some, but also serves an important purpose of providing a dignified life. Supply chains, both humanitarian and corporate, function on the basis of collaboration, meaning that there can be many stakeholders with different goals. This is particularly highlighted when the collaborating organisations come from different sectors, such as private companies and public sector stakeholders (Nurmala et al., 2017). These types of cross-sector partnerships could benefit all stakeholders in terms of adapting to new contexts and responding to changes.

Research design

The research was conducted through qualitative interviews with the coordination team as well as secondary data such as newspaper articles. As the pandemic and this aid programme are both unprecedented occurrences, an exploratory approach is warranted.

The interviews were all conducted on Microsoft Teams and recorded. The authors were also given access to interviews conducted by another team earlier in 2020, which was a big help. Altogether 15 interviews have been analysed for this study, with some overlap in interviewees between the two research teams. The interviews were with the management team of the programme, as well as with some private company partners.

Case description

When Covid-19 hit Finland in early March 2020, the elderly and other risk groups were advised to stay at home and avoid going out in public altogether. Due to this, access to essential needs such as groceries and medicine became limited, especially for those who had no relatives etc. living in the vicinity. The aid programme started out as a phone service for the elderly to get information regarding the pandemic but expanded into food deliveries. The entire project was set up and functioning after only seven days of planning among the management team.

One of the largest grocery chains in Finland instigated the food delivery service in cooperation with the church and the city of Helsinki. The idea was the food was ordered by phone, and the order relayed to the 18 coordination points placed strategically around the city according to zip code and parish. The coordination points were physical locations, primarily working from the parish offices. Volunteers in the aid programme then picked the orders from nearby grocery stores and delivered them to the beneficiaries' door.

The food delivery programme involved several groups within the project. The initial point of contact was the contact centre, which also coordinated information and mental health hotlines. There were altogether almost 68 000 phone calls that went through the contact centre, with 60 000+ outbound calls. The city of Helsinki pledged to call all citizens over the age of 75 to enquire whether they needed assistance and to make sure they were aware of the aid programme. Table 1 presents the numbers in more detail.

Table 1 Summary of calls

Outbound calls	60 541
Inbound calls	7304
No. of over 75-year olds reached	33200
Grocery deliveries	3662
Acute grocery aid	2535
Pharmacy	342
Mental health	~700



Grocery deliveries and acute grocery aid differ in several ways. Grocery deliveries are specific orders placed and paid for by beneficiaries. The acute grocery aids are food assistance bags made up of surplus food. This aid is meant for those who are unable to purchase food and contain basic items such as dry goods, bread, and canned foods. Under ordinary circumstances beneficiaries would queue at distribution points for these bags, but the pandemic situation did not permit this, so other arrangements had to be made.

All the calls were into or out of the contact centre, which was the central entity of the programme, employing 530 people. The outbound calls were made to the elderly to determine whether they were able to access groceries and medicine and inform them about the different services they were entitled to. A private company provided the software for the contact centre, while the parishes and city the equipment. The contact centre employees all worked from home, so the centre was not a physical location. The food and medicine orders were placed through the participating pharmacy and grocery chain. This way the programme was able to avoid financial transactions with beneficiaries, leaving that to the participating companies. The financial side was handled through invoices.

Collection and delivery of the groceries was conducted by employees of the city of Helsinki, whose normal work duties were on hold because of the pandemic. This included employees from for example the cultural and leisure sectors, such as libraries and sports facilities, which were all closed. This way the programme served a double benefit, as the city of Helsinki was able to avoid furloughing people by providing them with meaningful work while their regular jobs were on hold. Several private companies volunteered their services and products for the programme, for example electric scooters, cars, and coolers for the deliveries. The physical coordination points served as important points of contact for the deliverers. They would receive their initial instructions there, as well as additional security and hygiene guidelines. Figure 1 portrays the process in a simplified manner.

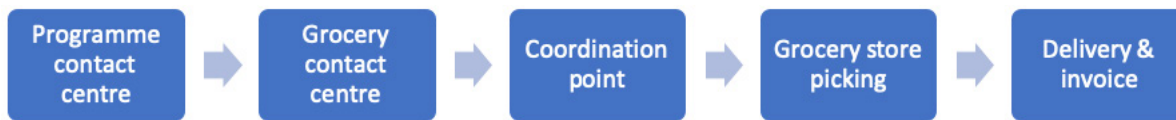


Figure 1 Simplified supply chain of grocery aid

A challenge that was mentioned among many of the interviewees was the cooperation between several very different organizations. One was described as much more hierarchical and bureaucratic than the other, resulting in issues with information flow and problem solving. Working remotely complicated matters further, as communicating with colleagues was more complicated and there were several discussions happening simultaneously in different channels. This was very difficult for management to follow. The core team did not meet live until the programme was essentially over. One member said it was rather overwhelming to acclimate to remote work and meetings while organizing such a huge endeavour, and the value of cooperation was highlighted. In addition to cooperation, the extraordinary circumstances were said to be more forgiving, and bureaucracy etc. was sidestepped in order to achieve goals in the allotted time.

Discussion

Covid-19 is unique as a disaster in the sense that infrastructure was not affected as it might be in a natural disaster, so food supply chains could continue working as normal. It was the access of individuals that restricted physical access to food, and this required a form of food aid.

As the project was put together in such a short time, the goals of the programme were in many ways made up along the way. There is for example very little documentation regarding the project, which is why also the empirical material for this study relies on interviews with members of the team. This is somewhat in contradiction to Haavisto and Goentzel (2015), as achieving goals is considered a significant part of measuring the success of the operation.

Considering this aid programme through the streams of humanitarian performance management (Najjar et al., 2019), measuring logistics efficiency has to do with allocating resources and distribution management. The main resource in this aid programme was personnel and the donated equipment, such as cars, coolers, and scooters. The personnel were one of the most significant factors in the success of the programme. Due to many functions in the city being closed for ordinary activity, there were people available to complete other tasks, such as picking and delivering groceries for the aid programme. A popular example mentioned by multiple interviewees was a flutist from the city orchestra making deliveries. Also, from the private sector side, the grocery chain also has a hospitality branch under the same brand, so as restaurants and hotels were closed, those employees were able to handle the contact centre on their end. Other resources included cars and scooters used in the deliveries, which were donated for use by branches of city maintenance and private companies. The software for the contact centre was also donated. The coordination points around the city were examples of managing distribution, as this allowed for efficiency within the deliveries.



Analysing for example lead times and volumes delivered, it can be said that the programme was success. The deliveries were made on a twice weekly basis, with over 6000 deliveries made, when combing the acute grocery aid and those picked from the grocery stores. There were no orders left undelivered once the order was made. Also considering the elderly residents of Helsinki that the outbound calls reached, the interviewees were certain that all those that were reachable were called. It was impossible to call those with private phone numbers for example. The lead time in setting up the programme was one of its strengths, as the lockdown for the elderly came about very suddenly, and there was very little time to ensure their grocery and medicine access. Considering this is one of the biggest aid programmes ever to be executed in Helsinki, the seven-day idea-to-functioning process is commendable.

In her doctoral thesis Ohisalo (2017) considered food aid from the perspective of the welfare state, where the state and private organisations donate food to those who need it, and this is one of the biggest studies of food aid conducted in Finland. However, the programme in our study needs to be considered from a different angle, as the obstacle here for most of the beneficiaries was physical rather than financial access. As well, in this study we consider the lack of physical access to the acute grocery bags rather than the financial reasons behind needing them, since those who receive them normally queue to get them, and this was prohibited due to Covid-19 restrictions. Food access in this case was ensured through a delivery system.

In Finland during Covid-19, ordering groceries online became unprecedentedly popular. However, the interviewees made it evident that the elderly were in general not as skilled in utilising web-based services for regular errands and were therefore left to their own devices. This programme was also a success due to understanding the specific needs of the beneficiaries, i.e. taking orders by phone and using invoices to charge them, which are methods the elderly are comfortable with.

As there were multiple organisations involved in the programme, communication among them was crucial, and this was something the interviewees said they struggled with, not least because of the remote work mandate. However, as the attitude in general was rather spontaneous due to the fast schedule and problems were fixed as they came about, the organisational culture differences were also sorted out. Many interviewees mentioned an attitude of cooperation and a will to make this work, which worked in the programmes benefit. There have also been some ameliorating factors, which have made the fast schedule possible, such as expedited bureaucracy. The public sector is ordinarily heavy in different permits, and/or approval chains in the hierarchy. In this case those involved were able to sidestep a lot of the ordinary chains and focus on the job at hand. Interviewees hoped this would ease some of the bureaucratic jungle in the organisations for the future as well.

The success factors for the food aid programme are visualised in Figure 2, which can be used as a framework in many different types of aid endeavours.

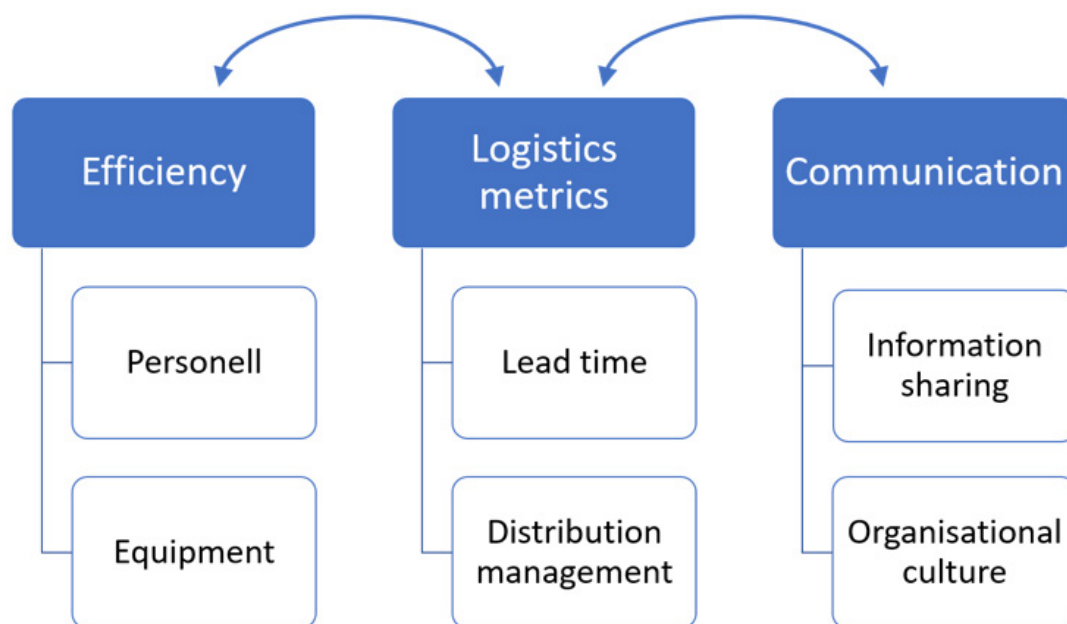


Figure 2 Framework for success factors of food aid programme (adapted from Najjar et al., 2019)



Conclusions

This programme was considered a success by the interviewees for several different reasons. The delivery scheme for groceries was utilised heavily by the elderly residents of Helsinki, as they were unable to frequent grocery stores or pharmacies. Factors contributing to the success were the availability of personnel, which was due to many municipal services being closed because of the pandemic. This served a double positive effect, as furloughing was unnecessary due to their duties being moved to the aid programme. The availability of equipment, most of which was made through donations from private companies was also a significant success factor. Regarding traditional logistics metrics this case was also interesting as the distribution of the grocery deliveries was conducted through coordination points and contact centre calls. This is a future research avenue stemming from the initial overview in this paper. The functions and basis or organisation for the coordination points is very relevant factor in the success of any food aid programme organised in an urban setting. Cross-sector partnerships and collaboration always include a clash of cultures and ways working. These are vital issues in any performance management, but particularly in the humanitarian setting, where lives are at stake. In this case, the organisations involved had to reassess their own ways of working as well, where the bureaucracy and approval chains might have slowed things down considerably. In the crisis situation that was declared in Finland nationwide, some of these were able to be sidestepped.

We suggest the following avenues for future research stemming from this initial study:

1. Human resource management (HRM) in the aid programme: as most people working in the programme were incompletely new territory and working with new people, what were the particular HRM challenges and how they were overcome?
2. Expand upon the urban logistics practices used by the delivery service and how they could be made more efficient and sustainable.

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THE IMPACT OF COVID-19 ON LOGISTICS AND SUPPLY CHAIN



THE LOGISTICS OF COVID-19: A CRISIS OF RESILIENCE TOO GOOD TO WASTE?

Richard Gibson ¹, Chris Savage ², Victoria Gibson ³

Introduction

Within the context of supply chain resilience, this research explores the impact which the 2020/21 pandemic had upon global, European and GB supply chains and examines the assertion that freight flowed regardless of the wider economic challenges. Data is drawn from the global freight forwarding sector, an international healthcare organisation, the GB pallet sector and a 2020 survey of logistics professionals.

Research Approach

Methodology

Following a review of literature that encompassed industrial as well as academic resources, a mixed methods approach was chosen. Empirical statistics gave a factual base that was combined with survey data garnered using the guiding principles of critical realism, which provides a particularly appropriate framework for designing real world studies' (Robson 2011). The combined output then used a deductive approach to challenge the historical approach to risk management.

Literature review

Approaches to supply chain risk management over the last two decades, are typically vertical and may have a limiting or narrow scope. The definitions for this topic within supply chain management are detailed in table one.

Term	Definition and notes
Supply chain risk	Probability of disruption multiplied by impact (Christopher 2004)
Resilience supply chain	A system which can be returned to its original state after a major disruption (Manners-Bell 2014)
Supply chain agility	A company's ability to quickly adjust tactics and operations within its supply chain (Gligor 2015)
Supply chain risk appetite	To what extent risks should be taken to achieve strategic and operational goals, sustain competitiveness and increase agility (Hippold 2019)

Table one - Supply chain risk management definitions

An industrial view – from leading consultancies?

These suggest that supply chains are failing in the face of disruption and will need to change going forward, inevitably costing money. As always, companies need to analyse trade-offs between asset costs (e.g. facilities & inventory), time-based performance measures (lead-time & delivery variance) and other cost factors (e.g. transportation), but that risk assessment should play a more important role going forward.

McKinsey advocate two factors to improve resilience (Lund, Manyika et al. 2020): Firstly, visibility to the various supplier tiers and data, and secondly building more redundancy into supplier networks. The Gartner team echo this by suggesting 'the cost of retaining multiple supply locations must be seen more as a cost of doing business, rather than an efficiency' to support supply chain resilience (Hippold 2020). The team at Accenture (Accenture 2020) suggest supply chains are breaking down in the face of multi-country disruptions and the supply chain of the future will be characterized by both resilience and responsibility.



What does history and academia tell us?

Risks may be benchmarked using the SOD mechanism described by (Slater 2005) and illustrated in table two. Populating a risk register, understanding the severity of each risk, the likelihood of it occurring and the ability to detect the risk happening are the three aspects of this calculation.

RISK FACTOR	S Severity of effect (1-5)	X	O Likelihood of Occurrence (1-5)	X	D Likelihood of Detection (1-5)	=	Total Risk Σ
A	2		2		2		8
B	5		1		5		25
C	1		1		1		1

Table two - The SOD equation

Christopher (2004) described the four Rs principle, the third R representing resilience and the assumption that organisations seeking low-cost solutions driven by margin pressure may lead to leaner, but more vulnerable supply chains. Christopher suggests that the characteristics of a resilient supply chain include the recognition of the importance of strategic inventory and the selective use of spare capacity to cope with surge effects.

Waters (2011) says that good supply chain management (SCM) practices are seen as the pre-requisite for a resilient supply chain. To create agility, Waters relies upon spare capacity, stocks of finished goods, good backup systems and someone to pay for these. Walters also describes the principles of both physical and relationship dependencies and includes of risk compensation (insurance) and business continuity planning. Wright (2013) suggests a blueprint for resilient supply chains containing the four core components of partnerships, policy, strategy and information technology. The vertical and narrow stance is echoed again by the need for an agile supply chain to support resilience Manners-Bell (2014). The collaboration required between tiered suppliers assumes alternatives are available during disruption and a strategy of reviewing emerging trends suggests there is time enough to do this in the face of bigger and more frequent disruptions, now often referred to as the improbable and unforeseeable Black Swan (Taleb 2008) or Gray Rhino (Wucker 2017) events.

What else should we reflect upon?

The SOD paradigm described by Slater (2005) is only part of the identification, assessment and prioritization of risks. Calculating the Expected Monetary Value (EMV) (Glen 2020) helps the organisation prioritize the risk register, for instance if a risk has an anticipated cost of US\$1m and probability of 5%, the cost of the planned response should cost no more than US\$50,000.

Measuring resilience performance

Finally, all good supply chain managers know what gets measured gets done. Karl, Micheluzzia et al. (2018) identify a suite of Key Performance Indicators pre, during and post disruption. Concluding that visibility is an essential element to achieving supply chain resilience, recognizing that visualizing conditions of inventories, demand, and supply from upstream to downstream can serve as a warning strategy that provides valuable time for companies to align their capabilities to mitigate disruptive impacts.

Findings and Originality

1. International freight flows

From a global perspective, trading blocs responded differently to living and working through the pandemic, in turn creating imbalanced demand on the established international freight modes and routes.

The air freight industry during the global pandemic experienced these key themes:

- Global jet fuel USD/barrel (bbl) in JAN20 was USD83, slumping to USD19 at the trough of demand, therefore any air freight transit rate increases during this period were not driven by fuel price (Platts 2021).
- Year on year global air freight demand reached its nadir at -23% in APR20, with a steady straight line recovery per month to year on year (yoy) parity in DEC20 (Accenture 2021).
- In JAN21 overall air freight capacity was down 32% on the year. (DHL 2021). Note: At the end of 2020, demand was back to normal, capacity was not.



Still expensive, using this mode requires greater planning throughout the distribution channel. Lead times may be longer, more thought must be put into which destination airport to use and a longer road leg may be required to reach the final customer. Using block space agreements can swiftly put freight onto a plane, albeit with heightened commercial risk.

In contrast to air freight, ship operators are focused on lane utilization and yield; this prompts the practice of 'blank sailings' where a sailing or even a port is cancelled by the carrier if ship fill rates are not high enough, or the market rate diminishes ship revenues. Prices on some international lanes have hit record highs in 2020 as the various commercial levers are pulled to optimize shipper margin (Wackett 2020).

2. Network volumes for a European medical device manufacturer

The medical device organisation in this case develops and supplies clinical diagnostic equipment and consumables to the pathology market. The five largest markets in Europe are Germany (DE), Great Britain (GB), Spain (ES), France (FR) and Italy (IT), supplied internationally and locally from manufacturing locations in GB, Netherlands and Germany. As the COVID-19 wave of disruption moved around the world, this network gave insight to how the supply chain was impacted.

During 2019, the European (including Great Britain) markets received 50,767 deliveries from the four manufacturing locations and the average time taken between dispatching from a manufacturing location and the customer receiving a product was 2.8 days. In 2020, these key markets received 47,847 deliveries, 6% less than the previous year (note this is delivery frequency but not weight or value of goods delivered) with an average of 2.7 transit days.

As the waves of COVID-19 lockdown rolled through Europe, only the first wave in APR20/MAY20 led to a significant reduction in deliveries with a second wave having less of an impact in OCT20. In what has historically been a compound annual growth business, these two 'COVID-19 seasons' accounted for a yoy reduction of just 6% of the 2019 full year total.

The impact of the Europe-wide lockdown in APR20 and MAY20 is evident, but thereafter different in-market government policies had differing impacts. Local in-market public healthcare purchasing policies will often encourage full budget spend regardless of demand and the fear of losing 2021 budget may too have influenced the peaks across the four markets in NOV20 and DEC20.

3. GB Pallet network volumes

The ability of freight to find a way through the pandemic disruption is further illustrated by the GB pallet network activity throughout 2020. Traditionally a business to business (B2B) sector, demand from locked-down consumers generated volumes into the business to consumer (B2C) sector rising from 12.5% in 2017 to 36% in 2020 of network pallet volumes (APN 2021).

Despite a poor outlook at the beginning of 2020 (APN 2021), once the industry had endured the immediate slump in volumes during APR20, demand reappeared with a vengeance delivering a 3.2% growth overall year on year.

The impact of COVID drove volume into alternative distribution channels including the pallet networks and seven months of negative volume growth was transformed into year-on-year volume growth of 9%. Amongst the group of operators within the network, the leaders saw nightly cross dock volumes increased by over 20% to the point where some networks were handling more than 19,000 pallets per night!

The metrics for GB pallet operations during 2020 are many and impressive as illustrated in table three.



Table 3: 2020 GB pallet network statistics

2020 pallets delivered	27.8m (APN 2021)
Palletforce	2020 pallet volumes +20% on previous year (Millett 2021)
Pallex	Handling an additional 3,000pallets per night at the Northamptonshire cross dock (Jervis 2020)
Pallex	2020 pallet volumes +11% year on year (Jervis 2020)
Home delivery pallets	Rose from regular 14% to a peak 36% during lock down (Millett 2020)
Volumes in JUN20	2.46m pallets were moved in JUN20, the fourth largest month on record (APN 2020)

Is this volume increase from new customers or just the same customers handling new volumes? The metrics available confirm average pallets per consignment remained consistent pre and post Covid suggesting there were more consignments and hence new volume entering the pallet network amidst a backdrop of suppressed consumer spending in traditional markets which were hibernating during lockdown.

4. A qualitative view.

A survey of logistics professionals was conducted and involved several countries including GB, Ireland, France, Belgium, Luxembourg, Denmark, Switzerland and the Middle East and encompassing most sectors including: 3PLs, Manufacturing, Haulage, Couriers, Shipping, Passenger Transport, Retail and Freight Forwarding. Respondents represented various positions including: Directors, Fleet and Supply Chain Managers, Project Managers, Buyers, Supply Planners, Owner operators and a pilot turned van driver!

Respondents were asked for their views on the impact of the pandemic, ways of dealing with it and the future for the logistics industry. The answers were subject to matrix analysis (Cassell.C and Nadin.S 2008), which endeavoured to identify recurring themes, their frequencies by question as well as similarities & difference across the whole population.

The survey respondents drew various conclusions, which can be summarised as:

- Logistics will have to match the migration of retail to online:
 - o Final legs to homes rather than depots.
 - o More consumer deliveries via the pallet network.
- Logistics companies that are flexible and able to react to circumstances by quickly changing their operating methods and preferences will thrive. Those that are slow to react or prefer to stay with traditional haulage operations will probably not survive.

It is difficult to predict what the 'new normal' will look like but it is apparent that to get the best of it, actions will be required by all parties. Successful companies will be those that are flexible and responsive so that they can ensure that border processes are improved, cross supply-chain collaboration is developed making use of on-line / digital technologies to shorten supply chains and possibly making use of reverse globalisation or reshoring. For this to succeed, forecasting will need to be further digitised to enable better strategic planning, using scenario modelling that will incorporate risk assessment supported by disaster planning that is outward looking rather than parochial.

5. Business interruption insurances

'Pandemic' has been on risk registers for a long time. Plans generally address loss of staff through sickness or caring; however, the most impactful consequences of Covid-19 have been through lockdown restrictions: limited movement, loss of footfall, enforced closures, fluctuating guidance.

Insurance is one method of mitigating risk through transference. Business interruption insurance (BI) is typically purchased to recover profits and additional expenses incurred through losses such as property damage or equipment breakdown.

Businesses experienced unprecedented disruption from the effects of the 2020 pandemic; many of those forced to close premises turned to their insurers. These BI claims were widely denied and in SEP20 the Financial Conduct Authority (FCA) commenced legal proceedings to gain clarity on contractual uncertainty. Sample wordings from eight insurers' policies were considered by the High Court who found largely in favor of policyholders.



What does this mean for insurance? Policies will need to ensure clarity for all parties; customers may switch insurers. More claims paid will mean pricing increases.

Businesses themselves will also need to adjust: flexible working is becoming the new norm and property portfolios are being reduced. In terms of risk management, organisations should reflect on Covid-19 and adjust risk management processes accordingly.

Key questions remain: Does my insurance cover adequately transfer risk? Do we understand our key strategic risks? Is our supply chain risk management fit for purpose?

6. Findings and discussion

The historical approaches to supply chain risk management advocate holding strategic inventory and spare capacity. These approaches have a lesser role to play in modern supply chains amidst the current style of frequent, high impact disruption events around the world and throughout markets.

To continue working through the new all-consuming disruption events we need timely information, visibility to the flow of goods and the ability to make commercial decisions swiftly to take advantage of the modern and resilient freight networks available to us.

In the case of the international medical devices organisation, a policy of holding spare supply chain capacity would have been a wasteful use of cash in the face of a rapid decline in consumption. When the markets returned, product was manufactured and freight could still be moved to consumers.

Across Europe, markets reduced or closed and then returned within about eight weeks. The movement of EU mainland parcel freight continued with little or no impact on transit times as evidenced in the medical diagnostic experience and in GB pallet volumes; these can be used to inform resource decisions when the next interruption occurs.

The pallet network experience in GB saw regional providers benefitting from consumer demand switching from established distribution modes to reach consumers who were buying differently during lockdown.

With the knowledge that a) supply chains can flex swiftly during disruption events and b) markets hibernate for only very short periods of time, then we can adopt a more flexible approach to supply which is dependent upon visibility and not stock-piling and spare capacity.

What did we learn to apply to the next event?

- Price of moving things – Freight still moves but may need to transfer to other carriers or modes, which will be likely to have a price impact.
- Lead time – As the supply chain networks reconfigure, so lead times may be impacted but as seen in the EU, this phase may not last long.
- Inventory levels – The established supply chain risk management approach to inventory is to stockpile and have spare capacity. If demand switches off for a short period, then re-appears across different markets at different times; keeping inventory virtual for as long as possible is a better use of cash and will yield a better service level.

From the risk and resilience perspective there are at least three avenues to pursue during the next interruption:

- Closer monitoring (of key materials suppliers and transport providers) during the pandemic is common advice. But when demand disappears suddenly, visibility becomes key to controlling the supply chain and minimizing disruption up and down the distribution channel. Visibility of service availability becomes the primary tool.
- Support and collaborate with those around us. Established suppliers and business partners may also need help in terms of operating cash and other aspects required to run their organisations. Their failure becomes our failure and working more closely helps to mitigate this event in the face of markets and supply lines hibernating for short periods.
- The role that Business Continuity Planning plays is further endorsed with our learnings from the pandemic



Conclusion

Supply chain disruptions are more visible, impactful and frequent than they have ever been, and the global pandemic has added the complexity of entire market sectors hibernating for extended periods.

This research has challenged the established models of supply chain risk management, which depend upon stockpiles and spare network capacity, demonstrating that they do not appear to be very effective when dealing with all-encompassing disruption events. Further, it has shown that freight movements continued at the Global, European and GB level with the rich fabric of logistics distribution channels providing a real internet of physical pathways.

Amongst the survivor organizations, the global pandemic has involved an overhaul of processes, a change in operational execution and finding different ways to satisfy customer demand; a true digital transformation. Supporting this new way of working were visibility tools which a) allowed operators to retain virtual inventory for as long as possible before b) submitting it to the variety of distribution channels for delivery to the customer. The insurance industry had a challenging 2020 further highlighting the need for agility as a business survival technique.

In conclusion, amidst chaos in international supply chains, the freight continued to flow.

Practical Impact

This study shows survivor organizations:

- Need not hold spare stocks and spare network capacity, but rather keep inventory virtual for as long as possible and be agile in their use of distribution channels.
- Agility and visibility are important perspectives for organizations hit by market disruption or market hibernation events.

Future research may choose to:

- Look into how organizations gain visibility to their supply chain and how they can use this with enough time to make a difference during a disruption event.
- Explore how organizations can support and collaborate with competitors in similar market sectors without breaking acceptable market practices during disruption events.
- Investigate the application of Business Continuity Planning: What is an acceptable investment in this activity?

Keywords

(Dealing with) a pandemic, resilience, supply chain risk, digital transformation.

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FACTORS AFFECTING SAUDI ARABIAN SME RETAIL E-COMMERCE FULFILMENT DUE TO COVID-19

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INTRODUCTION

During Covid-19 small and medium enterprises (SMEs) have changed their logistics process to maintain electronic commerce (EC) fulfilment and meet consumer expectations. More than 73 articles discuss the factors of Covid-19 e-fulfilment from consumers to the supply chain (Chowdhury et al., 2021). However, each country has differing specifications of technology and infrastructure. Further, cultural aspects are considered essential to maximize consumer fulfilment. On the other hand, SMEs have various perspectives for dealing with such urgent matters but coping with fast changing situations might confuse firms with unfortunately lost sales or business closure. The focus of this study is to understand the situation in the Saudi Arabia (SA) EC market and emerging factors that affects SMEs and e-fulfilment. This study explores that through six general questions:

1. What factors due to the Covid-19 pandemic affected your business operationally?
2. Which of the above factors most affected your business operationally? Why?
3. What actions have you taken to address these factors?
4. What technological solutions have you considered to address these factors? Which ones have you adopted and why?
5. What results have you seen both positive and negative?
6. What has been difficult for you during the pandemic? Why?

LITERATURE REVIEW

EC in Saudi Arabia (SA)

SA is a large country with a population of 30 million inhabitants. The major city is the capital Riyadh followed by Jeddah and Dammam. SA has highest number of internet users at 25 million compared to the rest of the G20 countries. The highest percentage of users are between 15-32 years of age. The communication and information technology commission CITC is the regulatory of internet activity (CITC, 2020). A previous study by (Alotaibi, 2018) found the SA postal system inaccurate when delivering consumer shipments and that cultural factors play an essential role in e-fulfilment. SA has rapid growth of internet users which consider the highest country in the middle east after Iran (CITC, 2020). The number of e-stores are 36,447 with rapid sales growth which duo heavy investment in internet infrastructure. Hence, SA placed in top ranking of 5G connection among G20 (MCI, 2020). Moreover, SA has significant rankings in the World Economic Forum (36th place) and the Logistics Performance Index or LPI (55th place) which is the result of the new vision for 2030 led by Crown Prince Mohammad bin Salman (weforum, 2019).

E-fulfilment in Covid19

A variety of studies have discussed the pandemic and the effective factors from wide different of views. Previous studies consider the factors from supply chain or technology factors (Chowdhury et al., 2021). Moreover, previous studies focus on supply chain demand especially in health care and vital goods. This study investigates the factors of Covid-19 in SMEs, which have had little research to date, to illustrate their status in SA EC fulfilment. A full lockdown and quarantine took place in SA from February March 2020 with a partial opening beginning at the end of May 2020.

Factors Influencing E-fulfilment

Covid-19 has affected enterprises from inbound through outbound activity. The reaction of countries over the world has been different regarding policy, international trade and strategy (Gunessee & Subramanian, 2020). Therefore, factors affecting e-fulfilment and consumer behaviour vary across each country. However, there was rapid introduction of similar quarantines, which required firms across countries to redesign their business strategy (Hobbs, 2020). However, others have delayed due to consumer confusion of various hygiene processes. Social distance is another factor that needs to be considered during deliveries. Delivery packaging and provision of additional hygiene and



safety play an essential role. Additionally, delivery channels whether via third-party logistics service providers (3PLs) or directly requires new policies and rules. Some factors considered important but which have not present been detailed in Covid-19 studies, such as cultural factors, also play an important role in SA (Alotaibi, 2018). Finally, regulatory policies have appeared quickly due to the pandemic, which usually not happened before, and regulations keep changing regarding society's health to try and respond to their needs (Quayson et al., 2020).

Grocery and E-grocery

Regarding groceries, perishable food and dealing with them in SA is a challenge due to the extremely hot weather for most of the year (Kumar et al., 2021). In addition, the SA e-grocery market is still not mature with few active grocery firms and 3PLs. Notwithstanding the pandemic, when facing high demand both physical store and EC channels struggle to fulfil consumer orders and hence dark stores have become a solution for delivery (Tanskanen et al., 2002; Al-Nawayseh, 2012; Alotaibi, 2018). Finally, complexity or delays in global supply chain have direct effects on food supplies and may lead to shortage (Onuma et al., 2021) and thus grocery firms need to assure consumers their supply chain work efficiently to prevent panic buying (Ghezzi et al., 2012).

Logistic service providers

We define 3PL in this study as a 'mobile application that handle orders from stores through consumer delivery'. During the pandemic 3PLs are involved in most logistic operations and can help by providing more innovative solutions (Ramcharran, 2013), and this involves e-fulfilment for any inbound or outbound element of logistics operations. Further, global LSPs can enhance innovative solutions with expertise and experience whether in e-grocery and non-food segments.

METHODOLOGY

This study is inductive and uses an interpretive theoretical paradigm of empirical reality and qualitative interviews to obtain information and understand the current environment of e-firms in SA by gathering in-depth data of factors affected logistics operation in e-commerce channel (Collis & Hussey, 2009). Fifteen semi-structured interviews were conducted with SME owners or CEOs and logistics managers in SA EC firms in the capital Riyadh and other cities. Due to Covid-19 and social distancing two interviews were conducted in public spaces in Riyadh and the rest through technology platforms such as Teams, Skype and Zoom. All interviews were recorded, and verbal consent agreed before starting the interview. Each interview took from 30-45 minutes. The firms are anonymously named as E1 to E15. All interviews were done in Arabic language and then translated, and back translated again to assure validity. All data were input into NVivo 12 software with subsequent analysis leading to six main themes that follow in the next section (Neuman, 2004 Marshall, 2014).

FINDINGS AND THEMES

Change business strategy

Most e-firms immediately changed their strategy to cope with pandemic matters however sales declined by up to 20% of total sales on average for non-grocery retailers. Two non-food e-stores closed their businesses after three months. Thus, in the beginning of the first lock-down non-food businesses were affected by new regulations except for the grocery sector, which continued running their businesses as essential services. In addition, some firms relied on 3PLs as the only way to keep customers as they first have permission to take the delivery channel with increased the online advertisement to aware the service still available. In addition, moving residence of working staff to be closed to their stores and offices to avoid changing of regulations and keep works continues. On the other hand, SA as a large country, which large city have optional of 3PLs and human resources (Chowdhury et al.) to work on delivery, whereas small city still suffering from the contrary of that as too high demands and less of firms of 3pl and HR make the situation worse and affected strongly SMEs.

Grocery retailers saw a positive impact with sales significantly increased. Further, supermarkets who have a large supplier base had more revenue than SME grocery retailers. The regulation that food and pharmacy were exempt from closure during quarantine helped walk-in customers residing in the same district as well as other segments from health staff and police. An important point related to grocery supplies were that they mostly came from distributors to retailers. SMEs expressed that large grocery suppliers had high price during pandemic except E4, who offered lower prices to all small retailers to be the main supplier to them.



Limitations of 3PLs and HR issues

As the previous theme presented, 3PLs have different distributions over the eighteen cities. All 3PLs struggled during the outset of the pandemic with the sudden increase in demand along with new regulations and limited HR. SA regulations only allowed one 3PL to handle deliveries in first part of the lockdown and that firm couldn't meet the high volume of demand and thus service and quality were affected. The next phase in the partial re-opening allowed other 3PLs to participate but a new regulation that only Saudi firms could do deliveries, except grocery stores. The Saudi market is large but there was not enough staff in the indigenous 3PLs to cover deliveries regardless with 50% of customers receiving either wrong or late orders, or both. The grocery segment did not provide a 'pick-up' model as there were no plans to execute that for high demand in the 'closed window' of shorter working hours. However, five new 3PLs entered the market but three ceased trading in the market leaving only the other two operating. Small cities have one or two 3PLs, which puts SME retailers in a difficult situation as deliveries did not arrive in time as 3PLs had limited staff without using non-SA citizens.

Government support

This theme emerged from analysis. Most firms, whether small or large enterprises, noted that without initiatives from the SA government the situation would be worse, and a few commented they would be out of business without it. The support included postponed transaction bank interest and 50% coverage of Saudi staff salaries. Labour card for non-Saudi staff were extended three months for all labour in the SA market. In addition, SA applied new rules to allow everyone in country affected by Covid-19 to have health care and treatment including medicine no matter if the labour identity card was expired or lost. If any staff of grocery or delivery staff were infected, they had to go to a special residence provided by the government to quarantine which the accommodation and food. Moreover, the government provided a service called 'Estrdad', which refunded administration fees to the firm's bank account for six months to help them with business expenses. Finally, the government extended the labour card expiry date for all staff abroad until they could to SA.

Policies for Operations

Besides the foregoing government support, changes to regulations and policies were needed to deal with new issues arising from the pandemic. Some regulations were clear and easy to cope with, however, the rapid change affected SMEs and 3PLs. First, permissions to only have limited number of staff prevented some retailers from delivering, leading retailers to designate only certain stores for delivery. Second, strict traffic zone controls led to undeliverable orders as new delivery drivers were unable to go into these areas, which led them to return to their zone when they became lost. Changes for 3PLs were noted above but hygiene processes and social distancing saw some 3PLs only provide one delivery method, i.e. leave an order at the door, to adhere to a safe social distance. New packaging that completely seals products were applied but some firms declared that delay us for a while as manufacturing late. Lastly, drivers had to provide evidence of a negative Covid-19 test result to start employment with any firms.

Technology

Investment in technology was a major theme for most firms, especially for grocery retailers who had have to stop or postpone sales due to high demand in stores. During quarantine, the only channel to reach consumers was e-commerce driven by technology. Easy to use technology made shifting to e-commerce easy for consumers who were retained. Some firms established their own website, enhanced their pages on social media platforms, and engaged 3PLs more predominantly. In addition, some firms designed phone applications to respond to consumers and fulfil their demands. During the pandemic most 3PLs were busy to respond to high demand and tried to serve firms' current in-store and e-store customers with the applications to avoid any errors. Lastly, 3PLs provided results on one app or platform for three user levels: consumers, retailers, and delivery staff. However, grocery retailers still have not focussed on technology during pandemic.

DISCUSSION

1. What factors due to the covid-19 pandemic affected your business operationally?

There are various factors, such as declining in-store sales 20% for some firms. Additionally, the regulation to assign one 3PL as the outset unfortunately could not address the high demand and fulfil full delivery services in most cities except the capital Riyadh (Quayson et al., 2020). The other cities suffered shortage of 3PL services (Brintrup et al., 2020). Furthermore, technology emerged that did help provide full service online, in particular for stores with regular walk-in customers (Rowan & Laffey, 2020). Suppliers providing products had major issues which led to shortages for most SME retailers. However, grocery retailers did not endure many of these factors, as government permission allowed them to open as usual. E-grocery however was not very effective and had little focus on technology, which meant their platforms were not ready for high volumes. Their sales increased, especially



those who focussed on wholesale to other SME retailers, and was in contrast (Onuma et al., 2021). Non-food stores had to change strategy as lack of inventory caused issues during the pandemic, which led some firms to make major business changes to remain open running and risk a loss of supply and inventory (Guan et al., 2020). Hence, they provided discount offers on excess stock and increased marketing for new methods of service.

2. Which of the above factors most affected your business operationally? Why?

The grocery segment had the advantage of increased sales, government support, and an ability to provide wholesale services (Gao et al., 2020). However, if any staff were infected it had a negative impact as the store had to close for at least two weeks. Therefore change strategy to cope with this was a theme for all firms (Gunessee & Subramanian, 2020). Amended business plans or using different services were used to run the business and include moving to investing in technology solutions with applications.

3. What actions have you taken to address these factors?

All firms had to cope with new hygiene protocols and some firms solved that situation with using new packaging, however about one-third of them had to wait for new packaging designs to bundle goods for delivery (Laborde et al., 2020). In grocery retail, they competitively priced against the other large store who were also wholesaling to obtain a value return (Hobbs, 2020). Most 3PL have reject full shipments due to being unable to cope with high volumes, which caused delay and cancelled some delivery shipments. High demand cause grocery retailers to focus on in-store but most 3PLs didn't provide fully grocery services. Small grocers could deliver urgent products, but hygiene processes were not fully followed. The pandemic affected all stores in all matters from sales, new policy, hygiene, and delivery, leading the government to provide various initiatives to help private sector to survive as long as possible. They first gave permission for more 3PLs to deliver and secondly supported Saudi employees by paying half of their salary. Lastly, they postponed all bank transaction interest for all firms to provide cash and liquidity for SMEs and large firms. One authority under Ministry of Trade launches the 'Estrdad' service to return administration tariffs to all firms that registered formally with the government (Monshaat, 2021).

4. What technological solutions have you considered to address these factors? Which ones have you adopted and why?

Technology solutions were provided by some firms during the pandemic, including some grocery retailers. However, the then current technology for stores and 3PLs couldn't meet the high demand. SA is a large country with 18 cities with suppliers in various areas. Large cities have more 3PLs who have sufficient HR staff available to undertake most deliveries. However, small cities have one or two 3PLs and cannot service all stores. Two stores in smaller cities went into bankruptcy and one changed its entire business model to cope with the changing situation (Nichiporuk, 2021). For grocery retailers, technology could not help with deliveries due to lack of specific focus, leading some firms to design their own website, app and pages in different platforms, while other SMEs in small cities initiated their own 3PLs as they could not afford to purchase technology (Rowan & Laffey, 2020). Nevertheless, 3PLs could not deliver all shipments as desired and could not cover all areas, including new drivers not reaching old consumers. Therefore, existing consumers were lost despite new ones being gained (Laborde et al., 2020).

5. What results have you seen both positive and negative?

Investment in technology though phone application design and more availability in different platforms is a positive result. Another is exploring new consumer segments by contacting them directly and obtaining feedback to improve deliveries (Farias & Araújo, 2020). This includes a better understanding of consumer experience with technology and to enable targeting more segments across different generations. Furthermore, online service practices are at a higher level than before the pandemic with more than 25% of stores continuing their same strategies and plans applied during the pandemic, which has led to reduced costs through changing rented space to cheaper, non-store front locations to rely mostly on online channels (Hobbs, 2020). Logistics and supply chain strategies for stores have changed by make contingency plans to not buy high volumes and changing suppliers for assured supply to fulfil consumer high demand (Guillen-Royo, 2019). On the other hand, some focussed too much on technology and neglected their normal channels. A move to outsourcing some service and delivery channel to 3PLs may have been an error of strategy by both that some areas have orders without delivery driver available. Strategies by SMEs to close some non-primary store branches and focus main ones led to 'dark stores', which were successful for half of stores during quarantine, but which provided a mixed message about product and service offerings. Government support has been welcomed, especially by grocery stores who struggled with repeated closures as infected staff emerged by time to time (Gao et al., 2020). Lastly, larger size and SME grocery retailers have provided pick-up and delivery plan in closed areas as a starting point for a new strategy.



6. What has been difficult for you during the pandemic? Why?

Difficulties include not being ready for technology regarding staff dealing with new tools and being sufficiently trained (Ker & Cardwell, 2020). Also, strategy decisions whether to insource or outsource deliveries is a major issue. Investment in technology in an immediate manner cost more as opposed to normal procurement practices (Rowan & Laffey, 2020). Few firms had emergency plan ready to deal with sudden and rapid changes. Cancelling or postponing rent was considered an extreme issue as not all space owners and companies assisted with that and thus store costs were too high relative to reduced sales. Furthermore, new agreement contracts required more legal services to avoid losing money without any revenue in quarantine. In addition, reducing staff was a hard decision to keep business going, and firms lost experienced staff, which has a direct effect on consumer support and trust. HR shortage was a major difficulty with all stores and 3PLs. New packaging requirements and trained delivery staff were also issues. Location errors remained as not all Google or satellite navigation directions are correct, especially with apartments in older areas. Use of technology was an issue, particularly if there were new software programmes or where there was no internet available. The initial choice of one 3PL to provide all SA delivery services led to 'leave order at front of the door' were issues due to finding locations i.e. apartments, especially when consumers could not confirm receiving an order. Hygiene concerns for most consumer was a challenge for firms as consumers wanted to receive their correct order in the right place with proper social distance. This was not always assured by the delivery driver and thus delivery was not confirmed to the store to close the order. Lastly, only one 3PL provided paying online. Others 3PL drivers had to carry cash which provided its own transaction difficulties regarding hygiene and social distancing.

CONCLUSION AND CONTRIBUTIONS

This paper has discussed factors that affected SMEs in Saudi Arabia during the pandemic of Covid-19 and the fifteen interviews conducted with firms, e-firms and 3PLs have provided an understanding of this situation in Saudi Arabia. The exploratory empirical study followed an interpretivist approach whereby "the social world is mostly what individuals perceive it to be, and that reality is socially constructed as individuals attach meaning to their experience" (Narcisse & Harcourt, 2008). Hence, the rich data available in interview transcripts enabled five themes to emerge from analysis to address the six research questions. SME retailers and the Saudi market have not been the subject of much previous study from an e-fulfilment logistics perspective. Furthermore, the findings have illustrated different factors driving strategic change with extraordinary government support. To that end, this paper contributes theoretically to our knowledge of in store and online retailing in both grocery and non-grocery settings, and related business strategies to address the immediacy and depth of business issues resulting from the pandemic in the non-Western context of Saudi Arabia. This paper also contributes practically by detailing business operational problems emerging during the pandemic and what solutions worked or didn't work to address them. Firms elsewhere in Saudi Arabia and other country settings should be able to consider these findings within their own context and adopt what will work for them.

As with all research there are a few limitations. First, there have been many studies in the last year considering the effects of Covid-19. Many are desperate and thus a good synthesis of conceptual and empirical papers should be done to provide contacts veracity and ensure validity and reliability. Furthermore, the study reported in this paper is exploratory and could be extended to determine generalizability of the findings across not only in SA but across other non-Western contexts.

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RESILIENCE CAPABILITIES OF THE ACTORS IN THE SUPPLY CHAIN ECO-SYSTEM IN THE LIGHT OF COVID-19 EVENTS: A TRANSPORT SYSTEM PERSPECTIVE

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Introduction

In addition to being a global health crisis, COVID-19 has affected the economic, social as well as technical advancements all over the world. For supply chains and the logistics sector the pandemic has uncovered several vulnerabilities and triggered the need for rethinking strategies, like shifting from Just-in-Time (JIT) to a combination of JIT and Just-in-case (JIC) inventory management (Brakman et al., 2020). Events such as the closure of territorial borders and the shutdown of factories are expected to occur more frequently as a consequence of disruptions like weather extremes and cyber-attacks (Aula et al., 2020). Therefore, the need for having resilient supply chains has increased during the past decades and will be even more important in the future. COVID-19 has provided an opportunity to review current practices and the overall supply chain eco-system where transportation plays a vital role. The learnings can be used to improve transport system resilience capabilities.

Review of current practices can help in understanding a system's structure and dynamics that can be beneficial in evaluating existing and desired resilience characteristics. In the context of COVID-19, several efforts have been made to improve the understanding of different societal systems. Many quantitative models about the spread of the virus have been constructed, including e.g. Struben (2020) and Butler et al. (2021). These models are built to find relationships between mitigation policies and the spread of virus. Other efforts include Oz et al. (2020) and Kontogiannis (2020), where wider level and medium-term implications on different parts of society are visualized, by developing a causal-loop and a system dynamics diagram, respectively. Although supply chains and transport systems are crucial in modern societies, studies about the effects on them of the COVID-19 pandemic have been limited. With this study, we aim to contribute to filling this gap, by studying the transport ecosystem's resilience in the context of the COVID-19 pandemic.

According to O'Connell et al. (2015), the term resilience refers to the capability to persist, adapt and transform. Many resilience theories, such as Jenelius (2020) and Kontogiannis (2020), focus on the persistent part of resilience. Therefore, there is a risk that proposed measures only target the 'apparent' and that underlying fundamental causes, in systems thinking jargon also called 'deep leverage points', are overlooked. For example, it is known that customer behaviour and delivery prices affect the supply chain (Hjort and Hellström, (2014)). This in turn means that, in addition to aspects such as timing optimization and reduction of CO₂-emissions, analyses about resilience aspects should also incorporate factors like customer behaviour and policies.

With transportation as the focal point, this paper utilizes the opportunity provided by COVID-19 to complement the aforementioned studies, using a systems thinking perspective. The study examines the logistics systems of three different types of industries, namely healthcare, automotive manufacturing, and e-commerce. The objectives are as follows:

1. Identify research areas within transportation that are crucial to improve resilience capabilities.
2. Analyse the relationship between the research areas and the three types of resilience.
3. Analyse the relationship between the research areas and the systems thinking leverage points.

In this paper we present a qualitative study of the effects of the pandemic during the first and second wave of COVID-19 in Sweden (considered March-December 2020). We address global supply chains in general and (road) transportation specifically. The focus is on sustainability aspects as well as on resilience, both in the short- and long-term.

Method

This study is based on a literature review, semi-structured interviews with transport actors, and two workshops. Based on the literature study (Qureshi and Mulder, 2021) and consultation with several transport experts, questions for semi-structured interviews were set-up, focussing on resilience capabilities and sustainability aspects. The questions targeted events, responses and other observations from the pandemic as well as desired adjustments to achieve resilience. The interviews were conducted with 12 senior employees from 10 different organisations, including an OEM, logistic and mobility solution providers, municipalities, counties, consultancy firms and research institutes. The organisations reflect small and medium as well as large enterprises. Before conduction of the interviews, a full-day workshop was conducted to educate the interviewees about the concepts of resilience and trigger reflection on the application of resilience in their own area of expertise. The second workshop was conducted after the interviews and was used further improve the understanding of the interviewees' views.



The output of the interviews consists of interview notes and automatically generated transcriptions. Analysis of the interview results is carried out using the Gioia method (Gioia et al., 2012). This method for qualitative data analysis focuses on crafting a data structure from the raw data. The method uses so called 1st-order concepts, 2nd-order themes and aggregate dimensions, where the 1st-order concepts are a categorisation of the outputs and stick to the informants' terms, while the 2nd-order themes and aggregate dimensions add a level of abstractness and identify underlying themes in the data.

These aggregate dimensions are sought in the context of resilience, where the following definitions for three different types of resilience are used, as defined by O'Connell et al. (2015):

- Persistence (short-term): the ability of a system to absorb disturbance and reorganize so as to retain its 'identity' – the same function, structure, and feedbacks.
- Adaptation (medium-term): responsive change that improves the ability of a system to achieve desired goals, including by reducing vulnerability to disturbances or threats.
- Transformation (long-term): the process of changing from one type of system to another with different controlling variables, outputs, structure, functions, and feedbacks ('identity').

Furthermore, the interview results are also used to identify leverage points: "places in a system where relatively minor interventions can lead to relatively major changes in certain outcomes" (Meadows, 1999). In our analysis, an adopted version of the leverage points classification as defined by Abson et al. (2017) and Fischer and Riechers (2019) is used. In this adopted version, the twelve leverage points identified by Meadows (1999) are grouped in four categories: Parameters (altering rewards & material flows), Feedbacks (changing feedbacks), Design (redefining goals, information flows and self-organisation) and Intents (changing mind-sets and paradigms). Parameters and Feedbacks are considered shallow leverage points, where easy interventions bring relatively little change. Design and Intents are deep leverage points that reflect more fundamental and difficult changes in the system, but that potentially result in more transformational change.

Results

In this section, the 1st-order concepts and 2nd-order themes are discussed, and listed in Figure 1. This is followed by an analysis of the relation of the 1st-order concepts to the systems thinking leverage points, and a separate analysis of the 2nd-order themes with respect to the three types of resilience.

1st-order concepts

Using the Gioia method, seventeen 1st-order concepts as listed in Figure 1 were extracted. The interviewees mentioned that most of the 1st-order concepts, such as data sharing and a shift to e-commerce, were already ongoing developments before the pandemic and are accelerated under COVID-19. Resilience capabilities were not explicitly considered as a goal and the concepts were mainly addressed for their potential to increase efficiency.

2nd-order themes

The 1st-order concepts are translated to six overarching 2nd-order themes: crisis management, transport planning, supply chain visibility, regionalisation of production, new role for governance and e-commerce of the future. The six identified 2nd-order themes are described below with quotations from the interviewees that illustrate each theme.

1. Crisis management is the first response mentioned by most of the interviewees when asked about the effects of the pandemic. Their actions focused on continuing normal practises in the best possible way, and seeking minimum adaptations to cope with the temporarily changed situation. Most interviewees experienced a sense of urgency that induced flexibility internally in organisations, but also between cooperating organisations.

"We wanted to find solutions for the problems, ..., before it was more of discussions, discussions and discussions and not much used to happen." – Interviewee 1 (illustrating the sense of urgency)

"During the pandemic we considered deploying office personnel out in the field because we were so short of logistics personnel. But fortunately, it never came to that point." – Interviewee 3 (illustrating the flexibility internally within an organisation)

"We have a really good relationship with our suppliers. If one couldn't support us, then in almost all cases we could turn to another to support us in this." – Interviewee 10 (illustrating cooperation/goodwill between organisations)

The sense of urgency mentioned by the interviewees and the flexibility within and between organisations, came at the cost of sustainability. During the pandemic, the focus increased on managing the crises. As a result, sustainability considerations were decreases resulting in low-fill rates and the less sustainable transport modes.



“At some point we had an almost empty taxi driving from A to B, just because we needed to deliver X.” – Interviewee 8 (illustrating the prioritisation of effectiveness over efficiency)

The restrictions issued by governments to limit physical interactions, forced many activities to be carried out in a digital environment. The digital tools for communication and conferencing provided useful experience and revealed new opportunities as well as challenges.

“It has been hard to get service technicians on site ..., which has put much more stringent requirements on our remote diagnostics capability, remote operations even.” – Interviewee 4 (highlighting one of the challenges the shift to digital communication posed)

2. The interviewees were specifically asked about their experiences during the pandemic from the transportation sector. The pandemic itself was not a direct cause any heavy disruptions in the (road) transportation sector (in Sweden). However, the disruptions in other parts of the supply chain (mainly the ends of the supply chain: customer behaviour and production of raw materials) propagated to the transportation sector in both positive and negative senses. For example, the decreased people transport volumes on rail allowed for different transport planning, namely more freight transport on rail, which itself is more sustainable. In a similar fashion, this was also a solution to the problems of 1) strict border controls hindering truck drivers to travel internationally and 2) the scarce availability of truck drivers because of infection with the virus or unwillingness to travel. Especially this later case has drawn more attention to the development of systems with little or no need for human intervention such as driverless vehicles.

“There is a political will to increase transport by rail and also more companies are wanting to use railway. Now it was easier to try rail transport and they dared to do so, so to say.” – Interviewee 9 (explaining why the pandemic provided an opportunity for goods transport on rail)

“In Sweden we have a very robust road and also rail transportation network. That we saw again during the pandemic. The main problem was in availability of containers.” – Interviewee 3 (about the resilience in the Swedish transportation network)

3. Supply chain visibility was already a topic of discussion in the logistic sector before the pandemic, but its urgency became even more apparent during the COVID-19 crisis.

“The shortage of raw materials came in as a delayed disturbance, and could at least partially have been foreseen.” – Interviewee 2 (on the shortage in raw materials could have been predicted)

This delay in information is also confirmed and further exemplified by Shih (2021). Before the pandemic it was mainly the supply chain experts that acknowledged the complexity of supply chain management and advocated for adequate data collection, visualisation tools and data sharing efforts. Now other (higher) management levels also acknowledge the urgency to increase efficiency and effectiveness as well as build in more resilience in the supply chains.

“We should combine the delivery of food and pharmaceuticals, with seldomly purchased things, so that these deliveries can some sort of piggy-back. You could compare it to ride-sharing, both aim to increase the efficiency or fill-rate.” – Interviewee 5 (on how data sharing could increase efficiency)

4. The past decennia ongoing globalisation has moved production facilities to low-wage countries, making Europe including Sweden dependent on these countries, for example when it comes to supply of medical equipment. This has triggered an interest for de-globalisation or regionalisation of production to ensure increased self-sufficiency. The ongoing trend of automation eliminates the advantage of low wages, and affordable regional alternatives become more probable.

“The problem with health care supplies starts in procurement...” everything is dependent on money.” Interviewee 8 (referring to procurement from other parts of the world)

“There is a trend towards more circular economy that in itself also promotes more regional production.” – Interviewee 11 (listing regional production as a ‘side effect’)

5. The crisis itself and the accelerated transition towards an electrified and digital society, which in turn points to the need for a new role for governance. Regulation and policies to ensure everyone’s accessibility to these increasingly essential infrastructures is one example. The ongoing digitalisation makes us more susceptible to digital hazards and there are only few possibilities to store large amounts of energy as back-up in case of a power outage. Public-private partnerships could be an opportunity here, and this new role for governance should be leading this.

“Regulatory principles, value chain design, operational and planning process should be streamlined across physical infrastructure, energy-carrying infrastructure and digital infrastructure.”
– Interviewee 4 (on the increasing entanglement of the critical infrastructures)



"We were getting new information and restrictions almost every day, and at the same time we had no time to wait for the new information. Maybe we as society should agree upfront about some responses to certain scenarios, if that would be possible." – Interviewee 7 (about the unpredictability of governments' decision, and the confusion this led to)

Additionally, the pandemic confronted humankind with its vulnerability which induced some sense of urgency that was used to activate problem-solving capabilities in society. The same kind of urgency might be required for other, longer-term, disasters, like climate change.

"I am thinking about legislation that forces people to use more sustainable (transport) options."
– Interviewee 8 (about using legislation to enforce a change in mental models)

6. The pandemic has shifted much of physical grocery-shopping and retail to their online equivalent (Andruetto et al., 2021) (in Sweden up to 49% under quarter 2, 2020), changing the flow of goods dramatically. The interviewees mentioned that current e-commerce processes are in general not sustainable nor profitable, because of amongst other low fill rates and high damage rates. New business models need to be designed for the e-commerce of the future, where attention is paid to clever collect-, delivery- and return-policies, combined with good data visualisation, the latter being a demand from customers as well.

"E-commerce of the future is accelerated by the pandemic and really changing, like different customer behaviour and environmental footprints, impact on local logistics, and working conditions for drivers."
– Interviewee 6 (illustrating the numerous changes e-commerce should/will undergo)

"We notice now with our customers, that they want things cheap, fast and green. Before it was only cheap and fast, but now this is really changing and they push hard for sustainability." – Interviewee 12 (exemplifying how customers' mental models are already (slowly) changing)

Leverage points	1 st –order concepts	2 nd –order themes	Aggregate dimensions/ Resilience behaviour
P	Sustainability was not a primary goal during the pandemic, while the general attention for long-term sustainability might have increased	Crisis management	Persist
P	Flexibility and a flexible attitude in all parts of the supply chain and across supply chains (including offices) helped in coping with the consequences of the pandemic		
-	A sense of urgency and uncertainty about the future resulted in different priorities and decision-making processes		
P	Redundancy in the supply chain was valuable and should be implemented more, and in various ways		
P/I	The forced shift to digital communication tools has shown both its potential as well as drawbacks	Transport planning	Adapt
P	Increased attention for different modes and multi-modal transport (= more resilient and profitable)		
P/D	Transport crisis mainly struck sea and air transport, rail and road merely affected and received even positive attention		
P	Disaggregated data could give better insight into system status and needed actions	Supply chain visibility	Adapt
D	Data sharing (without giving away company secrets) would allow for better prediction, real-time planning and replanning		
D	Omnichannel logistics will, amongst others, allow for higher fill-rates and less damage		
D	Regionalisation (or de-globalisation) of production of essential goods is required to ensure our independence	Regionalisation of production	Transform
I	Earlier incentives for regionalisation are (becoming) obsolete		
D	Access to digital infrastructure is becoming an essential need, and should be provided and secured by public institutions, like the physical and energy-carrying infrastructure are	New role for governance	
D	Legislation should not be in the way of innovation and solutions, and rather promote/oblige sustainable choices and behaviour		
I	Politicians should look further than their own time in office		
D	E-commerce is increasingly used, but processes still have to become profitable/sustainable	E-commerce of the future	
I	In order to make transport sustainable, unsustainable customer desires need to change		

Figure 1 Visualisation of the interview results in relation to resilience. Left: comparison leverage points: Parameters, Feedbacks, Design, Intent. Right: comparison with different types of resilience.



Results in relation to three types of resilience

The output from the interviews is put into the context of resilience, by classifying the first- and second-order concepts as either persistent, adaptive or transformative behaviour. This is done to further understand the interviewees' experience and interest in different type of resilience and identify the opportunities for improving resilience capabilities of the transport system. As visualised in Figure 1, the 2nd-order themes each map clearly onto either persistence, adaption or transformation, except for supply chain visibility and new role for governance for which there is a slight overlap (combination of persistence/adaptation and adaptation/transformation, respectively). Ideally, 2nd-order themes address all three types of resilience. Absence of one type of resilience thinking within a 2nd-order concept indicates the lack of a well laid-out plan which simultaneously considers short-term changes and long-term transformations. The dotted lines in Figure 1 indicate that there is an overlap between the two types of resilience. Further research is needed to assess the type of resilience these 'borderline cases' belong to. Also, for some of the overlaps it is only possible to conclude whether behavioural changes caused by the pandemic have remained, when the pandemic is over.

Almost all interviewees focussed mainly on the persistent behaviour (crisis management and transport planning) in the beginning of the interview. The 2nd-order themes related to adaptive and transformative actions were addressed only at a later stage. This is a natural response (O'Connell et al. (2015)), where the initial reaction is to mitigate problems by finding quick fixes that work in the short-term, and where only at a later stage the need for more fundamental, long-term changes is addressed.

Comparing the mapping of the results to the two resilience frameworks, the shallow leverage points P in all cases correspond to persistent behaviour, while the deep leverage points D and I corresponds to either adaptation or transformation.

Discussion

Interviewees' understanding of and urge for resilience

In general, the themes and concepts related to long term resilience (adaptation and transformation) and deep leverage points (Design and Intent) seem less on top of the mind of the interviewees and received limited attention. Additionally, the responses of the interviewees showed much variation. Depending on the experience of the crisis (being in the "war zone" or at the "side-line"), the interviewee's focus was on different aspects, which impeded the comparison of the interview outputs. The difference in experiences could also relate to the attitude towards resilience as well as the variation in the level of resilience thinking among different types of actors (commercial/governmental/academic, small/large). While some actors acknowledged the need for resilience, others were more hesitant about it. Smaller companies tend to be more flexible and adapt faster to changing situations compared to the larger ones. Similarly, the actors from the public sector are less driven by economic targets than commercial companies.

All the interviewees showed a keen interest in resilience thinking, however the mandate to implement resilient measures in the transportation sector and/or supply chain was not evident. This observation corroborates the conclusion in the report of the World Economic Forum (2021), where it is suggested to appoint so-called 'risk champions', who lead the development of amongst others resilience capabilities, to prepare for future crises. These high-profile risk champions take initiative and expedite cooperation between different stakeholders – including academia, policy makers and the private sector – to foster innovation, as it is acknowledged that this collaborative action is needed to improve risk-preparedness. Other suggestions to overcome the reluctance to work towards deep and longer-term resilience made during the interviews, are 1) education about the importance of resilience and 2) outlying KPI's that are of interest to the specific partner and simultaneously identify how these KPI's could benefit from long-term resilience.

Transferability of the results

All interviewees were located in Sweden and working for Swedish companies or institutions over the course of the pandemic. Therefore, the results should be understood in the context of the Swedish approach to the pandemic, i.e. relatively lenient restrictions to mitigate the pandemic in Sweden (De Vos, 2020). However, given the global character of the supply chains considered, the results are expected to hold (partially) for foreign transport sectors as well.

The interviews did not indicate a difference in response between the automotive, e-commerce and food/health sector in handling the transportation issues during the pandemic. This is in contrast with our initial hypothesis that, given the different types of supply chain management followed by these sectors, the responses would be different. All sectors suffered from inventory shortage requiring instant and low-fill rate transportation. In addition to this, the experts mentioned how the goods transportation network is internally highly connected and that the issues in one sector caused by a disruption like the COVID-19 pandemic, propagate through the whole transportation sector. This is also acknowledged by the European Union, ordering open borders for transportation of all goods, not only essential goods (European Commission, 2020).



The interviewees mentioned that the disruption in the transport sector could have been much worse, and that the worst case scenario's that the actors accounted for, in many cases did not become reality. The transportation sector in Sweden itself was not severely hit during the pandemic, rather it was affected by disruptions in components of the supply chain beyond transportation. In fact, to some extent the transport sector was able to cover up for challenges in other sectors.

Changing customer behaviour was one of the driving factors behind the supply chain disruption. As the human behaviour is highly influenced by measures such as restrictions during the pandemic, it can be beneficial to have a detailed analysis of the effects of policies on human behaviour.

Conclusion

By providing an important initial analysis, this paper has laid the foundation for the required research related to resilience capabilities in the transportation sector. In this paper, semi-structured interviews focusing on the resilience capabilities of the transportation sector in Sweden, in relation to the COVID-19 pandemic were analysed. The interviews were assessed for their relation to the systems thinking leverage points and resilience capabilities. Three main takeaways are:

1. From the interview we could extract six main areas of interest for future research with the aim to enhance resilience capabilities. Some of these areas were already of interest before the pandemic, and during the pandemic more attention was drawn to them.
2. The potential research areas relate to the whole spectrum of resilience and are slightly biased towards short-term resilience. Long-term resilience thinking is challenging and requires much effort.
3. The taken and desired actions during the pandemic relate to both shallow and deep leverage points. The interviewees tended more towards the shallow, more obvious, leverage points, but were also able to list more fundamental changes, addressing the design and intent of the system at hand.

In general it can be concluded that the transport sector was mainly affected by problems in the ends of the supply chain (production and customer demand), aspects beyond the (road) transportation sector. Organisations appeared to be prepared for much worse situations than what eventually happened. This optimistic view of the resilience capabilities of the transportation sector requires further examination, given the limitations of this study, such as the number of interviewees. To obtain a more holistic view, more thorough analysis is needed. However, these results provide an important first analysis of the resilience capabilities in the transportation sector and give a starting point for future research.

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BETTER AGILITY, BETTER RESILIENCE: AN INVESTIGATION OF THE ITALIAN GROCERY SUPPLY CHAIN DURING THE COVID-19 OUTBREAK

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Introduction

In today's global and increasingly dynamic and turbulent environments supply chains (SCs) face numerous events that threaten to disrupt operational activities and jeopardise performance (Hosseini et al., 2019). To anticipate, adapt, respond, and recover promptly from unpredictable events, companies are increasingly recommended to enhance their SC resilience (Ponomarov and Holcomb, 2009). Robustness and agility can be considered as the dimensions of resilience (Durach et al., 2015). Specifically, agility is defined as the ability to respond quickly, smoothly, and cost-efficiently to abrupt changes in supply or demand (Christopher and Peck, 2004). However, most of the previous research is of theoretical nature and scholars are increasingly suggested to collect first-hand data (Wieland and Wallenburg, 2012). In 2020 the COVID-19 pandemic swept across the globe in a matter of months, abruptly reminding companies how vulnerable their SCs are. Empirical research focusing on exploring risk mitigation strategies has been recommended for several times in recent decades to support and facilitate SC managers decision-making, and the COVID-19 pandemic provided a rich opportunity to conduct research about SC resilience (Kilubi, 2016; van Hoek, 2020).

This study aims thus at investigating how companies coped with the disruption introduced by the COVID-19 pandemic, to develop broader insights about increasing SC agility to improve SC resilience. Qualitative case study research was conducted, and a multiple-case research design was shaped to increase external validity and to reduce the risk of misjudging single events (Yin, 2014). To limit the research scope, and simultaneously address the urgency to quickly provide answers to contingent issues (van Hoek, 2020), the problem is considered within a given empirical domain, thus resulting in a mid-range theory approach (Stank et al., 2017). Companies active in the Italian grocery SC were considered, including 15 manufacturers and 6 retailers. COVID-19 effects were suffered by almost every business (Napoleone and Pratavia, 2020), but grocery SCs were unanimously considered vital for any country, thus implying the possibility to continue the daily operations, as long as firms could guarantee employees the workplace safety (Hobbs, 2020). Moreover, Italy was one of the first European countries to be hit by the pandemic, and also experienced major disruptions related to plants' shutdowns or truck drivers' shortages. Two original macro-categories of solutions emerged, being identified as "Decomplexity" and "Streamlining". Such macro-categories include more specific categories of solutions that were related to definite strategies developed by the interviewed companies. Decomplexity- and streamlining-related strategies could help cope simultaneously with cost reduction and resilience improvement, and as it will be explained, they emerged as closely connected to agility. Also, the identified strategies exhibited different triggers' points for activation, being introduced before, during, or after the occurrence of Covid-19 related disruptions. The paper is organised as follows. Related literature is first proposed, followed by the methodology description and the findings' presentation. Findings are then discussed, and conclusions are lastly drawn.

Literature review

SCs are inherently characterised by uncertainty, being exposed to a wide array of possible risks (Christopher and Peck, 2004). SC risks can be categorised in many different ways and from different perspectives (Christopher and Peck, 2004), and many scholars proposed classifications in the form of typologies and/or taxonomies of risks (e.g., Juttner et al., 2003). A common approach distinguishes between disruption and operational risks (Chen et al., 2013). The former ones are related to the result of disastrous events caused by the nature or by humans, while the latter raise from demand and supply variations, people's mistakes, and control systems failures within SCs (Shekarian and Mellat Parast, 2020). From this last perspective, risks can thus be distinguished between supply-side (related to purchasing and supplier relationships) and demand-side (related to downstream SC operations) (Juttner et al., 2003). Moreover, how manufacturing operations are organised by single firms can cause deviations from the expected outcome in term of quality, quantity, and time, e.g. workers unavailability due to labor shortages can reduce the operational rate (Chen et al., 2013).

Closely interconnected with the concept of risk is the notion of SC vulnerability (Colicchia and Strozzi, 2012), defined as an exposure to serious disturbance whose deviations can cause negative effects or consequences (Christopher and Peck, 2004). A proven option to face SC vulnerability is resilience (Colicchia and Strozzi, 2012), which often implies that a system can adapt to regain a new stable position – recovering or returning close to its original state – after perturbations (Ponomarov and Holcomb, 2009). Resilience initiatives can be clustered according to whether they are introduced before,



during, or after a disruption (Hosseini et al., 2019), thus highlighting their proactivity or reactivity. This relates also to what the main phases of SC resilience could be, namely readiness, response, recovery, and maintaining (Hohenstein et al., 2015). Previous literature widely acknowledged that proactive or reactive resilience strategies can contribute to reduce vulnerability (Wieland and Wallenburg, 2012). Proactive strategies imply that SCs implement ex-ante measures to cope with turbulence, with no adaptation needed during times of change (Durach et al., 2015). Incorporating redundancy, e.g. developing back-up options, is a common measure to increase supply chain robustness (Wieland and Wallenburg, 2013). Conversely, reactive strategies entail that SCs adjust ex post to changes, which primarily corresponds to being flexible and increasing SC agility (Christopher and Peck, 2004) by allowing for quick responses to turbulent conditions (Hosseini et al., 2019). Agility can also represent the ability to respond promptly to unexpected market changes and convert those changes to business opportunities (Wieland and Wallenburg, 2012). It can not only enhance SC resilience but also have a positive effect on the value created for the SC customer (Hosseini et al., 2019). Making decisions rapidly, effectively, and collaboratively with other SC players is widely considered as a vital enabler of resilience, together with the inclusion of constant risk assessment, monitoring, and mitigation approaches (Christopher and Peck, 2004). Moreover, reviewing order quantity policies and batch sizes can help cope with SC risks (Juttner et al., 2003). Talluri et al. (2013) stated that changing batch sizes can strengthen the company's flexibility, allowing for more accurately following demand through a revision of production volumes. Therefore, it allows for coping with demand spikes while also simplifying production process and leading to cost savings.

Methodology

Research design

Case study research was conducted to explore how grocery companies tried to mitigate the adverse effects due to COVID-19 pandemic through SC agility. "Resilience strategies to improve SC agility to cope with the COVID-19 pandemic" acted as units of analysis. Multiple-case research design with exploratory purposes was thus shaped (Eisenhardt 1989; Ellram 1996). To limit the research scope, and simultaneously address the urgency to quickly provide answers to contingent issues (van Hoek, 2020), the problem was considered within a given empirical domain (i.e. the Italian grocery SC). The selection of cases and informants was driven by the potential to maximise conceptual insights and understanding. Heterogeneous purposeful sampling was applied (Voss et al., 2002), targeting both manufacturers and retailers and choosing larger companies as they are usually more prone to formalise and develop SC resilience. The research team developed a research protocol that included key research issues, the proposed methodology, and the interview guide (Yin, 2014). The interview guide was shaped differently for manufacturers and retailers, to improve the external validity and the study's reliability (Ellram, 1996). Research rigor was improved by designing a structured interview protocol. Then, a case outline with possible coding dimensions taken from the literature (Eisenhardt, 1989) was defined to support both data collection and analysis. A pilot study with few companies was rolled-out to improve and refine the research protocol previously developed, and concurrently to understand its main shortcomings and strengths (Voss et al. 2002). Researchers defined a set of four pilot cases, considering two manufacturers and two retailers, which were interviewed in July 2020. This diversification helped refine both the interview guides, and data collection was carried out between August and October 2020.

Data collection

A list of 34 companies were approached through contacts activated by two Italian universities, in collaboration with GS1 Italy that is the main trade association of peers in the grocery industry in Italy. 21 companies agreed to participate, including 15 manufacturers and 6 retailers. Due to the sensitive nature of the topic, confidentiality was guaranteed to interviewees and, therefore, neither company nor individuals will be revealed. Empirical data were collected through semi-structured interviews (Voss et al., 2002), with an average duration of 120 minutes. Multiple interviewees were involved to enhance construct validity (Ellram, 1996). To ensure an adequate understanding of the problem, primary informants were senior logistics and SC managers. The recourse to multiple interlocutors helped corroborate the evidence and reduce the information bias risk (Yin, 2014). Similarly, multiple investigators were involved to enhance the convergence of observations and thus increase confidence in the findings (Voss et al., 2002). The interview guide was shared in advance, to facilitate the collection of a more accurate, varied, and detailed set of information, thus increasing the quantity and the quality of the collected data (Yin, 2014). Internal validity was supported by using categories derived from the literature and then triangulating data collected through interviews with secondary sources (Ellram, 1996). Data triangulation was an integral part of the process, and multiple sources including industry reports, news from trade magazines and newspapers, and other available public documents were consulted to corroborate evidence and improve the study's construct validity (Eisenhardt, 1989). An internal review was performed by each researcher that attended any interview to develop a report for each company. Then, the draft of notes and the final documentation of each case were sent back to the firms' key informants to increase the study's reliability (Yin, 2014).



Data analysis

Within-case analysis represented the first step of data analysis (Yin, 2014). The main objective was data reduction and standardisation within each case study (Eisenhardt, 1989). A provisional starting list of coding dimensions was built upon the literature (e.g. Wieland and Wallenburg, 2013), and then updated during the 4 pilot cases. Coding dimensions included timing of application of the solutions, the related objective, the duration, the effect on internal costs, and the strategies' approach (i.e., proactivity or reactivity) (Table 1). To enhance the study's reliability (Ellram 1996), the 21 individual company reports were consolidated into the study database, which included all the strategies collected and the related explanatory notes and quotes. This allowed for performing a cross-case analysis, to find out similarity and difference patterns between different strategies and companies, enhancing internal validity (Voss et al. 2002). Data was analysed in several ways by iteratively applying open and axial coding to develop relevant categories (Ellram, 1996). When two or more strategies were recognised as conceptually similar, they were associated to the same higher-level category. Later, all the remaining strategies were evaluated according to their level of affinity with the identified categories, to define whether they could have been included. New information was constantly compared with that previously collected, and categories were updated whenever meaningful insights emerged (Yin, 2014).

Coding dimensions	Question	Alternatives		
Timing	<i>When was the solution conceived?</i>	Prior to Covid-19	During the first wave of Covid-19	After the first wave of Covid-19
Objective	<i>What are the related objectives?</i>	Risk Management	Cost Reduction	Service Level Improvement
Duration	<i>For how long is it going to be adopted?</i>	Temporarily	Permanently	
Effects on costs	<i>What are the related effects on costs?</i>	Penalisation	Benefit	
Strategy approach	<i>What is the underlying approach?</i>	Proactive	Reactive	

Table 1 – Coding dimensions, and related characterisation

During axial coding, categories were related to their sub-categories, and a series of interrelationships was defined (Voss et al. 2002). Despite the attempt to present a clear division among open and axial coding, they were strictly interconnected by an iterative rather than sequential process (Ellram, 1996), thus their boundaries resulted to be blurry. Finally, by interpreting contextual idiosyncrasies as empirical elaborations of more general categories, a sense of generality was established and the duality criterion proposed by Ketokivi and Choi (2014) was met.

Findings

The proposed findings focus on two macro-categories of strategies, namely Streamlining and Decomplexity, selected by the authors because particularly suitable to illustrate the link between agility and resilience.

Streamlining

Streamlining macro-category collects strategies aimed at increasing the speed of decision making and order fulfilment processes. Two more specific categories were identified: Decision Making Process Review and Logistics Streamlining. The first category includes solutions related to making quick decisions to mitigate the negative impacts along the SCs during the Covid-19 pandemic. Four strategies were identified:

- *Streamlining of decision-making procedures*, i.e. simplifying bureaucracy when making internal decisions and qualifying new SC partners. Benefits encompassed decision-making costs reduction and better speed in responding to the changing situation. Despite this strategy was largely applied after the Covid-19 outbreak, many respondents intended on reviewing decision-making processes to reduce internal complexity also for the day-by-day operations.
- *Business continuity plan (BCP) formalisation*, i.e. developing a formal plan that includes actions, protocols, and procedures for the entire company workforce to increase the preparedness against disruptions. Previously formalised BCPs enabled companies to reduce shutdowns operational costs and to speed up their responses to critical situations, being important also for the next future.



- *Crisis committee initiation*, i.e. formalizing the set-up of a task force to coordinate the response actions to the disruption. The crisis committee can also work as a control tower to assess, monitor, and mitigate risks. This strategy ensured a quick and agile response to the emergency highlighting the roles and responsibilities of the people involved in the crisis management process, also enabling a reduction of the adverse economic effects and being introduced both proactively and reactively.
- *Increase of the review frequency for the planning of production-logistics processes*, i.e. increasing the review frequency of production and logistics decisions to improve agility and effectiveness. This strategy was often accompanied by reviewing demand forecasting and sales plans to better align internal capacity and downstream demand. However, companies did not show interest towards keeping it permanently.

The Logistics Streamlining category addresses the need to quickly adapt operations to handle the changing demand. The interviewed companies implemented four main strategies belonging to this category:

- *Extension of receiving time-windows at distribution centres (DCs)*, i.e. enlarging the temporal extension of working hours (e.g., during afternoon, nights, or weekends) to receive goods at the retailers' DCs. This strengthened the DCs' capability to manage variable and fluctuating product flows during demand spikes. Few companies were willing to maintain it permanently, because of the increase in labour costs.
- *Working hours' extension*, i.e. re-organizing internal operations within facilities to spread activities over a longer period, improving the response agility through activating additional shifts. Extending working hours was often combined with receiving time-windows extension, being introduced mainly after the pandemic outbreak.
- *Drop-and-hook system adoption*, i.e. loading a trailer while a driver is on the clock, minimising live-loading. It allowed for reducing unloading waiting idle times and helped optimise logistics flows and the related costs. Only few retailers had already adopted this strategy prior to Covid-19 emergency, and mainly to reduce costs, but they were going to keep it permanently.

Decomplexity

Decomplexity macro-category encompasses the simplification of production and distribution operations, including two categories of strategies: Product Range Review and Order Size Increase.

The first category entails three strategies related to reviewing the product range offered to customers:

- *Product range prioritisation*, i.e. reducing or temporarily eliminating long-tail or low-selling products, until defining an "emergency product range" including only essential items. Processes were simplified to maximise the response capacity to demand spikes. It had been sometimes activated before the Covid-19 outbreak, and some companies stated that they were going to keep it permanently.
- *Product formats rationalisation*, i.e. standardizing packaging and reducing small formats. This strategy complemented the previous one, meaning that the product range review involved not only the type of products, but also their formats, helping in focusing the production and distribution capacity on the essential items for ensuring lower costs but also better availability and prompt response. This strategy was applied reactively after the Italian first wave of Covid-19, but companies were not interested in keeping it also after the pandemic.
- *New product launches slowdown*, i.e. reducing or postponing new product launches on the market, to reduce the complexity of products phase-in and phase-out during the emergency. This strategy was often combined with product range prioritisation, and both focused on ensuring great availability and quick response during the crisis. However, being new product launching highly important, companies were not prone to maintain this solution after the emergency.

The Order Size Increase category includes three strategies to increase the average lot size:

- *Full-pallet orders rounding-up*, i.e. rounding up orders to build single-product full-pallets. This reduced complexity and streamlined the order fulfilment phase, minimizing picking activities. The strategy was introduced mainly to reduce operational costs but it also increased SC resilience by enhancing the order fulfilment capabilities. The strategy was often activated after the pandemic outbreak. Despite the significant economic benefits, the majority of companies was not going to maintain this solution permanently.
- *Full-truck-load (FTL) orders rounding-up*, i.e. rounding up of orders to suppliers to FTLs to improve transport utilisation rate. This strategy not only allows for reducing the transport unit costs, but also for reducing the number of transactions simplifying the replenishment process and improving the response of companies during critical moments. Many companies have implemented the solution before the Covid-19 outbreak, and they were willing to keep it permanently.



- *Production lot size increase*, i.e. increasing the available production capacity by reducing changeovers and setups. This strategy allowed for coping with demand spikes while also simplifying production process and leading to cost savings. Its main drawback was the increase of the inventory carrying costs. Companies activated this strategy only upon Covid-19 outbreak, and they preferred to dismiss it after the pandemic due to the related rise of inventory carrying costs.

Discussion

The trade-off between cost and resilience

SC agility has been widely considered to ensure a rapid and effective reaction to disruptions, increasing the SC responsiveness (Christopher and Peck, 2004; Shekarian and Mellat Parast, 2020). Findings highlighted that the interviewed companies introduced original strategies to improve SC agility and cope with the Covid-19 pandemic. On the one hand, speeding-up decision-making processes emerged as one of the key areas that companies could pursue to be efficient and effective. On the other hand, some companies reduced SC complexity by reviewing the product range offered to customers or optimising order sizes (Tang, 2006).

However, resilience should not only help recover the desired states of a system within an acceptable time, but also at an acceptable cost (Hosseini et al., 2019). Findings confirmed that resilience strategies can allow for improving cost-effectiveness, along with coping with disruptions (e.g. streamlining of decision-making procedures, or product range prioritisation). Some strategies could be costly, but the related benefits in terms of service level to customers offset the cost increase (e.g. working hours' extension). Moreover, strategies that were mainly associated to cost reduction purposes (e.g. full-pallet orders rounding) also fostered SC agility and resilience, showing that the traditional cost-agility dilemma can be managed. Nevertheless, many initiatives were introduced during the pandemic to respond to the disruption but were not meant to be maintained after the end of the emergency. For instance, some companies combined reducing or postponing new product launches with product range prioritisation, to reduce SC complexity and costs. However, the general trend is to increase, and not reduce, the product range offered to customers. Consequently, companies clearly highlighted that they were not willing to maintain such solutions in "normal" times. Similar considerations concerned rounding up of orders to have a full pallet as a minimum order quantity, being companies afraid of the increase in inventory carrying cost. However, it is interesting that companies showed larger interest towards maintaining the rounding up of orders to suppliers to FTL to improve transport assets utilisation after the Covid-19 pandemic. On one hand, it could be illustrative that companies better understand transport than warehousing operations, thus underestimating cost savings related to reducing picking activities. On the other hand, commercial discounts related to FTL are usually more attractive than those associated with full-pallets. Therefore, when customers place orders to their suppliers, they are more encouraged to look for FTLs than full-pallets. This facet could pave the way for promising future research avenues, to understand if and how SC collaboration could help improve this current scenario not only in a cost perspective but also in a resilience one.

When to activate resilience strategies: proactivity versus reactivity

The distinction between proactive and reactive strategies is mainly driven by the moment when a strategy is introduced, whether before or after disruption (Kilubi, 2016). However, the same strategy could be considered both proactive or reactive (Wieland and Wallenburg, 2013). Agility is usually associated to a reactive approach towards resilience (Durach et al., 2015), but this study highlights that some strategies were in place even before the Covid-19 outbreak and then helped cope with the disruption. Such strategies were introduced to fulfil other objectives rather than SC resilience, but during the pandemic they allowed also for improving the SC agility. This facet could offer interesting directions for future research. Some scholars interchangeably associated "adaptive capability" with the concept of flexibility (Hosseini et al., 2019). However, flexibility is mainly considered as a dimension of SC robustness, which is usually referred to as that component of SC resilience that is developed in a proactive manner (Wieland and Wallenburg, 2013; Shekarian and Mellat Parast, 2020). Consequently, the relationship between agility and flexibility, and how different strategies could affect both, could be further investigated.



Conclusions

This study aimed at investigating how companies coped with the pandemic disruption, to collect insights about increasing SC agility to improve SC resilience. Qualitative case research was conducted, encompassing a multiple-case research design that considered the Italian grocery industry as its empirical domain.

The research let some categories of strategies emerge, contributing to exploring the link between agility and resilience. Multiple cases highlighted that the key enabler of agility is speed, and that agility could be achieved in two main ways i.e. by increasing the rapidity of internal and SC processes, and by simplifying both internal processes and external relationships with SC partners. Moreover, today the assumption that resilience can be “purchased” only at the expense of efficiency is increasingly under scrutiny, and some of the strategies illustrated in the present research confirm this evolution. Resilience strategies could help achieve different objectives simultaneously, and how such objectives could be interrelated deserves to be further explored.

Both theoretical and managerial implications could be inferred from this study. On the one hand, the research develops the current academic knowledge about SC agility and resilience. By highlighting original solutions that have been adopted by companies during the pandemic, it contributes to exploring the trade-off between cost-effectiveness and resilience through the lens of agility. Despite SC agility is normally described in reactive terms, the study also exhibits that some strategies were in place before the pandemic outbreak, thus paving the way for further inquiries regarding how to foster SC agility and its role in enhancing resilience and in shaping the journey towards the “new normal”. On the other hand, the study summarizes a set of agility-based strategies that managers could apply to preserve business continuity and improve their SCs resilience, both proactively and reactively. Suggestions are also provided to the industrial community to foster the ability to mitigate future risks efficiently and effectively through better agility.

Lastly, promising research avenues could be identified considering the limitations of this study. First, its scope was restricted to the Italian grocery industry, while other countries could be different. Second, SC agility could relate to a broader set of strategies. A wider study concerning SC agility could thus be developed, not only highlighting original facets and strategies but also acknowledging how previously identified ones had been adopted and shaped in the wake of the Covid-19 pandemic. However, the interdependency between different objectives related to the same strategy deserves to be further explored, also considering the trigger of the strategy’s activation and whether it occurs before, during, or after a disruption outbreak.

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THE IMPACT OF COVID-19 ON SUPPLY CHAIN RESILIENCY AND RISK MANAGEMENT: A STUDY ON THE ITALIAN MEDICAL DEVICE SUPPLY CHAIN

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Introduction

One of the most plausible reasons why the COVID-19 pandemic has caused severe problems and disruptions for several companies around the globe is the complex structure of their supply chains resulting from massive outsourcing of the production to the low-cost countries. This strategy increased the complexity and the number of actors in supply networks. Simultaneously with the expected cost and efficiency benefits, the risks of failure and disruptions in global supply chains have steadily increased. The effects caused by the COVID-19 pandemic might lead to long lasting structural effects with the potential to reconfiguring global supply chains in certain industries, accelerating re-shoring and/or near-shoring, as well as diversification of suppliers. In a context where severe disruptions (e.g., manufacturers closed or partially closed, airports operating with harsh restrictions, shortages of medical equipment and supplies) were recorded in global supply chains, for a number of industries (automotive, electronics, consumer goods, medical devices, etc.), the challenge is to make supply chains more resilient without compromising their competitiveness. In the medical devices industry, the COVID-19 pandemic led to major disruptions, causing huge shortages of devices and products. Italy was a good example in this context as there has been a dramatic concern regarding the shortage of masks, gloves, gowns, and ventilator machines during the first phase of the pandemic. This resulted in a relevant trouble for the Italian population and a considerable stress on the national health-care systems in spring 2020.

The objective of this paper is to analyse the impact that COVID-19 pandemic had on resiliency and risk management in the Italian medical devices supply chain for better facing future threats in the short and medium-long run. The exploratory survey was conducted in collaboration with the Italian medical devices association (Confindustria Dispositivi Medici – <https://www.confindustriadm.it/>) during the summer 2020 and involved a sample of Italian medical devices companies. The survey investigated the following topics: i) the business areas that suffered the most critical disruptions, ii) the impact of pandemic on supply chain resiliency and risk management practices, iii) alignment of business activities to the changed environment, and iv) the impact of pandemic on future supply chain developments. The paper is organised as follows: the section following this introduction provide a short overview of the literature on supply chain resiliency and risk management. The third section describes the methodology adopted. The results achieved are summarised in the fourth section. The discussion of results and related implications for both research and practices have been outlined in the concluding section.

Literature review

The COVID-19 pandemic has created a crisis that will have long lasting structural effects. Examples are the potential of the reconfiguration of global supply chains in certain industries, the acceleration of re-shoring and/or near-shoring strategies, diversification of suppliers as well as increased automation. In this context, severe disruptions (e.g., manufacturers closed or partially closed, airports operating with harsh restrictions, shortages of medical equipment and supplies) have been recorded in global supply chains (Ivanov, 2020; Reuters – Cal/Amp, 2020). As a result, a number of industries (e.g. automotive, electronics, consumer goods, medical devices, etc.) suffered negative effects.

To face such negative effects, management efforts should be directed to make supply chains more resilient without compromising their competitiveness. This is not very easy objective to achieve because many companies are not prepared to face catastrophic events and then they do not have formal plan in place to respond to supply chain disruptions caused by the COVID-19. A reaction often adopted by many companies is to focus on building inventory, which may act as a buffer to prevent future disruptions in the supply chain (Simchi-Levi, 2020; Dohale et al., 2021). Nevertheless, this reaction generally causes the accumulation of stocks with increasing costs and supply chain inefficiency. The need of building resilient supply chains that are able to better resist to the impact of vulnerabilities is a key element in recovering from supply chain disruptions caused by the widespread of pandemic (WEF, 2020).

The lack of emphasis on resiliency and risk management may be one of the possible explanation why the coronavirus has caused severe problems and disruptions for those companies who were not that well prepared. On the other hand, the widespread effects of the pandemic means that different strategies and actions are required in different situations; one potential strategy involves robust supply chain resilience (Chen et al., 2019), which redirects flows of materials within the supply chain and creates adapted structures for ensuring continuity in operations (Zhao et al., 2019).



Despite the large body of current research on supply chain resilience, the impact of a pandemic on the improvement of supply chain resilience are still unexplored. Even though previous research has studied resilience as a key part of a firm's ability to manage disruptions, more research on how firms can recover supply chains disruptions by developing resilience and improving risk management, especially during catastrophic events like COVID-19 (Yu et al., 2019), is needed. This is particularly true in the medical device supply chain, where the shortages of medical and personal protective equipment contributing to the widespread of the pandemic, creating huge difficulties, a worldwide health crisis and damages to the global economy (Iyengar, et al., 2020).

Methodology

The method used for this research was based on questionnaire survey. The survey was organised and implemented into three sequential steps. In the first step, the authors defined the content of the questionnaire and the different questions that were derived from earlier research experiences of the authors and the extant literature. In the second step, the motivations of the research and the content of the questionnaire were discussed with the staff of the Italian medical device association. The objective was to obtain a feedback on the appropriateness of the objectives of the study and the clarity and readability of questions. The scope of the questionnaire ranged from how COVID-19 affects (both directly and indirectly) different company business areas and its supply chain to the influence on resiliency and related supply chain disruptions caused by COVID-19 and risk management. In the final step, the survey was launched during the summer 2020 using a web-based platform. The Italian medical device association sent the questionnaire link to the associated companies. The questionnaire was submitted to 384 companies and 121 questionnaires were received in total, of which 89 were considered valid (equivalent to a response rate of 23%). Unfortunately, some respondents did not answered to all the questions included in the survey. In fact, with reference to the demographic information collected, only 64 companies out of 89 provided this information as shown in table 1.

Respondents by company size (employee's band)			Respondents by industry segments		
	n.	%		n.	%
Micro and small (1-49)	33	51.5	Medical devices	16	25
Medium (50-249)	19	29.8	Biomedical technology	3	4.6
Large (more than 249)	12	18.8	Services and software	4	6.3
Total	64	100	Lab. testing and in vitro diagnostics	12	18.8
			Others	29	45.3
			Total	64	100

Table 1 Respondents by company size and industry segments

Most of the respondents covered top management positions (46.8%), while the rest were almost equally distributed between those covering middle management positions (29%) and operational tasks (24.2%). Moreover, most of them have been in these positions for 5 years (35%) or 10 years (28%).

Finally, the medical-device industry was selected because the COVID-19 pandemic triggered unprecedented increased demand for some medical devices (e.g., masks, gloves, gowns, ventilator machines) and caused significant disruptions to global supply chain operations. The medical device companies were under two different pressures at the early stage of the pandemic. On the one hand, many companies in the sector faced a dramatic increase in the demand of personal protective products and other medical devices. On the other, there was a lack of availability of these products due to disruptions in the supply chain caused by the block of factories in China and other South-East Asian countries. In addition, the distribution of products on the domestic market became more complicated due to the mobility restrictions introduced by the government to stop the contagion. In this scenario, many companies have shown considerable vulnerability due to a failure in predicting and managing risks and a lack of visibility into all levels of their supply chain. In Italy, for instance, there was a significant concern regarding the shortage of critical one-time-use personal protective equipment (PPE), particularly in the northern part of the country, during the early phases of the pandemic (Aldrighetti et al., 2019).



Findings

The results of the questionnaire have been summarised using a descriptive approach. The impact of the pandemic on different business areas was one of the element analysed (see Fig.1). The analysis was performed taking into account three different level of impact (no impact, negative impact and positive impact). The data collected shown that the business areas most negatively affected by COVID-19 were delivery reliability (74%), overall company efficiency (70%), the company's ability to respond to customer demands (64%) and sales (64%). Interestingly, three out four business areas are related to the management of logistics (delivery reliability, responsiveness to customer and sales). Considering the size of the surveyed companies (see Fig. 2), it emerges that small and medium companies (SMEs) were particularly affected by the influences of the pandemic. For example, 38% in relation with the overall company efficiency, 34% in relation with the delivery reliability, 33% in relation with sales and 28% in relation with responsiveness to customer requests.

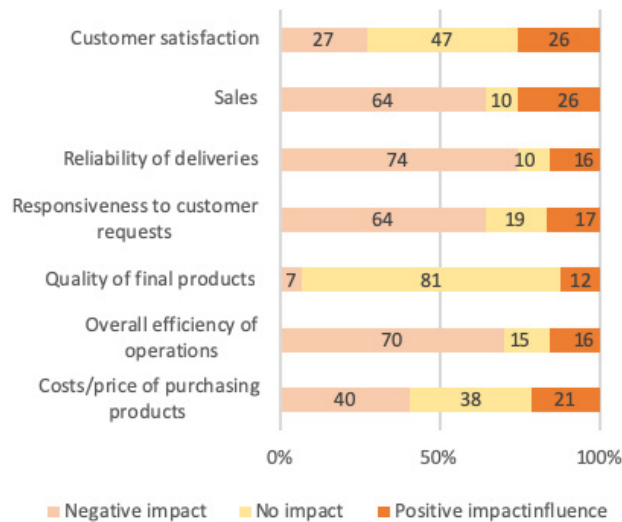


Fig. 1 COVID-19 influence on business areas



Fig. 2 COVID-19 negative influence on business areas by company size

When considering supply chain resiliency (see Fig. 3), most of the respondents stated that the overall impact of the pandemic on the supply chain was rather low (76%) while only a limited number of companies declared that such an impact was relevant (22%). The same issue was analysed from the company size point of view (see Fig. 4). Data evidenced that for all three type of companies, the impact of the COVID-19 on the supply chain was generally low. Only small and medium sized firms felt a high impact (11% and 6% respectively).

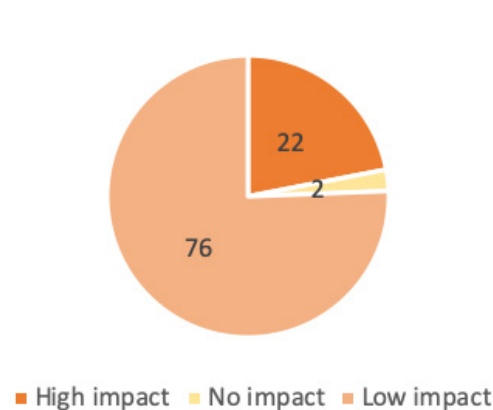


Fig. 3 Overall impact of the COVID-19 pandemic on the supply chain

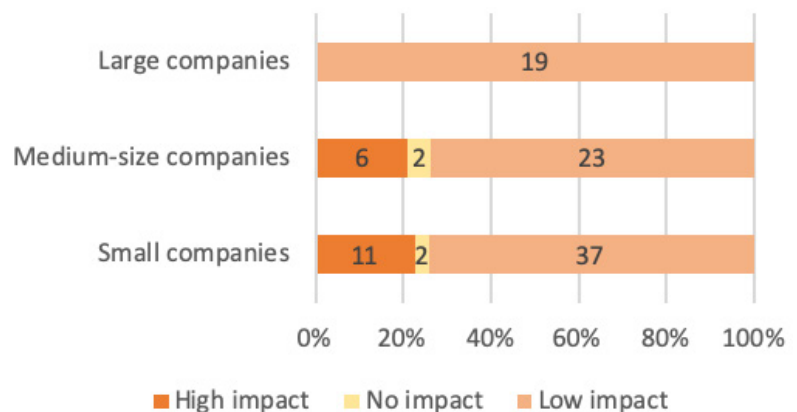


Fig. 4 Overall impact of the COVID-19 pandemic on the supply chain by company size



In relation with the ability to adapt to supply chain disruptions caused by COVID-19, the data provided in Figure 5 shown that for all three categories of firms the percentage of those that reported high adaptability is always higher than those that reported low adaptability.

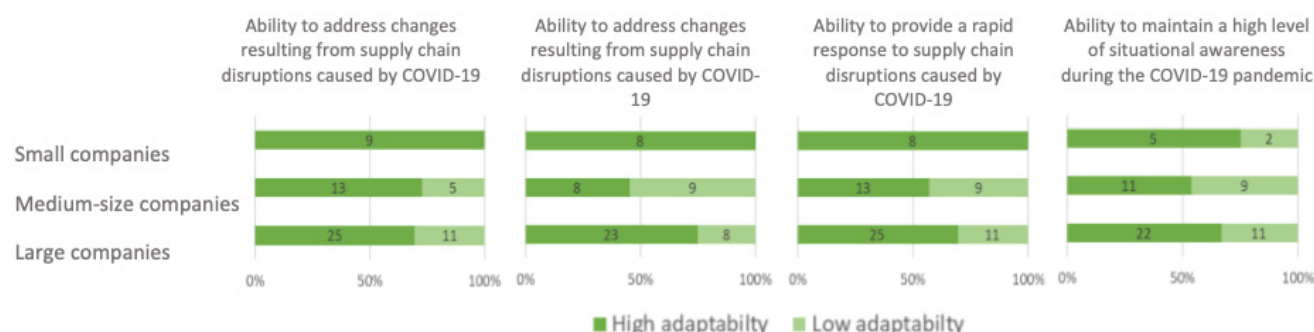


Fig. 5 Ability to adapt to supply chain disruptions caused by COVID-19

Only in the case of the ability to maintain a high level of situational awareness during the pandemic the percentage of medium-sized companies having low adaptability (9%) slightly exceeded those reporting high adaptability (8%). Furthermore, small firms reported low adaptability only in the case of maintaining a high level of situational awareness during the COVID-19 pandemic. Large firms show the greatest level of adaptability. This is particularly true when addressing changes and providing a rapid response to supply chain disruptions caused by COVID-19 (in both cases the percentage of high adaptability was 25%).

About the impact of risks on the company as a result of the pandemic (see Fig. 6), the following four macro-categories of risks have been identified: intangible risks (including risks related to ownership of collaborative innovations and intellectual property rights, risks to protect knowledge and skills, brand and image risks), logistics/supply chain risks (including risks related to product availability, risks related to delivery delays, quality risks, risk of supplier failure), financial risks (including cost/price risks, and currency risks) and production risks (including workforce risks, product safety risks, risks related to possible environmental damage caused by the production of the product). The logistics/supply chain risks were the most influential category with particular reference to delivery delays risks (47%) and risks related to product availability (39%). Figure 7 analyses the responses related to high impact of risks only (35%). It emerges that logistics/supply chain risks are the only type of risk affecting all companies' type (16% for small, 9% for large and 6% for medium respectively). Financial risks affected only small and large firms, while production risks affected large companies only. None of the companies stated that they were affected by immaterial risks.

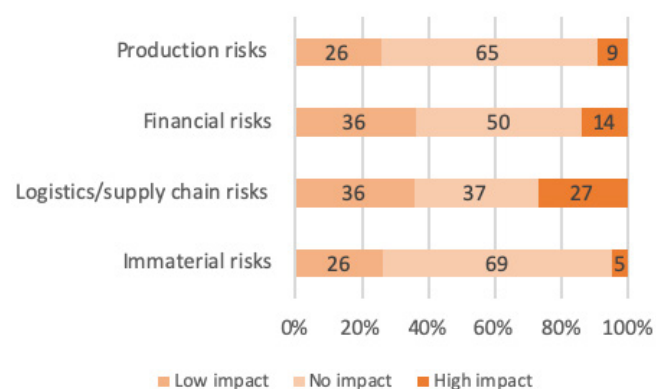


Fig. 6 Impact of risks on the company due the COVID-19

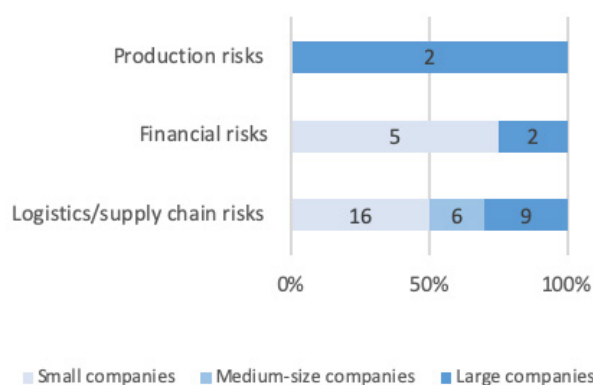


Fig. 7 High impact of risks due to COVID-19 by company size

Figure 8 provides information about the impact of the COVID-19 on risk management. It is interesting to note that, generally, most of the respondents reported quite a low impact of COVID-19 on risk management.



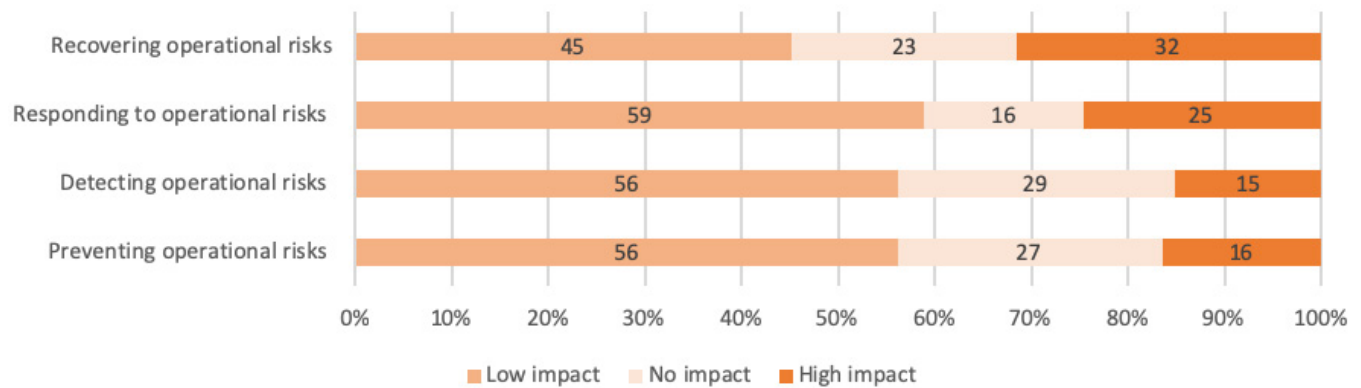


Fig. 8 Impact of the COVID-19 pandemic on risk management

Only in the case of the ability to recover operational risks (e.g. use of task forces, contingency plans, clear allocation of responsibilities) and the ability to respond to operational risks (e.g. back-up suppliers, extra production capacity, alternative transport modes) respondents claimed that the pandemic had a high impact on those ability. Regarding these two items, SMEs indicated a high impact in recovering (11%) and responding (9%) to operational risks, while large companies suffered more from the high impact in detecting and preventing operational risks (both 5%).

Another issue investigated in the survey was the awareness about the evolution of the external environment during the pandemic. In figure 9, the answers related to the high level of awareness were considered. Analysing these answers in relation to the company size, small firms shown the higher awareness about the evolution of the external environment during the pandemic in comparison with medium-size and large companies. From the industry segment point of view, companies operating in the biomedical engineering and services/software segment present the lowest level awareness. The pandemic forced companies to improve the alignment between internal activities and changes in the external environment. This aspect was analysed in the survey in relation to company size (see Fig. 10).

In the figure, small and large companies were much more effective in the ability to integrate and combine existing supply chain resources (respectively 22% and 12%), while medium-size companies were more prone to realign the entire supply chain in response to market changes (14%). From the industry segment point of view and considering the companies that declared to have a high alignment only, a small percentage of biomedical engineering companies declared to have realigned the entire supply chain in response to market changes (2%).

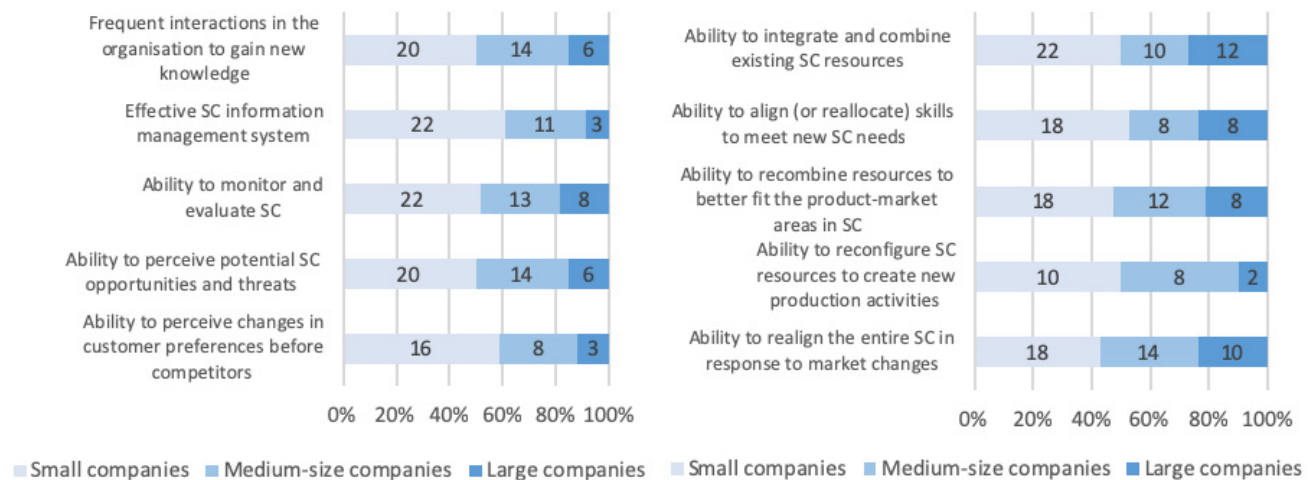


Fig. 9 High awareness on the evolution of the external environment during the COVID-19 pandemic by company size

Fig. 10 High alignment of business activities with the changed business environment during the COVID-19 pandemic by company size



The same percentage were detected for services and software companies that declared to have to aligned (or reallocate) skills to meet new supply chain needs and ability to reconfigure supply chain resources to create new production activities (both 2%). Technical and auxiliary equipment companies declared to have high ability to recombine resources to better fit the product-market areas in the supply chain (10%), while laboratory tests and in vitro diagnostic companies were much more effective in the ability to integrate and combine existing supply chain resources (12%).

The intensity of the impact of the COVID-19 pandemic on the future development of the supply chain was also surveyed. Considering only the answers “high impact” from the company size perspective, it emerged that generally small firms were more aware of the impact of the pandemic about the future developments of their supply chain. On the other hand, medium-sized and large companies shown lower values (almost the half of the percentage of small companies). In relation to the industry segment, technical and auxiliary equipment companies and the companies categorized as “others” declared that the COVID-19 pandemic had a high impact on the future development of their supply chain, while biomedical engineering companies shown a lowest percentage. In addition, it can be seen that, in relation with company size and industry segment, the percentage of responses is evenly distributed across the various answers.

Discussion, conclusion and implication

This paper explored the impact of COVID-19 pandemic on the Italian medical device supply chain. The results of the survey indicated that the main business area suffering from the effects of the pandemic was logistics management with a specific reference to delivery reliability, responsiveness to customer and sales. The impact of pandemic on logistics management seems more relevant for small firms than other companies. These results highlighting the strategic role played by logistics in the pandemic and the failure of small firms operating in the medical device sector to consider logistics as a competitive weapon to mitigate the negative effects of the pandemic.

Nevertheless, when considering the impact of pandemic supply chain resiliency the vast majority of the respondents stated that it was rather low regardless of the company size. This seems in line with the ability shown by the surveyed companies to adapt to supply chain disruptions caused by COVID-19. In fact, the number of respondent reporting a high level of adaptability is higher than those that reported low adaptability. About the impact of risks as a result of the pandemic, the risks related to logistics/supply chain were the most influential category with particular reference to delivery delays risks and risks related to product availability. In fact, this category of risks affected all companies' type.

Beyond logistics risks, financial risks affected small and large firms, while production risks mainly affected large companies. The information collected on the impact of the COVID-19 on risk management put in evidence that most of the respondents reported quite a low impact of COVID-19 on risk management. Only in the case of recovering and responding to operational risks, it was indicated that pandemic had a substantial impact on that ability especially for SMEs. On the other hand, large companies suffered more from detecting and preventing operational risks.

About the awareness concerning the evolution of the external environment during the pandemic, the results indicate that small firms shown the higher awareness about the evolution of the external environment during the pandemic in comparison with medium-size and large companies. When considering the ability of companies to align internal activities to changes in the external environment, the results indicate that small and large companies were much more effective in the ability to integrate and combine existing supply chain resources, while medium-size companies were more prone to realign the entire supply chain in response to market changes. Finally, looking at the impact of the pandemic on future supply chain developments, the results indicate that small firms were more aware about this impact in comparison with medium-sized and large companies.

On the basis of the above results, it is possible to identify some interesting implications from the managerial and research point of views. From the managerial point of view, investment to improve the efficiency of logistics and the delivery systems should become a priority to prevent the setbacks and disruptions seen in the COVID-19 outbreak. In fact, to manage and reduce the impact of future catastrophic event, medical device companies need to build up strong relationships with key suppliers and invest in supply chain planning systems that are able to provide visibility across the entire supply network. On the other hand, even if the surveyed companies declared that the overall impact of the pandemic on supply chain resiliency was not so strong, it is evident that ability to predict changes in the business environment is limited and risk management is generally underestimated. For this reasons, decisions related to the realignment of resources to better respond to customer demand needs to be carefully reconsidered and the realignment needs to involve decisions concerning several areas, such as logistics, where it may be crucial to evaluate alternative outbound logistics arrangements. Medical device companies need to ensure that their logistics service providers have enough capacity to ensure continuous production activity. Another critical area is inventory management where the pandemic resulted in an inventory shortage. In this case, communication with key customers is necessary to find alternative supply arrangements, avoid conflicts with customers, and minimize losses.



From the research point of view, further studies in this area need to investigate larger sample firms in order to generalise results. In addition, the development of case study analyses could provide further insight into how medical device companies reacted to COVID-19. Finally, carrying out studies of this kind in different countries and comparing results may allow to identify best practices that may improve the level of preparedness of Italian medical device companies to face future similar catastrophic events.

In conclusion, COVID-19 pandemic caused significant disruptions in the medical device supply chain with shortage of medical and personal PPE that have complicated that the control over the spread of the virus. For this reasons, future strategies of medical device companies to prevent the consequences of catastrophic events should be based on appropriate capability and skills to manage logistics and supply chain activities with a view to preventing and mitigating the effects of catastrophic events.

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USING SENTIMENT ANALYSIS AND TOPICMODELLING IN COVID-19 PANDEMIC WITH SOCIAL MEDIA DATA: EVIDENCE FROM THE UK SUPERMARKETS

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1. Introduction

The case of Covid-19 is a worldwide pandemic, and it has shown a critical impact on consumer behaviours. Both consumers and supermarkets are experiencing unprecedented challenges. Consumer behaviour became much less predictable when the context is ad hoc natural disasters (Sheth, 2020). Many supermarkets struggle to adapt to the change of customer behaviour and struggle to understand and meet customer needs, leading to issues like food scarcity and shortage of delivery slots. In order to analyse the customer perspectives expressed on social media accurately, it is necessary to consider the element of time. Hence, the research questions of this study are as follow: (1) How do changes of customer opinion correlate with COVID-19-related government policy and supermarket regulations? (2) What are the main reasons for the changes in volume and sentiment of supermarket-related tweets? (3) What important insights can supermarket retailers gain from utilizing SMD to improve their service during times of crisis? This study examines the customer comments and posts on the retailers' official Twitter accounts since the start of pre-lockdown until the end of the first lockdown. During the first lockdown period customers and supermarkets were not properly prepared for the changes, so the data from that period indicates how customers think and behave under uncertainty. Using time series and sentiment analysis, we detected shifts in tweets' volume and sentiment. After dividing the sample period into smaller time ranges, we applied topic modelling to identify the emerging topics at particular time points.

2. Literature Review

Crisis management is defined as "a systematic attempt by organizational members with external stakeholders to avert crises or to effectively manage those that do occur" (Pearson and Clair, 1998, p.61). Social media offers a rich data source for professionals and practitioners, which can contribute to the crisis management framework by facilitating the flow of valid information (Roshan et al., 2016). Social media has transformed how crisis management professionals and researchers view, interact with and disseminate information to affected communities. For example, researchers have investigated the effectiveness of crisis communication via social media (Utz et al., 2013). Social media provides a real-time, precise communication channel for people to cope with uncertainty and generates valuable data for socio-behavioural online participation analysis (Palen and Anderson, 2016). The abundance of textual data generated by social media users offers great potential for mining sentiment. Sentiment analysis aims to discover the opinions of authors about specific entities, it can help researchers to elucidate the relationship between the formation of public opinions and events or business-related issues. Changes in customer sentiment can be used to help companies identify and tackle underlying problems (Chatfield and Reddick, 2018). However, research that merely describes customer sentiment cannot offer sufficient explanation for the drivers behind those changes. This study combines time series analysis with sentiment analysis to show how user sentiment altered during the lockdown.

To better manage the explosion of unstructured data from social media, the topic modelling technique is developed to identify word patterns from document collections automatically. Topic modelling is powerful and efficient, it provides a convenient way to discover hidden thematic structure from unstructured textual data (Alghamdi and Alfalqi, 2015). LDA topic modelling has also been frequently used in business research, such as deriving latent brand topics from Twitter to help brand managers understand consumers' overall attitudes toward their brand (Liu et al., 2017). This research focuses on discovering customers' ideas and attitudes about groceries when different measures announced by the UK government. We adopt sentiment analysis and time series analysis to identify the critical moments, and then combine LDA topic modelling with time series analysis to extract multiple topics from the different dataset that represent different phases. Therefore, this research is able to provide a dynamic observation of customers sentiment changes and reasons behind.



3. Methodology



Figure 1. The research framework.

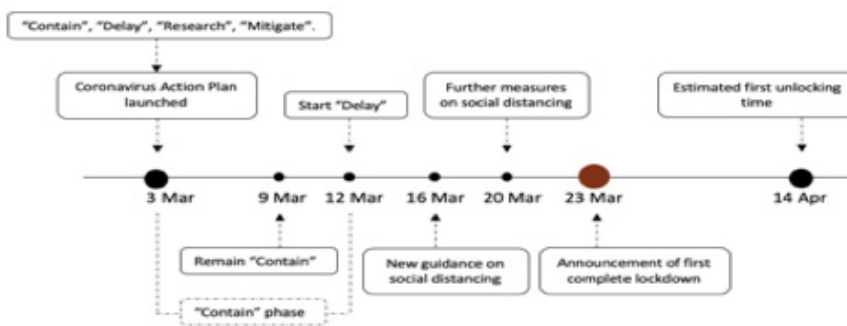


Figure 2. Timeline of UK government announcements around first official lockdown.

Figure 1 provides an overview of the research framework. The UK government launched the Coronavirus Action Plan (contain, delay, research and mitigate) on 3 March 2020 (Figure 2). The announcement of the first complete lockdown (23 March 2020) is considered as a critical time. Moreover, the estimated first unlocking/revaluation date is 14 April 2020. Therefore, we captured the data from 23 March 2020 to 14 April 2020. We capture the tweets mentioned about the five leading grocery companies: Tesco, Sainsbury's, Morrison, Asda and Aldi. Data were extracted using ExportComments tool, finally 161,921 tweets were collected. Following, we performed data pre-processing with RapidMiner Studio software to convert unstructured textual data to structure format. This process includes tokenisation, filter out stop words and reduce the words to their stems.

Sentiment analysis was performed to uncover and classify semantic from customers' tweets. Sentiment analysis aims to help users find opinionated information and detect the sentiment polarity. Pang and Lee (2008) suggest that sentiment analysis is the extraction of positive or negative opinions from the text. Sentiment analysis has been widely used on social media research, such as exploring UK consumers' sentiment about the horsemeat scandal by tweets data (Tse et al., 2016). With the assist of SentiStrength, a lexicon-based sentiment strength detection software, we obtained the final result of sentiment score with an 11-point scale that ranges from -5 (negative) to 5 (positive).

In this study, time series analysis will be employed to divide the shorter time intervals using the captured daily tweets. The first step in time series analysis is to explore the data and observe how the frequency changes. Time series analysis can also help investigate sentiment changes over time to understand the changes in popularity. As above, Tweets sentiment analysis can provide different sentiment strengths. This study refers to Lansdall-Welfare et al. (2012) for performing a series of analyses, including the frequency method and the difference in mean. The aim is to understand the different sentiment strengths and observe obvious sentiment changes, such as the largest drops, large increases in the time series. These relative changes will be emphasised in order to detect and divide the critical events and time points, which can lay the foundation for extracting emerging topics in topic modelling analysis.



With sentiment analysis and time series analysis, four critical points and five phases for sentiment change were identified. Following, we apply LDA topic modelling method to detect underlying thematic information from the corpora of each phase. LDA is a flexible and efficient unsupervised machine learning approach in extracting topics from textual documents (Blei and Lafferty, 2009). This method has been demonstrated to effectively perform with various sources of textual data. For the number of extracted topics, we use topic coherence scores to evaluate the degree of semantic similarity between high scoring words in the topic. Furthermore, we compare the result with different settings and evaluate which outcomes better explained our research goal. Therefore, 10 topics were extracted. Then, we labelled the dimensions of customer comments with topics. Three researchers labelled the detected topics independently with the pre-defined labelling criteria and determined the final topic by combined judgement. This process yielded 50 topics from five tweet corpora, ranked according to overall topic weight.

4. Analysis and Results

4.1 Trends in tweet volume and sentiment

During the pre-lockdown and lockdown period supermarkets implemented a series of measures to respond to government policy on COVID-19 prevention and control. As shown in Figure 3, government policy and supermarket regulations aroused intense discussion on social media. We observed a spike, with 161,921 tweets, on 19 March, when the majority of UK supermarkets introduced limits to shopping hours, with early closures for restocking. Coincidentally, 19 March was also a day after many supermarkets began limiting shoppers to a maximum of three of any of the same grocery item and only two of products in high demand. Given that fear, anxiety and a sense of isolation tend to trigger stockpiling and panic buying (Sim et al., 2020) these measures might have heightened such negative emotions, while the inability to stock up on daily necessities led to a large number of complaints through social media.

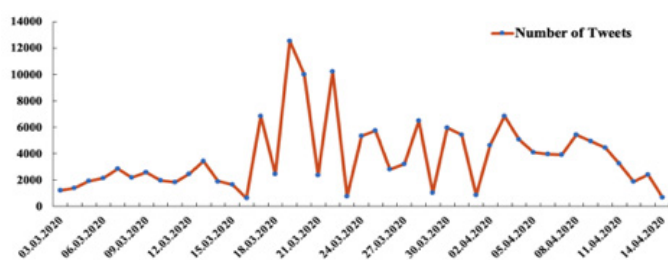


Figure 3. Twitter searching trends of the UK Top 5 supermarkets.

We narrowed our focus to the volume of positive and negative tweets during our study period. Figure 4 exhibits the daily normalized number of positive and negative tweets. Both positive and negative sentiments peaked on 19 March, the date when supermarkets received most tweets; however, negative comments outnumber positive comments, which indicates that the new regulations were causing inconvenience and disappointment among customers. Subsequent peaks were also found to be highly correlated with government announcements and the associated supermarket regulations. The volume of tweets in later peaks decreased gradually, perhaps due to the continuous improvement of supermarket services; however, negative tweets continued to outnumber positive tweets. The consistent standard deviation () trendline throughout the period indicates that our data was concentrated and not spread out, while the fluctuating mean shows the intense reaction of customers during this period.

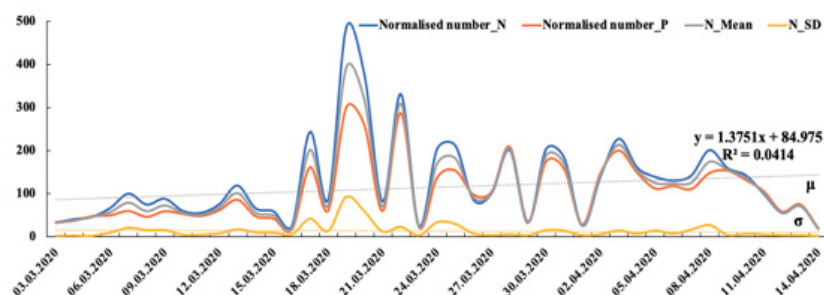


Figure 4. Volume of positive and negative tweets.



To further understand the sentiment trend in the time series, Figure 5 was generated to reveal the evolution of the daily average sentiment polarity. It shows that negative sentiment scores gradually decreased, while positive sentiments were increasing. This indicates that while customers were dissatisfied with the supermarkets in the early days of the crisis, over time they did recognize the retailers' efforts to respond to the pandemic. Several significant spikes can be detected from the graph. For the negative sentiment in Figure 6(a), 15 March, 30 March and 8 April show the lowest emotional scores, whilst for positive sentiment in Figure 6(b), 14 March, 21 March, and 28 March show the highest scores. The graphs also show that the range of average score for negative sentiment is greater than that for positive sentiment, indicating that customer negative tweets may have become more extreme.

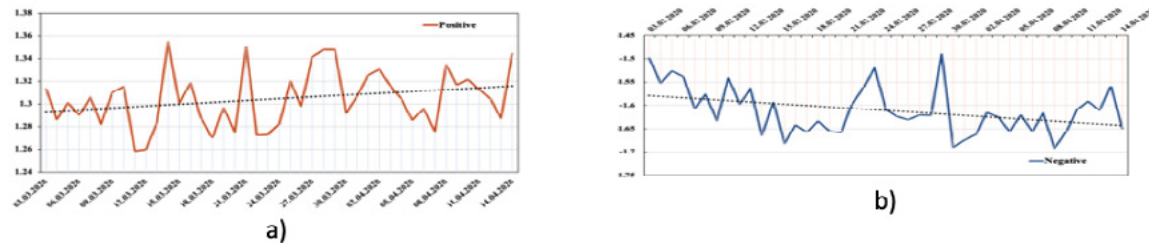


Figure 5. Trend of (a) positive sentiment polarity and (b) negative sentiment polarity

4.2 Event detection

According to Lansdall-Welfare et al. (2012), significant events can be detected from the sentiment time series. In social media research, the events detected are those that lead to changes in the number of SMD discussing related topics at a specific time (Chen et al., 2019). In this study, we used event detection analysis to explore shifts in sentiment and capture the times at which these changes occur. As discussed in 3.4, we employed two approaches to detect the time points in the time series: the frequency method and the difference in mean.

Figure 6 displays the time series of positive (a), negative (b), total (c) sentiment frequency. Overall, we can see that some critical time points tracked by the frequency changes of negative sentiment in Figure 6(b) are closer to the events on the timeline we previously defined. The key events include the launch of the COVID-19 Action Plan and the first official lockdown announcement. Figure 6(b) shows the time intervals detected under negative tweet sentiment. This figure captures some key dates, including March 5, 6, 24 and 26, at which the frequency of negative emotions changes most significantly. These changes are likely to stem from several critical measures introduced by the UK government. For example, March 3 saw the launch of the Coronavirus Action Plan, which set out how the UK would take all necessary and reasonable steps to tackle the outbreak. On March 23 British Prime Minister Boris Johnson announced the first UK complete lockdown. Compared to Figure 6(a), the time series of negative sentiment frequency accords well with critical events over the study period.

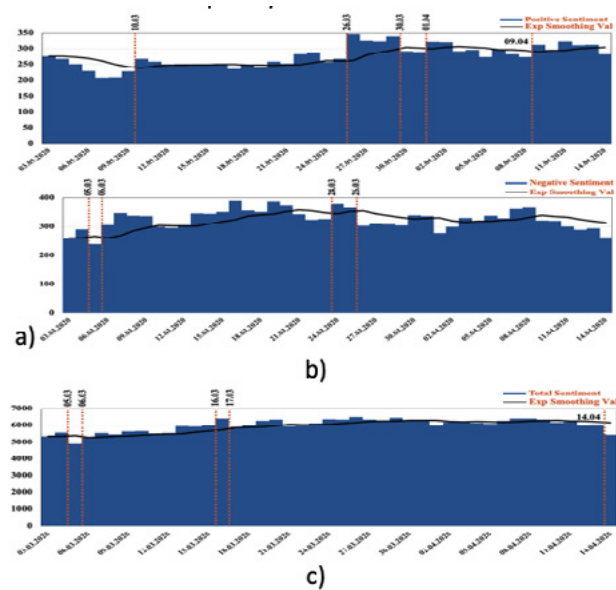


Figure 6. Daily frequency of (a) positive sentiment, (b) negative sentiment, (c) positive and negative sentiment.



We tracked the peaks in the negative sentiment time series by establishing the mean difference to verify the negative sentiment analysis results, including the most negative or positive spikes. The spikes indicate the days that show the most significant shifts and have the largest increasing impact in the following days. Following the method of Lansdall-Welfare et al. (2012), we calculated the mean difference by measuring the absolute difference between the daily averages. This measure is used to identify apparent changes in the mean of sentiment valence and detect significant events. In Figure 7, there is a fluctuating curve, representing the changes in mean difference for each day. We can observe large peaks in negative sentiment between March 9 and March 10 and between March 12 and March 13, related to the “Contain” and “Delay” phases respectively of the COVID-19 Action Plan. A similar peak occurred between March 23 and March 24, when the UK entered its first lockdown. There are two prominent spikes around March 29 in the time series. Motivated by concern that such a small time interval might impair the effectiveness of the overall data analysis, and that the interpretation of one day’s dataset would be inadequate in the later topic modelling, we selected the more significant spike on March 30. This time point falls about one week after the announcement of the first official lockdown. Event detection analysis helped us identify the key time points that fit our time series. Maintaining a focus on the peaks indicating abrupt changes in customers’ negative sentiment, in the later analysis we used topic modelling to identify the topics of most concern to customers and to determine the reasons for the changes.

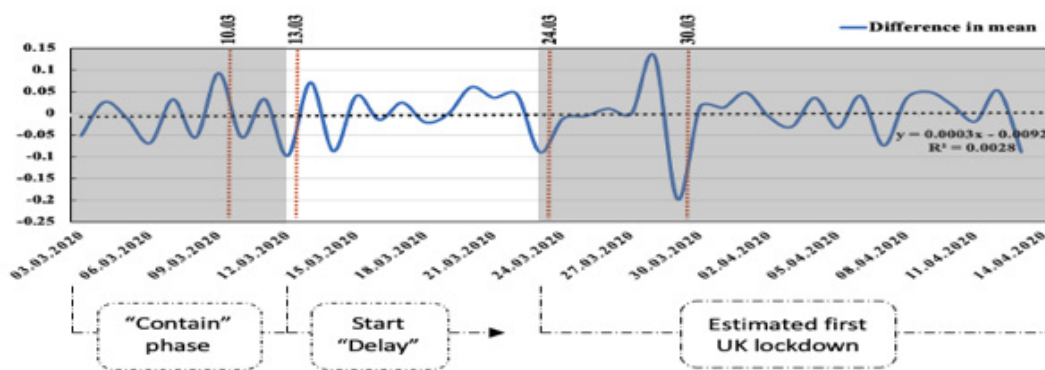


Figure 7. The comparison of the UK government announcement timeline and difference in mean of negative sentiment (Note: The date for the end of the “Delay” phase was not announced during the study period).

4.3 Evolving topics over time

This section discusses the key topics of concern and customer sentiment dynamics using a topic modelling approach. The time series was divided into five phases (Figure 8), each containing ten topics, listed in descending order of topic weighting. These topics changed considerably throughout the time series.



Figure 8. Topics dynamics over time (Note: Only the recurring topics and their related topics were highlighted in colours).



The LDA topic modelling results reveal that the weight of “delivery” increases, and remains heaviest among all topics from P3 to P5, implying that it is the chief customer concern in the time series. During P1&2 customers were less sensitive to delivery slot issues than in subsequent time periods. During P3 the UK government announced further measures against COVID-19, such as closing restaurants and cafes, requiring work from home, and determining the first complete lockdown. The dramatic increase in demand for deliveries created difficulties for supermarkets, and slot availability became a severe problem. We suggest that supermarkets expand their delivery teams and reserve special delivery slots for vulnerable groups, making delivery arrangements more flexible.

“Food and essential supplies” emerged as a particular customer concern in each phase. For example, customers commented on the lack of “toilet roll” and “pasta”. This was the most discussed topic in P1, indicating heavy demand for essentials in the early period. Similarly, “hygiene” refers to the shortage of hygiene products (e.g. hand sanitizer) and remains relatively important in P1 and P2. Hence, we suggest grocery companies enhance their essential product stock management and shift their attention from product diversity-oriented to essentials and key product continual supply-oriented under the conditions of crisis. Moreover, it is recommended that grocery companies establish tighter cooperation with their suppliers and develop more flexible procurement strategies. Customer concerns regarding panic buying and hoarding behaviours rank second in P1 and first in P2, then become less discussed in P3. “Empathy”, which refers to thinking about others, presents an opposite trend, increasing in frequency from P2 into P3. In P3, “buy limit order” is discussed as retailers introduce purchasing limits on essentials. Interestingly, with the increase of “empathy” and the appearance of “buy limit order” in P3, “panic buying” disappears, indicating that the restrictions on purchases was an efficient means in ease stock shortages. Therefore, we suggest that companies combat false information and rumour by actively communicating with customers online and offline.

“Responsiveness” refers to how quickly and well a person or an organization reacts to something. It occurs with high weights in P2, P4, and P5, mainly representing the complaints regarding supermarkets’ failure to provide timely feedback or solve customer problems. Current relationship theories regard perceived responsiveness as the key aspect of a satisfying relationship (Lemay et al., 2007), and a practical method to yield better feedback and accelerate improvement in service quality (Voss et al., 2004). Low ratings for responsiveness reflect poor service quality and further reduce customer satisfaction. Consequently, supermarkets should strengthen interaction with and timely response to customers under special circumstances.

From P3 to P5, customer complaints mainly concern the shopping difficulties faced by the vulnerable and the lack of support for vital workers. With the gradual implementation of lockdown policies both in-person and online shopping became harder, while social distancing rules meant that elderly or disabled people could not necessarily get help from family and friends. Simultaneously, the question of whether vital workers could purchase necessary products was also attracting public attention. Although supermarkets introduced measures such as reserving certain shopping hours for essential workers, different shift patterns meant that not all such workers could benefit. The continuous discussion of these topics shows that customers’ concerns are still not completely resolved. Therefore, more improvements are needed to support special groups. “Staff-related issues” include both staff behaviour and supermarkets’ treatment of their employees. Concerns regarding employees’ behaviour focus mainly on failure to maintain social distancing. A possible reason for this is that in P3 and P4 many supermarkets recruited large numbers of new employees, who might not have received adequate training before starting work. Many customers expressed concern about insufficient protection for supermarket employees, for example a lack of protective equipment and the behaviour of some managers in requiring staff with symptoms to work. Therefore, we suggest that supermarkets provide their employees with timely training and improve staff protection systems.

Among the emerging topics, only “delivery” maintained a high weighting throughout the time series. This reveals that customer concerns regarding delivery-related issues remained constant throughout the period. The importance of other topics changes over different phases. While “panic buying” is prominent in the first three phases, with the resolution of product shortages this topic disappears. Such declines in topic frequency can provide useful evidence for the supermarkets on the effectiveness of measures used to address problems. We observe a similar pattern for “hygiene, food and essential supplies”. In addition, we capture the topics of “responsiveness”, “vulnerable shopping priority” and “supporting vital workers”, which highlight concerns regarding the lack of care for certain special groups. Despite actions taken by the supermarkets, such as limiting purchases, and reserving priority slots for vulnerable people and NHS staff, these topics continued to be discussed, which demonstrates that the measures were insufficient to resolve the concerns. Therefore, supermarkets are encouraged to offer better solutions regarding the protection of special groups.



5. Discussion and Conclusion

This study makes theoretical contributions to the social media and crisis management literature. This research extends existing knowledge by providing a vivid account of how the analysis of SMD can help supermarket retailers to understand customer sentiment. Moreover, this mixed-method research presents a dynamic development process of the SMD, and reveals the underlying causes of sentiment change in every time series. This study also offers detailed information regarding the specific areas that supermarkets should prioritize and monitor in unusual circumstances. By examining the emerging topics in the time series according to the fluctuation of customer sentiment, this study unfolds the strategies that supermarket retailers should consider when a crisis occurs. Meanwhile, with the implementation of relevant lockdown policy and of new supermarket regulations, the topics that customers focused on dynamically evolved. Therefore, this study not only gives a guideline of the new areas that supermarkets need to improve in times of crisis, but also points out the optimal timing to carry out the improvement strategies.

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LOGISTICS AND TRANSPORT TECHNOLOGY



CABLE REEL LOGISTICS

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Introduction

Cable Reel technology can provide logistics and human transport powered by electricity from sustainable sources for a wide variety of applications.

The limitations of using aerial-tramway or gondola-style cablecar systems (for urban public transport or movement of goods) include vulnerability to high winds, and the restrictive 2D linear nature of transport only from point A to Point B. Overcoming these limitations is important to enable an electrically-operated cable-based transport system that can dispense with fossil fuel power.

This paper shows how, by scaling up existing 3D cable-based technology, cable reel solutions can be used to transport goods & people over a wide square area, irrespective of road access or topography.

Using this innovative technology for moving cargo is believed to be a new idea, so the term 'Cable-Reel' has been used to define this novel method of moving loads.

The existing technology: Skycam

Skycam technology was invented by an American cinematographer, Garrett Brown ASC. He filmed many hit movies such as Rocky, The Shining, & Return of the Jedi. He needed a means of elevating and stabilising heavyweight professional cameras that was not susceptible to high winds (as with a drone), or bumping on uneven ground. He wanted to both control a camera, and transfer a filmed digital image by wire (rather than as a radio signal that was subject to electronic RF interference). Initially used on film sets, Skycam prototypes were first used for sports stadia in about 1984.

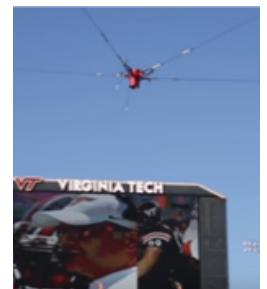
Sports fans across the world are now familiar with seeing the images taken from an overhead camera, the Skycam, that is suspended from 4 cables traversing a stadium.

The fundamental principle of the Skycam is that there are 4 cables suspended in a cross-shape over a target area, such as a football pitch. In each corner of the stadium or target area there is a pulley mounted on top of a tall tower. At the foot of each of the 4 towers is a massive reel of kevlar cable, controlled by an electric motor.

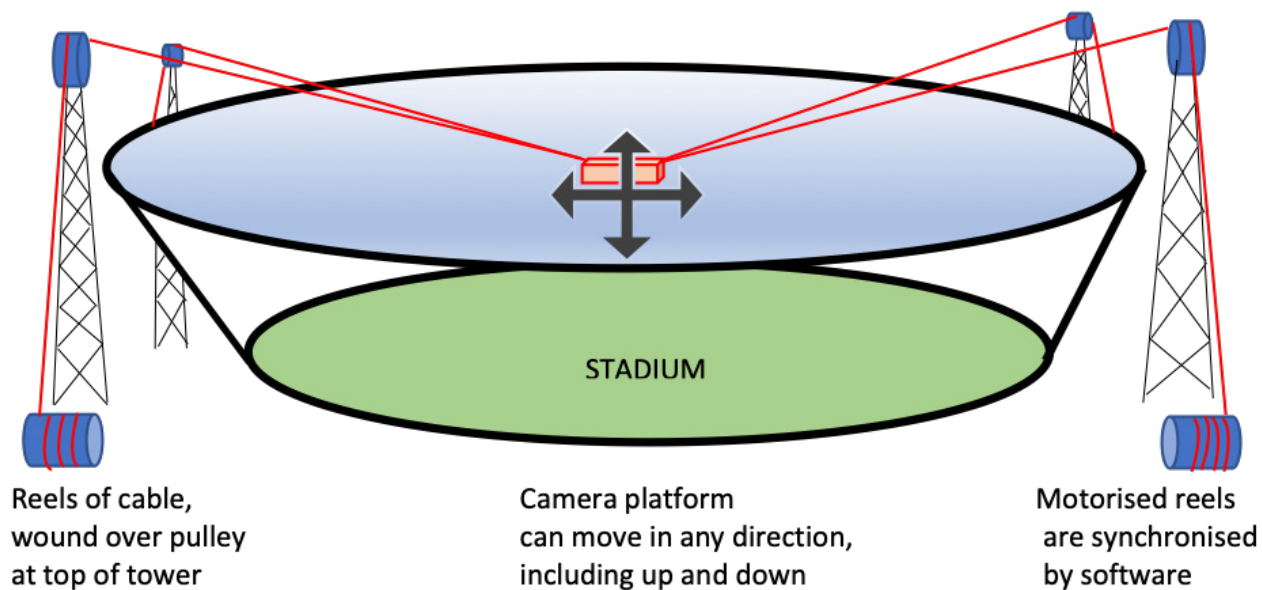
The 4 cables each run from one of the motorised reels over a tower pulleys, and meet in the middle of the target area. Suspended in the centre of the 4 wires is a central dolly or platform, which is attached at each corner to one of the 4 cables. The gyro-stabilised camera, usually weighing about 25kg, is mounted on the platform (also known as a 'spar'), giving it 360° rotation & 180° pan.

The key feature of the cable reel technology is the proprietary software that co-ordinates the 4 reels to activate simultaneously. The 'pilot' of the Skycam can now use a joystick & a computerised control panel to taughten all 4 reels, and so lift the camera platform into the air. The pilot now 'flies' the camera around the stadium by moving a joystick, and operating other height controls to enable the camera to 'swoop' down. For a major sports match, there is a separate camera operator (nicknamed the 'gunner'), who swivels the camera to focus on the action.

The computerised joystick control synchronises the 4 opposing motorised reels (or winches) to alternately reel-in and out their cables, so moving the platform from side to side, and up & down.



The basic cable reel concept, used for a Skycam over a stadium



To cover a typical large stadium, each reel has about 1400 feet of Kevlar cable wound onto it. By linking two opposing cables in the middle of the pitch, this gives a total length of cable of 2800 feet (853 metres). If these are suspended from pulleys on towers that are 50m high, the typical target area that can be covered is 750m².

To achieve this area, the Kevlar cable is about 8mm in diameter (the 'thickness of a pencil'). It has a fibre-optic cable wound into it, for controlling the camera, and to relay the camera image back to the broadcasters. The Kevlar sheathing is instrumental in protecting the inter-twined data cable. The 4 supporting cables are as thin and unobtrusive as possible, as they usually hang over a sports field and may interfere with the view of the audience.



In the USA, the Skycam company use Yaskawa servo systems to smooth the operation of the reel motors, so they stop smoothly with pinpoint accuracy but without bouncing, to keep the camera stable. The safe speed of the system is 29 mph. (100mph is technically possible over extreme lengths.)

Before a Skycam operation, the stadium is surveyed. A cartesian grid is programmed into the software. This will set a minimum height that the camera can descend to in any area, and will include projections such as high canopies or flagpoles that must be avoided. The surveyor effectively geo-fences 'no-fly' areas into the software to create automatic obstacle avoidance. Once done, the program for this stadium can be repeatedly re-used until there are any significant alterations to the structure.

A temporary Skycam system is delivered to a stadium on a series of HGV's. The large cable reels are fixed down with substantial counter-weights, often filled with either water, sand, or rubble. Newer stadia are being built with purpose-built support towers, but temporary towers can rapidly be built to a standard design from scaffolding or other materials.

Temporary or mobile cable reel systems

Temporary systems used for transporting goods or people over a smaller area – perhaps up to 1km square – could either be truck-mounted, or be delivered to a site on the back of a lorry. If expense is critical, it can use towers constructed from scaffolding.

In the first world, large cranes could be used on the corners. However where cost is a primary consideration, but the system needs to be frequently moved (e.g. in developing world agriculture), purpose-built 'corner trucks' could be mounted with cheaper extending boom arms or self-elevating towers to hold up the pulleys. These 'corner trucks' could either use outriggers like a crane, or be braced against purpose-built earthworks constructed at the regular operating sites.



Payload

The payload of a cable-reel system is determined by the thickness or strength of the cable. This in turn is determined by the size of the target area to be covered. The larger the set target area, the greater length of cable required on each reel, and so the greater the weight and size of the reels.

Consequently really heavy weights, such as full sea containers, might be limited to a smaller area due to the thickness & weight of cable required. Such heavy-duty systems might require stronger corner towers, reels and large electric motors. Permanent installations would be preferable.

For temporary or mobile systems, the aim is to have the thinnest possible cable capable of supporting the necessary load to cover as wide an area as possible. The thinner the cable, the less the size and weight of the cable reels. In turn this means smaller and cheaper servomotors, less energy consumption, more lightweight towers, and a reduced counter-bracing requirement against lateral forces. The combined effect is to minimise the total weight that must be transported between sites.

An area for future research is whether graphene or other novel substances can be used to create thinner, stronger cables to cover greater operating areas. However, in practice, – even with graphene cables – the practical limit of a target area is a few miles square. For a system 5 miles square, it would almost certainly have to be mounted on a hillside (due to ‘droop’, and the height of the towers required). A platform would take as much as 6 minutes to traverse that distance at a speed of 30mph.

Applications in Logistics

The target area where there is a load to be either collected or delivered is called a ‘drop zone’.

There are two ways in which goods can be hoisted up from a drop zone:

- a) One is for the platform to be lowered, by slacking off all 4 cables so it sinks to the ground. This is likely to be undesirable because it is highly unlikely there will be clear line-of sight for the cables to lower between all 4 towers and every possible drop zone in the whole target area. Any feature of height such as a tree, hill or building is likely to interfere, unless the entire target area is flat.
- b) If there is a hoist on the platform, it can lower a grab or carrier to collect or deposit a load.

If required to move people, the platform-mounted hoist can lower a person-carrier that should have additional safety measures (extra safety attachment cables, padding, safety harnesses, etc.). For person-lifting capability there should be a voice/audio link between passenger and pilot. In all situations, there should be a camera on the platform so the remote pilot can see.

Warehousing

The cable reel technology may be less attractive for indoor permanent warehousing in a first-world environment, where large scale automation and robotics are available and affordable. However temporary applications would still be very attractive, especially outdoors.

Ideally loads would be stored in standard-shaped boxes or carriers, with a uniform attachment arrangement. Cable reel technology may be more attractive for movement of slow-moving items, where full automation is expensive for rare use. It is not appropriate for a high-bay warehouse.

A benefit of the cable-reel system is that the computerised geo-mapping means that items can be stored and recorded very accurately for later picking. The scope for human error is greatly reduced.

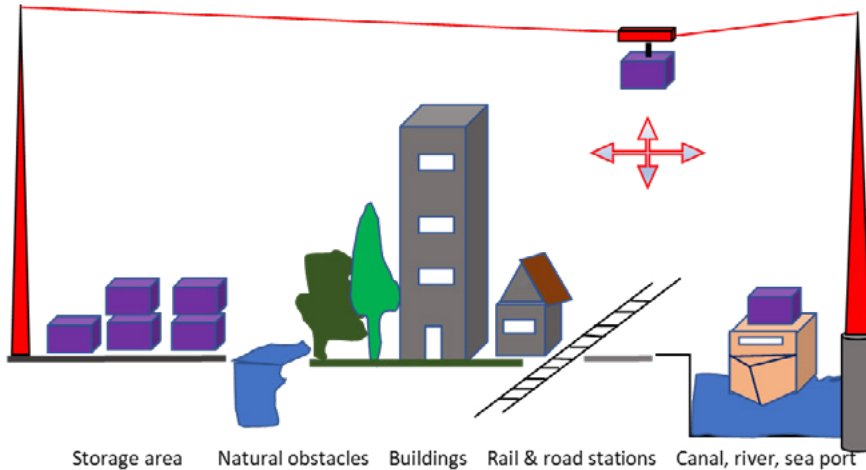
Even in a situation where human order pickers are physically collecting items from stock bays, the cable-reel system can be used to transport the picked items to the final-mile delivery vehicle loading bay quickly and accurately, without the order picker having to make frequent trips back and forth to deposit the picked items. Fresh picking lists or goods carriers can be despatched to the human order picker at the far end of a warehouse on the cable-reel platform.

Potentially cable-reel systems can be multi-layered over each other. If the computer control system can prevent the various platforms from overlapping at any one drop zone, multi-stacking is quite possible. This would speed up movements for busier environments, even if occasionally some platforms had to wait to access a drop zone location. This could be achieved with pulleys at multiple heights on the same corner towers, also giving some degree of dual redundancy.



Intermodal transport - Loading vehicles, rail carriages & barges

One of the main strengths of this system is its ability to pass easily over both land and water, and over buildings. In a situation where goods need to be loaded from a truck, railroad carriage, or yard onto a canal barge or ship in a dock, this is easily achieved if support towers can be erected the other side of the water. Potentially these could be installed on a suitable base in the water, although it would be preferable to have the towers mounted on land where the base can be readily inspected.



The computer-driven precision of a cable reel system, combined with the ability to have an overhead camera on the dolly observing the lowering of goods (or people), means it can be used accurately. It is ideal for moving smaller or more lightweight containers between vehicles, rail carriages and ships. Potentially the system is much cheaper than the large container-carriers used in advanced ports, and allows storage areas to be more remote (i.e. not directly connected to the port by road or rail), so perhaps bringing into use land that is currently unusable, such as small islands in a harbour, or where separated by rivers). An overhead cable reel system allows stacks of containers to be quickly shuffled in a storage area to 'get at the bottom one'.

In temporary settings, especially where rapid deployment is needed, (e.g. during a war, for emergency disaster relief, for a one-off construction project, or for a port where there are very few container movements), it may be that a cable-reel system is cheaper and faster to install than conventional port equipment. This may be true where there is no clear quayside, or where silting/lack of dredging prevents deep-draught ships getting close to a shore. It also enables double-stacking of ships against a dockside, as both can be unloaded simultaneously. There is the potential to allow ships to be unloaded from the middle of a harbour (perhaps at low tide) if the cable reel system is large enough to cross the expanse of water, or is mounted on towers sunk into the seabed. Unloading ships in the middle of a harbour should increase the capacity of the port.

Even for major ports where capital investment is not a problem and large-scale container carriers are affordable, a cable-reel system can be used to complement the existing docks technology. This may be on the periphery, carrying slower-moving items, shuffling stacks of containers, or loading vehicles.

Marinas & harbours

In marinas or small harbours not every boat can be tied up alongside a quay. Issues such as tidal rise & fall mean boats are often moored in the middle of a harbour or river. Currently the sailors travel to the quayside in smaller boats. A cable reel system can move sailors and loads, such as containers of fish, between quay and vessel promptly and accurately. For masted vessels, tying up to a small square pontoon would provide a better drop-zone. A cable reel system over a harbour could make it easier to transfer ship's pilots or customs officers aboard.

Aquaculture

A cable reel system over fish farms can allow accurate feed distribution into distinct fish pens, and easy transfer of farmhands and vets between pontoons. When harvesting (e.g. mussels, lobsters or crabs), loads can be easily transferred to shore and directly onto vehicles. The hoist on the platform could be used to lift creels straight out of the water, and possibly transfer the entire creel directly to shore without the need to empty it on the pontoon.



Construction

This application might include moving items around an area such as a building site. For instance a platform fitted with suction cups could be used to move glass panels from a secure storage yard to the structure being built. High value or vulnerable items such as glassware, boilers or electrical components can be moved without danger of damage from rough roads. Aircon units or windows could be moved either from a JIT delivery vehicle or a storage yard directly into position on the outside of a building, and being suspended are easier to fit directly onto the mountings. Every item moved reduces a conventional vehicle movement across the site, and saves labour time.

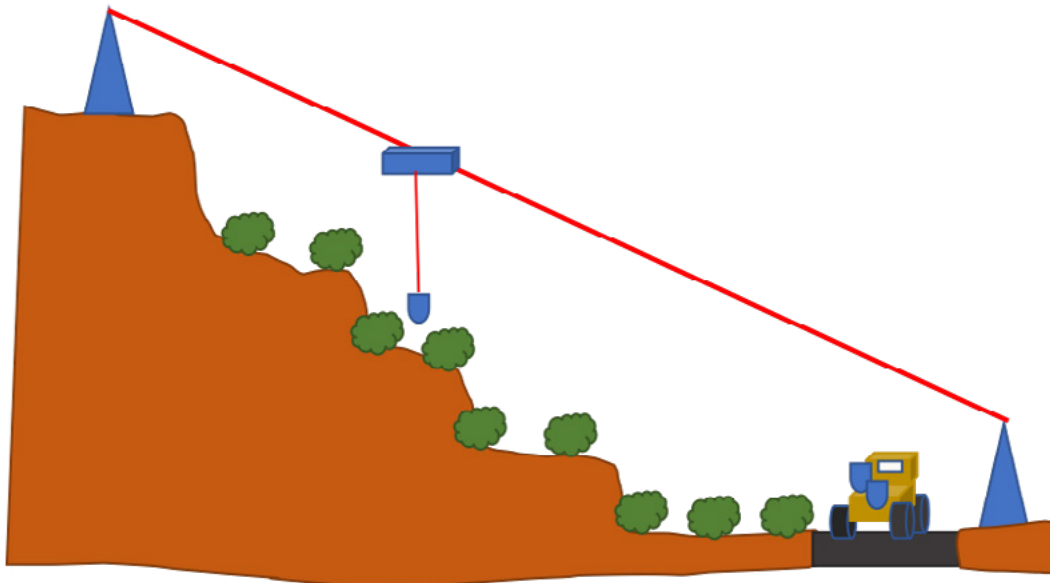
Solar panel farms

A cable reel system is ideal for smoothly lifting solar panels and the associated stands, cabling, etc from supply trucks or the yard directly into position during the construction phase. This is useful on hillsides where vehicles may struggle to get close. The platform can be mounted with reels of electric wire and run these accurately along a predefined path. After installation, a camera mounted on the platform can inspect all components, especially for trouble-shooting. If a specific panel or electric wire is damaged in the middle of an inaccessible area, an engineer can be lowered in from above. The platform can drag sweeper-brushes or spray water along the length of arrays to keep the solar panels clean & maintain optimal photovoltaic efficiency. If brushcutting is needed to control vegetation, fuel and victuals can be supplied to the workmen from above, minimising loads carried.

Agricultural applications – especially in areas of rough terrain

A cable reel system can cope with any sort of terrain, as long as at least one of the towers is high enough to ensure clearance for the platform to pass over the whole target area. This makes it ideal for country areas where there are multiple obstacles such as rivers, hillocks, thick vegetation, steep hillsides, deep holes, multiple fences, or varying surfaces such as ploughed areas, soft sand, or snow.

Particularly good applications include harvesting where access is difficult by road. This includes steep hillsides (vineyards), hilltops (tea), and terraces (rice paddies).



A cable reel system allows a harvesting worker to proceed along a row of plants and summon a platform when their basket is full of fruit. The overhead platform hoist can lower a fresh empty basket to the worker on a hook, and quickly transport the full basket directly to a waiting vehicle. This saves much time and effort (and manual handling), by obviating the need for a worker to have to descend the hill to the nearest track to unload a full basket.

At the end of the day, a person-carrier can collect workers and take them to a bus. The next day it can return them to exactly where they left off, avoiding discontinuity in harvesting, pruning, etc.

When bringing currently inaccessible areas into production, the overhead system can be used to bring tools, fertiliser, seedlings and water to the worker for planting. This reduces the weights that must be moved by human or pack-animal, and the time taken.



Crop spraying

The dolly platform can be equipped with a tank containing fertiliser or pesticide spray (or even water for irrigation). By precise navigation along rows of plants, including accommodating curves in the terrain, the spray can be much more precisely targeted than by using a plane, and can carry a heavier payload than a drone. At 30mph, the speed of returning from the drop-zone to the tanker to refill means that enormous loads do not need to be carried. This can result in a smaller, lighter system.

Because the platform travels overhead, it will not damage crops as it moves along, unlike tractors. The current spacing in farmers fields to allow the passage of tractor tyres are no longer necessary for spraying; so the crop-growing area is nearly doubled, increasing vegetation density and harvest size. Applying different sprays to areas in close proximity would be especially useful in research farms.

Laying netting or covers (e.g. bird- or insect-prevention netting, or frost protection covers).

This might require two platforms working in tandem, with both potentially still using the same corner towers, but at different heights. So if working over one target area, one cable-reel system could be mounted directly above another – i.e. multi-stacked.

The netting would be delivered to site and laid on a long horizontal reel in a line along one edge of a target area, ideally at the top of a hill. The front corners would be attached to the 2 overhead platforms, which are either side of the target area. By taughtening the cable reels, the front edge of the netting is lifted into the air and can then be dragged across to the other side of the target area, then lowered. The origin should be higher than the destination drop-zone to prevent any snagging.

In future, rather than using rigid panels, solar energy capture may involve flexible matting, which could be laid across inaccessible barren hillsides by this technique. Cyprus would be an ideal location.

Animal feed

This system could be used to disperse grainfeed, such as chicken feed, evenly over a wide area, by scattering from a hopper on the platform. This has the benefit of ensuring all livestock have equal access to the food provided. For organic or free range farms, it has the attraction of ensuring animals are stimulated in their search for food over a wider area.

Where animals are penned or caged, and spread out over a large area, the precision of a computer-operated cable reel system would allow specific feedstuffs or particular quantities to be supplied to different enclosures. This might be useful for catering to different needs, such as animals in a zoo.

Laying pipelines or cables

The dolly platform can be used in two ways:

- (a) By having a reel of electricity or telephone wire, or fibreoptic cable, or a reel of pipeline, mounted on the dolly, unravelling as it crosses the target area. Depending on the payload, heavier pipes may need to be laid in sections of a few hundred metres at a time, then jointed. It is possible a worker can be lowered into place at the jointing points by a person-carrier attached to the same system.
- (b) A reel of pipeline or cable is delivered to and mounted on the edge of the target area. One end of the pipe is attached to the dolly and 'flown' through the air to the other side, before being lowered to the ground. The reel of pipeline or wire would need to be at the top of a hill, or mounted high up on a pulley on a tower, to prevent snagging.

Disaster relief & refugee camps

A cable reel system would be ideal for providing supplies in refugee camps. In Cox's Bazaar, the terrain is undulating, riven by streams, with narrow paths, is muddy, prone to flooding in the monsoon, and there is potential for supplies to be stolen en route within the camp. This system could allow precision deliveries of food, water, wood or other fuel such as LPG cylinders, to particular areas of a camp from a secure logistics base. This might be either directly to the tent that needs it, or to a local drop zone at a distribution point, where an envoy takes delivery and rations supply to nearby camp dwellers.

If the ability to lift people is proven, person-carriers or even stretcher-carriers mounted on the dolly can be used to lift and move people smoothly between different locations in a camp. If somebody falls ill in a remote tent, then after a call from a first responder the cable-reel system can hoist the patient overhead directly to the hospital compound. This could be considerably more comfortable than being stretchered on foot or by vehicle on poor roads.



Where accommodation is dire and resources are limited, a refugee agency could use this system to hoist a large sheet of tarpaulin over a wide area to provide fast protection against rain and sun. It may rely on the erection of internal supports to hold the tarpaulin up high – similar to a giant marquee.

In humanitarian field hospitals where there is a severe infection risk, such as an Ebola hospital, a cable reel system could be used to move goods from a logistics base outside the perimeter (the non-infected area) into the red-zone (i.e. the 'potentially infected' or hot-zone). This would reduce movement of people between zones, and minimise person-to-person contact, with the loads coming out of the red zone being disinfected before handling.

Where frequent deaths are occurring in a red zone from a highly contagious disease such as Ebola, an overhead cable-reel system could be used to transport bodies out of the hospital area directly to mass graves dug outside the perimeter, so minimising human handling.

Applications in security

A platform could be mounted with spotlights and infra-red cameras to respond to alarms activated within a target area. For instance, if a container alarm was to go off in a port storage area, an overhead cable-reel platform could arrive overhead at 30mph and then keep a 'watching brief' until security staff arrived. This would be useful in detecting false alarms.

Urban area use, for local goods delivery and public transport

This topic is a separate subject. However it is possible to envisage a giant framework built at height, with numerous multi-stacked cable-reel systems in operation over a target area, using computerised auto-avoidance to prevent conflict between the layers. While only practical in a low-rise urban area, it would benefit from buildings with flat roofs to act as local drop zones. Cable reel installations in neighbouring and overlapping target areas can interact to create goods-transfer systems and even public transport, depending on the type of carriage used. It would emulate an aerial tramway-style carriage, but working in 3D. Logically, such a system could result in a passenger choosing their destination by grid-square, rather than having it predefined like a bus route.

Conclusion

Cable reel systems offer a practical solution for moving goods or people over any surface with pinpoint accuracy. They can be used to replace short-distance vehicular transport, and be powered by sustainably-sourced electricity. They can be instrumental in bringing inaccessible land into production. Cable reel transport systems can be instrumental in creating sustainable energy installations.

Once the technology is scaled up, and when cost-effective mobile systems are created, cable reel systems should change the future of transport, and in particular agriculture, as we know it.

Bibliography:

As the use of cable-reel technology for logistics is a novel concept there is no pre-existing literature.

Links to videos of the existing Skycam technology:

<http://skycam.tv.s28625.gridserver.com/about-us/> (Manufacturer website)

https://www.youtube.com/watch?v=j0K3XUqZl9w&feature=emb_rel_end (Behind the scenes)

https://www.youtube.com/watch?v=6EdvcuVD_OU (Reel operation)

<https://www.youtube.com/watch?v=zktOZvoTTI8> (How does Skycam work)

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Keywords

Cable Reel, overhead, all-terrain logistics, Intermodal, 3-dimensional



A SECURE DEPLOYMENT OF AN AUTOMATED DRONE TRANSPORT NETWORK ALONG THE MANCHESTER SHIP CANAL: CHALLENGES, RISKS AND THREATS

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1. Introduction

Unmanned Aerial Vehicles (UAVs) or drones, while initially developed for military use have expanded in application over time. Drones are now being used or experimented with as a solution for surveillance, agriculture, medical services, cinematography, 3D mapping, disaster rescue, transportation and delivery (Choudhary, et al., 2018) (Mehta, et al., 2020). The interest in the use of UAVs in logistics and delivery applications is increasing as we see more academic research and commercial investment focused on developing solutions powered by UAV technology. Google, DHL, Amazon, UPS and several startup companies are developing and testing autonomous drone delivery services. Drones present unique advantages to delivery including faster delivery and energy efficiency (Seo, et al., 2016).



Figure 1: The Manchester Ship Canal Route

The Manchester Ship Canal (MSC) is a 36 mile inland stretch of water that runs between Salford Quays and Eastham Docks connecting Manchester, Liverpool's port and the Irish Sea as shown in Figure 1. It was the birthplace of the industrial revolution in the 18th century and it could become a green and blue highway for Manchester supply based on a futuristic use of technology in the 21st century.

UAVs are aircraft that are flown without an on-board human or pilot. They are typically controlled remotely by the pilot or are programmed to operate autonomously (Mehta, et al., 2020). As shown in Figure 2, a UAV system consists of the following components:

1. *UAV*: the UAV itself consists of components such as sensors (gyro, accelerometer, etc.), a communication module, a power system and a control system (Zhi, et al., 2020).
2. *Remote Control/Ground Control Station (GCS)*: drones can be controlled using dedicated remote controllers or mobile phones. In an autonomous drone network, drones are programmed with flight paths, but still require a GCS to administer the network (Zhi, et al., 2020).
3. *Satellite*: a UAV needs to know its current position and as such requires GPS capabilities. GPS signals are received from satellites (Zhi, et al., 2020)
4. *Network infrastructure*: UAV networks are supported by WiFi or cellular network connectivity. In the case of the drone highway, drones will be connected through cellular network base stations.





Figure 2 MSC drone highway architecture

This paper focuses on analysing the security requirements and challenges of establishing a drone highway for the transport of packages along the MSC route. An analysis of the security challenges, threats and risks that would affect the deployment of a drone highway in the Manchester Ship Canal is presented along with a simulation experiment of a miniature version of the drone network.

The remainder of the paper is organised as follows: Section 2 introduces related works. In section 3, we detail the problem statement before presenting the methodology used in the research. Section 5 presents experimental analysis and details the simulation steps and requirements. A security analysis of the drone highway is introduced in Section 6 before concluding in Section 7.

2. Literature Review

This section provides a discussion of peer-reviewed works related to the security of UAV networks.

Su et al. (Su, Zhou, & Guo, 2020) consider 5G as an enabler for Beyond Line of Sight (BLOS) UAV control. The authors discuss the 5G UAV communication architecture and propose a trust evaluation scheme for UAVs using the trust threshold to filter out malicious nodes. Simulation results demonstrating the effectiveness of the proposed scheme are presented. The system includes UAV nodes, MEC (Mobile Edge Computing) nodes, a cloud platform and a secure management platform. Choudhary et al. (Choudhary, et al., 2018) discuss the challenges of the Internet of Drones (IoD) and provide a taxonomy of security attacks divided into privacy, confidentiality, integrity, availability and trust. The authors cite resource overheads, dynamic load balancing, survivability, cost of operation, throughput, performance and reliability, dynamic topologies, failure rate, efficient deployment of countermeasures and cooperation as pressing open challenges. Ossamah (Ossamah, 2020) presents an analysis of security challenges in drone services (focusing on health, military and industrial applications), threats and vulnerabilities. The security threats are correlated with the corresponding CIA parameter and impact. The paper also argues for blockchain as a solution for data security, consensus and fingerprinting and proposes a blockchain network architecture. In another blockchain-focused paper, Bera et al. (Bera, et al., 2020) discuss the challenges of applying blockchain in the 5G connected Internet of Drones. According to the authors, 5G will provide 3 main services: Management of drone traffic, BVLOS (Beyond visual line of sight) flights and sensor data transmission. A threat model is presented based on the Dolev-Yao model showing that due to the ad-hoc nature of the network, an adversary can eavesdrop, modify, insert or delete messages.

In 2020, Kim and Kang (Kim & Kang, 2020) proposed a drone security module for data encryption to protect data in transit and data at rest in UAVs. The module is wired to the flight control computer via a USB interface and encrypts control signals and telemetry data between the drone and the GCS. The module can be connected to the flight control computer, mission computer and communication device and supports key management, cryptographic operations, certificate management, authentication, and key agreement. It can be used to encrypt flight paths, GPS data and waypoints.



Kulp and Mei (Kulp & Mei, 2020) propose a framework for detecting radio frequency attacks like jamming, GPS spoofing and control channel disruption on medical delivery drones. The authors argue that any function added to a UAV not specific to delivery will add overhead i.e. more weight and additional complexity. As such, the benefits must weigh more than the drawbacks. The paper highlights the value of maintaining an audit trail of telemetry data and monitoring the stream for indicators of attack even if the attack is successful. This helps with the identification of the malicious actor, area avoidance by other drones and active monitoring. In Feng et al. paper (Feng, et al., 2018), a solution to detect drone hijacking was proposed by combining information from GPS, gyroscopes, and accelerometer. However, inaccuracies occur due to calculation and measurement errors and false positives in curve trajectory situations. The authors propose a simple hijacking detection method based on GPS and gyroscope parameters only, which overcomes the problem with accelerometers.

A secure disaster surveillance drone system was proposed (Abdallah, et al., 2019) using clusters, sensory nodes, relay nodes and a central substation, supported by UAVs communicating via the IEEE 802.11ah wireless standard. It applies data redundancy and fingerprinting to protect integrity. The authors discuss characteristics of UAV networks to consider when designing a UAV system such as limited energy, computational capability and dynamic network topology. A critical evaluation of the security and privacy challenges of the Internet of Drones was conducted by Ilgia & Everb (Ilgia & Everb, 2020). The authors discussed the security challenges including threats and attacks. Based on their research, the authors conclude that tampering, Denial of Service and control message modification are among the threats facing UAVs. They also note eavesdropping, software-based threats and signal interruptions as significant threats. They also identified WiFi attacks and GPS spoofing as low-cost attacks that can be used to maliciously access confidential information.

3. Problem Statement

While drones introduce new possibilities and enhancements to the application areas, they also introduce new risks and challenges. UAVs and the communication networks that enable them (WiFi, 4G, 5G) are vulnerable to security attacks that could lead to the failure, hijacking, diversion, modification and eavesdropping of the devices (Choudhary, et al., 2018) (Liu, et al., 2019).

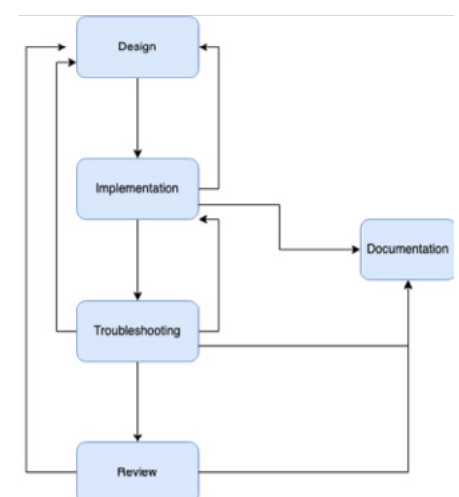
For the drone highway to be successful, it needs a security system that accounts for the vulnerabilities that exist in 5G and UAV systems. It also needs to achieve the security requirements, i.e., confidentiality, integrity and availability (C-I-A) without reducing the network performances. For instance, adding security functionalities such as attack detection techniques, can increase the communication overheads and complexity to the drone network. This underpins the need for careful consideration and prioritisation of the security functions being implemented.

4. Methodology

The simulation was conducted using NS-3, an open-source discrete-event network simulator (Nsnam, n.d.). NS-3 has several research applications including Wi-Fi, Mobile Ad-hoc Networks (MANETs), Wireless Sensor Networks (WSNs), Underwater WSNs, mobile cellular networks and UAV networks.

An Agile methodology was adopted while developing the simulation as it allows for continuous review and update of the implementation process. The iterative process to simulate the network is illustrated in Figure 3 and explained below:

- a. *Design*: the design phase entails deciding on the network parameters, nodes, configuration and simulation time.
- b. *Implementation*: the network is then implemented in NS-3 using C++ code. The implementation phase on its own is iterative as the simulation code is run several times to ensure it works as expected. Changes are made according to the code, and sometimes to the design.
- c. *Troubleshooting*: all issues that spring up from the simulation (errors, crashes, etc.) must be resolved before proceeding. Troubleshooting may lead to a change in design.
- d. *Review*: after running the simulation, the results are then collected and analysed. This may also lead to a change in design.
- e. *Documentation*: results, findings and challenges are documented throughout the process.



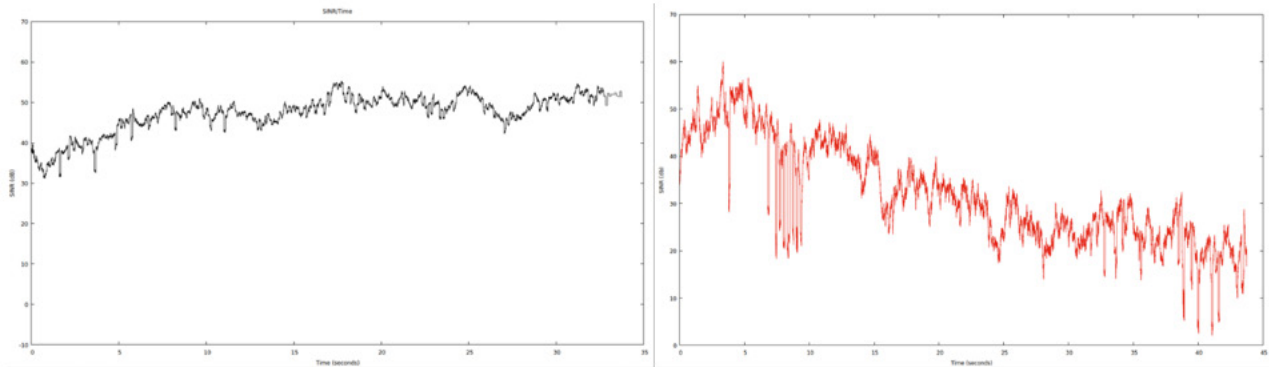
5. Experimental Analysis

The simulation was implemented using the mmWave module of NS3. MmWave is a high-frequency spectrum above 10 GHz and enables ultra-low latency communications.

The mmWave module outputs several trace files. The most relevant trace file to this research is the MmWaveSinrTime.txt which shows the Signal to Noise Ratio (SINR) values over time and is a way to measure signal quality in the network. The flow statistics were collected by configuring flow monitor (flowmon) (Nsnam, n.d.) to measure and output results. Two scenarios were recorded: one with a single UE (UAV) and another with two UEs. The purpose of these scenarios is to assess how network performance changes during mobility and with the introduction of additional nodes.

5.1. Simulation Results

The results from flowmon show a throughput of 242.20 Mbps in the downlink (GCS to UAV) and 242.27 Mbps in the uplink (UAV to GCS). There was also a mean flow delay of 343.98ms. This puts the total lost packets at 9.014667Mb for downlink 8.949851Mb for uplink. The SINR/Time data was extracted for the two mmWave cells (cells 2 and 3) as shown in Figure 4.



In the second simulation run, a second UAV node was introduced (c.f., Figure 5). The mean flow throughput and delay show that with the same infrastructure, introducing new UAV nodes affects the network performance significantly. In this scenario, the differences between the transmitted packets offered and throughput are significantly more than the 8.94 and 9.01 Mb of the previous scenarios. There is a mean flow delay of 577.11 milliseconds, a major increase from the 343.98 of the first scenario. Unless mitigated, the network throughput and SINR are expected to decrease when the network is under attack. These results show that there is enough throughput to support the drones. However, the delay increases when more nodes are introduced. The 5G-only simulation has an extremely low delay of 11.8ms compared to the dual connectivity setup which ranged between 300-600ms. Furthermore, there is a significantly lower loss as the difference between the transmitted bytes and the throughput is less than 1 megabit. While the dual connectivity looks viable, it is still nowhere near the performance of the full 5G implementation.

5.2. Simulation Requirements

In this paper, we have introduced a simulation of the proposed drone highway, however, few requirements need to be fulfilled in order to create a full simulation that imitates the real-world highway when developed. In the following, we discuss these requirements:

1. *Node placement and mobility*: Evolved Node B (eNB) nodes should be placed in a similar fashion to the current real-world setup. This will ensure that the results will be closer to a real setup. UAV nodes should be positioned at the same height that they would fly in the real world. A custom mobility model might be needed to accurately simulate the UAVs' flight pattern including take-off, acceleration, deceleration, altitude adjustment and landing.
2. *Buildings*: since the MSC route runs through an urban area, buildings are an important factor of the simulation. Particularly, it would be interesting to explore the effects of path loss and obstructions on UAVs versus ground users.
3. *Route and No-Fly-Zone avoidance*: the route would need to be implemented with its curves – and importantly, a diversion to avoid the Liverpool John Lennon airport. This is to prevent collision with manned aircraft.
4. *Secondary User Equipment (UE)*: the full simulation needs to account for other User Equipment in the area. This includes mobile network users in buildings and on roads. A 1:1 replication is not feasible, but accounting for this factor should lead to more accurate results.



5. *Custom applications*: custom applications (extending the NS-3 Application class) will need to be developed for UAV-specific functions. Examples are mission control and coordination with neighbour nodes.
6. *Primary cell (Long Term Evolution LTE) handover*: given the high mobility nature of a drone highway, handover is a key part of the system. Primary LTE cell handover needs to be simulated. This would require an extension of the dual-connectivity feature of the mmWave module.

6. Security Analysis

6.1. Threats

In this paper, we use Persona non Grata (PnG) as a threat modelling method (TMM) focusing on user archetypes who exhibit unwanted or nefarious behaviour (Mead, et al., 2018). The motivations, abilities and actions of attackers are considered, along with any attack vectors that could enable them.

Recently, an Anti-5G movement has appeared and therefore it is the PnG that is most likely to specifically target the drone highway. There is a rising anti-5G movement across Europe including the UK fueled by 5G and COVID-19 conspiracy theories and other forms of misinformation (Cerulus, 2020) (Mukena, 2020). These groups have been attacking 5G infrastructure by torching masts and harassing telecom engineers (Cerulus, 2020) (BBC, 2020). A 5G-enabled drone highway is a highly likely target for this threat actor group. They can do a lot of damage and garner media attention for “disrupting the new drone highway”.

Furthermore, drones have been attacked using low-cost toy laser guns by protesters in Chile (Boyd, 2019). The adversaries have low-cost tools that can be used to disrupt drones. All PnGs have the potential to directly or indirectly cause financial loss. Even if an attack does not cause loss of cargo or drones, any failed mission is a potential financial loss. Organised cybercrime gangs are mostly after financial gain. With ransomware being the new trend and the rise of ransomware gangs (Security Boulevard, 2021), the drone highway would be an attractive target for such campaigns. Similarly, malicious hackers and drone/package thieves can exploit vulnerabilities or physically attack UAVs for financial gain. Insiders (malicious or non-malicious) also need to be considered as possible threats due to their access to systems and information.

Additionally, various security risks have been identified such as jamming attacks, data exfiltration, spoofing and data tampering. In the following section, we propose countermeasures against these attacks.

6.2. Security Countermeasures

Technical, operational and administrative controls were recommended for each of the threats. The controls are aimed at reducing the likelihood and/or severity of a risk.

1. *Anti-jamming techniques*: implementation of anti-jamming countermeasures is needed to protect the drone highway. Research by Liu et al (Liu, et al., 2019) demonstrates an effective technique against both jamming and eavesdropping. This control can also help defend against malicious hackers.
2. *Anti-spoofing*: spoofing is a security attack that enables an attacker to pretend to be a trusted user to access sensitive information. Anti-spoofing methods for GPS have been developed in recent research. A framework (Kulp & Mei, 2020), which has been developed specifically to protect medical delivery drones, can be applied here.
3. *Access control*: least privilege, segregation of duties and robust access control mechanisms should be implemented to limit the damage of deliberate and accidental privilege misuse.
4. *GCS cyber defence*: perimeter security and data loss prevention techniques should be in place at the GCS. A security framework or information security management system with clear security policies should also be implemented.
5. *Network segmentation*: in addition to GCS cyber defence techniques, the drone network should be segmented from public networks as much as possible. This will limit the attack surface for malicious hackers.
6. *Informational campaigns*: anti-disinformation campaigns should be run in the areas surrounding the MSC. People should be educated about the benefits of the drone highway with transparency even before deployment. This should reduce hostile sentiment and reduce the likelihood of such attacks. Of course, the environment should also be monitored for any potential hostilities; new controls can be deployed to contain threats as they spring up.
7. *Physical security*: the GCS and other drone highway infrastructure should have physical security controls to prevent, deter or detect physical breaches. However, the 5G infrastructure also needs to be protected. Since they are under the control of other entities, cooperation with them will be paramount.



6.3. Trade-offs

For the drone highway to be successful, it needs a security system that accounts for the vulnerabilities that exist in 5G and UAV systems. It also needs to consider the CIA-tradeoffs. Confidentiality and integrity can be supported by cryptographic techniques. However, these security techniques are battery-consuming techniques which present a challenge to availability. This also leaves the drones more vulnerable to resource depletion attacks. This is further highlighted in the research by Ozmen and Yavuz (Ozmen & Yavuz, 2018) where the key size adds a significant memory overhead to the UAV. Furthermore, different scenarios and cargo types may require different security setups. For example, when delivering medical supplies, availability will have to be prioritised above all else as the mission is highly time sensitive. However, integrity and authentication have an influence on availability as spoofed identities or messages can disrupt the mission itself. In essence, when it comes to a drone network, the C-I-A requirements tend to work in tandem.

7. Conclusion

The main challenges that make UAVs susceptible to security attacks are resource constraints, open wireless communications, sensors and reliance on unencrypted GPS services. These constitute vulnerabilities to the drone highway that threat actors can exploit. In the risk assessment, the threats (Personae non Gratae) that were identified as posing the greatest risks are anti-5G groups, drone pirates/thieves and human error by privileged non-malicious insiders administrating the system.

Techniques such as GPS spoofing, eavesdropping, signal jamming and sensor manipulation can be used by attackers to disrupt operations or hijack drones. Some controls were recommended for the risks such as anti-jamming schemes, anti-spoofing techniques, network segmentation, access controls, and anti-disinformation campaigns. However, there are some trade-offs between confidentiality, integrity and availability since any security functionality adds an overhead to the drone. Security mechanisms must be well balanced and consider the context. The simulation results show that while the 3GPP Non-Standalone Architecture or 4G-5G dual connectivity looks viable for the drone highway, the performance is still far behind what is offered by the full 5G implementation. However, the results are limited to two UAVs and may vary if the network size is increased. A full simulation would require more computing resources, time and a custom solution built to support handover between 4G primary cells.

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LOGISTICS DECARBONISATION



ON-SITE PV GENERATION TO SUPPORT LOCAL FLEET VEHICLE CHARGING

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Introduction

Continued population growth has led to an increase in greenhouse gas (GHG) emissions globally from the transport sector. As a consequence, this has been a significant impact on urban air quality, and this is now a major concern driving global process towards the decarbonisation of this sector. In particular, the United Kingdom has set very ambitious targets to achieve net-zero emissions by 2050 (CCC, 2019) that will transform the transportation sector. Local authorities are also taking leadership in the response to the Climate Crisis by introducing policies to establish Clean Air Zones (CAZ) and Low Emission Zones (LEZ) in major UK towns and cities (Ballantyne & Heron, 2020). Road freight transport, and particularly commercial fleets, are the main focus of many CAZ policies that encourage the adoption of cleaner emission vehicles to improve air quality.

In general, electrification of fleet vehicle is seen as a potential solution for decarbonisation of freight transport. Switching conventional vehicles to EVs could help not only to reduce the GHG emissions at the tail pipe, but also contribute to meeting the zero-net target for 2050 and improve air quality in urban centres. In this regard, as it has been pointed out by Breuer et al., (2021) that the electricity to charge the fleet must come from renewable energies to completely avoid GHG emissions. Prior to Breuer et al., (2021), other authors have brought to light the importance of taking the electrification of transport and the production of electricity from renewable energies as a whole system (Saber and Venayagamoorthy, 2011; Keller et al., 2019; Calvillo and Turner, 2020). Additionally, it has been proven that the grid network could be highly affected by the penetration of EVs due to the high demand at peak times, causing thermal stress and voltage deviation (Hu et al., 2019) thus requiring significant infrastructure investment to upgrade the existing grid supply in the UK.

In line with this, the purpose of this research is to explore the feasibility of localised solar energy generation for EV fleet charging. Specifically, this paper considers two different commercial premises to evaluate mass EV charging opportunities, a food store, and a warehouse, in the region of South-Yorkshire, UK.

Literature Review

Nowadays, and despite the estimated impact that the coronavirus (COVID-19) pandemic has had in the reductions of GHG emissions, the transport sector continues to be the highest GHG emitter in the United Kingdom (BEIS, 2021). Furthermore, in the last 10 years, emissions from the transport sector have only been reduced by 3% (DfT, 2021). Within this context, road freight transport plays an important role not only due to its GHG emissions but also because of its negative impact on air quality. Heavy goods vehicles (HGVs) and light goods vehicles (LGVs) are estimated to account for around 44% of total road transport NOx emissions (DfT, 2020), while making up just 5% and 16% of vehicles miles, respectively (DfT, 2021).

The road freight transport sector is the main target under many CAZ and LEZ policies. According to a recent study from Solomon et al., (2019), pressure exerted from regulatory policies directly impacts the promotion of greener freight transportation. Rizet et al., (2016) showed the effectiveness that a LEZ could have in Paris, with 57% to 60% of CO2 emission reductions. However, freight transport fleets are not always ready for the transition and therefore, the rapid introduction of regulatory measures (i.e. LEZ) can have negative impacts (Settey et al., 2019). The road freight transport sector claims that collaboration between transport operators, local and central government, and academia is the key for a successfully transition towards more sustainable road freight transportation. mre et al., (2021) found that there is a lack of information and knowledge to evaluate the feasibility of operating electric freight vehicles. Operational needs, operational issues that may arise after switching the fleet, or what level of investment is needed, are major concerns amongst freight transport operators.

It is clear that decarbonisation of the road freight transport sector is a challenge. There is a wide range of vehicles with different uses, each with their own operational and logistics constraints. Within this context, electrification of the fleet is viewed as a potential solution to eliminate tailpipe emissions. Technological improvements of EVs and batteries along with an increased economic viability make the electrification a considerable opportunity (Carrese et al., 2021). Commercial EV fleets are more suitable to be electrified due to their operational characteristics. Commercial fleets are mainly made of light commercial vehicles (LCVs) for urban and local deliveries that usually require stop-and-go short distance routes, making them prime candidates for this technology. Improvements seen in recent years regarding the



growing range, and reduced charging time and purchase price of EV vans are drivers for commercial fleet electrification (Schücking and Jochem, 2021). For commercial fleets, the limited driving range could be less problematic having an efficient scheduled charging periods overnight (Mre et al., 2021), considering that the average daily distance travelled by a commercial EV is below the range of EV van models in the current market (Ehrler et al., 2020).

The benefits of transport electrification are reduced if the electricity to charge the fleets does not come from renewable sources. The increase in the share of renewable sources on the grid network can contribute significantly to clean the road transport sector (Ensslen et al., 2017). A case study based on Germany of a food retailing industry showed that GHG emission would be reduced approximately 96% if EVs would be charged completely from renewable sources, whereas if the energy comes from the standard sources, the reduction is around 26%, when compared to conventional vehicles (Martins-Turner et al., 2020).

Now that it has been demonstrated that urban logistics can benefit from fleet electrification (Jahn et al., 2021), transport operators concern focus on how to adapt their operations to EV fleets. According to Pelletier et al., (2016) commercial EV fleets are mostly charged at a depot overnight. Nevertheless, charging infrastructure availability is a major barrier for fleet operators specially when power grid capacity does not meet EV fleet charging demand during the off-hours at the depot (Quak et al., 2016).

This paper aims to quantitatively assess the on-site PV generation to charge commercial EV fleets locally and evaluate its feasibility to offset energy grid dependency within the premises. It also explores other key aspects of transitioning towards commercial fleet electrification, such as estimated potential GHG emissions savings and payback time of the technology (i.e. PV panels and BESS). These aims are achieved through use of a PV solar model that models solar radiation at the specified location and the corresponding energy generation, using battery energy storage system (BESS).

The assessment produced by this paper, in alignment with the UK government's plan to tackle climate change, will open new opportunities for commercial fleet operators by providing significant information and context in the adoption of on-site PV generation for mass EV fleet charging at a commercial depot.

Methodology

Solar energy generation modelling

The solar energy generation has been estimated using a PV solar model developed by the authors of this study. The model was developed using MATLAB and calculates the energy generated at a specific latitude and longitude from input data pertaining to solar radiation measurements. The model includes a BESS to minimise the effect of PV power fluctuations and reduce the dependency on the grid.

The assumptions for the integration of the on-site PV generation and EV fleet mass charging can be seen in Figure 1 and will be described here. The model seeks to reduce as much as possible the dependency on the grid for meeting the building and EV fleet charging demands. The dashed square in Figure 1 denotes the scenario in which the EV fleet charging is likely to take place. This is because overnight, in the premises that are analysed in this paper, when the EV fleet is charged, the solar energy generation is lower than the hourly building demand.

So, when the on-site PV generation is greater than the building energy demand, this is covered exclusively from the on-site PV generation. The solar energy surplus is sold to the grid if the BESS is full. If not, the PV solar surplus is stored at the BESS. When the on-site PV generation does not meet the building energy demand, if the BESS is empty, then the grid is used to cover the energy building demand that has not been met by the on-site PV generation. If the BESS is not empty, then it is used to cover the building energy demand. Once the demand of the building is covered, if there is still energy stored at the BESS and there is a demand of energy from the EV fleet, this is covered by the BESS. If there is not enough energy stored at the BESS, then the grid provides the rest of the energy required to meet the EV fleet demand.



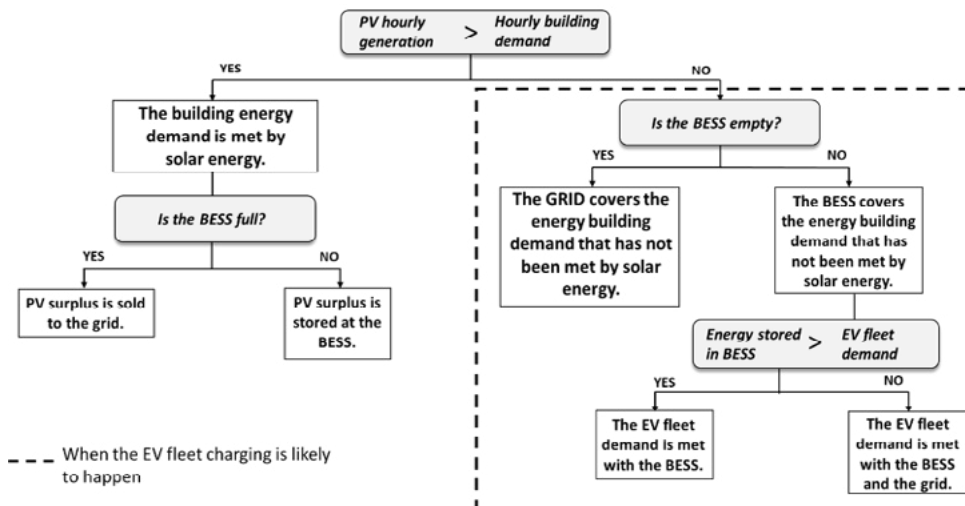


Figure 1. Model assumptions for On-site PV generation and commercial EV fleet mass charging at depot.

Scenarios

Two fictitious commercial premises located in the South Yorkshire area are analysed, a food store and a warehouse. The EV van model selected for this study is a Mercedes-Benz eSprinter with a gross vehicle weight of 3.5 tonnes. The battery capacity of the EV van is 55 kWh with an energy consumption between 30.9–36.5 kWh/100km. It is assumed that all the EV vans in the fleet require a full charge of the battery overnight.

1. Food store: The building characteristics can be seen in Table 1. The annual consumption assumed for the building has been obtained from the study conducted by Kolokotroni et al., (2019). In this study, 593 food stores in the UK were investigated.
2. Warehouse: In this case, the building is double the size of the food store, as can be seen in Table 1. The energy intensity used was obtained from BEIS, (2020b). The EV fleet has the same number of vans that the food store and are charged overnight during the same time period.

	Scenario 1: Food Store	Scenario 2: Warehouse
Building size (m ²)	12,000	24,000
Energy intensity (kWh/m ²)	329	30
N° of PV panels	3,500	1,500
Annual on-site PV energy generation (kWh)	928,440	397,900
EV fleet size	6	6
EV fleet charging time (hours)	22:00–06:00	22:00–06:00

Table 1. Characteristics of the food store and the warehouse investigated in the study.

Analysis

The commercial buildings are to be analysed in terms of dependency reduction from the grid, GHG emission reductions and payback time. They will be compared with the baseline scenarios, which correspond to the buildings without on-site PV generation.

Grid dependency. The percentage decrease of grid dependency is calculated following Equation 1.

$$\% \text{ Decrease} = \frac{\text{Energy from the grid without solar} - \text{Energy from the grid with solar}}{\text{Energy from the grid without solar}} \cdot 100$$

Equation 1

Emission reductions: The estimated annual emissions savings has been obtained assuming the following impacts. For the photovoltaic energy, an impact factor of 74 gCO₂eq/kWh is used (De Wild-Scholten et al., 2014). And for the electricity from the grid, an impact factor of 233 gCO₂eq/kWh from the is used, as per year 2020 (BEIS, 2020a).



The surplus energy is sold to the grid, where it avoids the need to generate electricity by higher-carbon intensive sources, because of this it receives a credit equivalent to that of the grid mix impact.

The payback time for each scenario has been calculated following Equation 2.

$$\text{Payback time (years)} = \frac{\text{Total capital cost}}{\text{Annual savings} - \text{Annual maintenance}}$$

Equation 2

The capital cost and maintenance are linked to the PV installation and the BESS system. The annual savings corresponds to the difference in cost between the electricity cost from the grid without and with an on-site PV installation. The payback time thus only evaluates the on-site PV installation and BESS.

Results

Scenario 1: Food Store

The model compares different BESS capacities to select the optimum, that balances higher emissions reduction and lower payback time. The results are displayed in Figure 2. As it can be seen, the annual GHG emissions savings are very similar with increasing BESS capacity. Because of the capital costs of the BESS, the payback time increases with increased BESS capacity. However, the emissions are not further reduced, this can be explained by the building energy consumption.

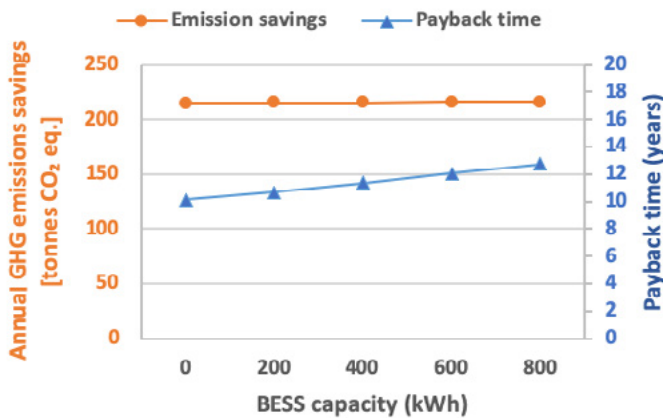


Figure 2. GHG emission reduction and payback time for the food store.

The annual energy consumption for the commercial building is shown in Figure 3, with and without on-site PV generation. When the PV installation is in place, regardless of the BESS capacity, the energy consumption from the grid is decreased. However, for this installation, the energy demand of the building is never fully covered by the PV installation, it only reduces its dependency on the grid by 24%. Therefore, there is no surplus solar energy available to charge the EV fleet, and little to no incentive for installing a battery storage for this application.

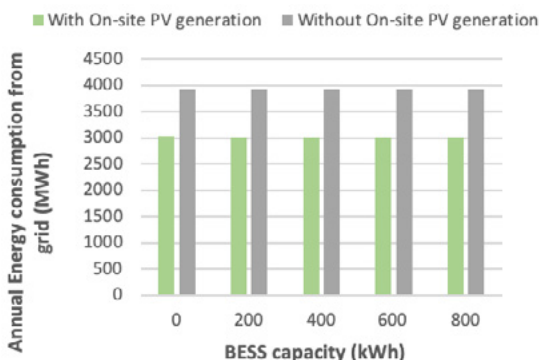


Figure 3. Annual energy consumption from the grid for the food store, with and without on-site PV generation.

The energy intensity (kWh/m²) in food stores is high when compared to other retail buildings. This is linked to the increased energy consumption for refrigeration of certain types of food (Kolokotroni et al., 2019). With a similar PV installation, the dependency on the grid will be lower in other types of buildings. To verify this, a warehouse is studied.



Scenario 2: Warehouse

The warehouse has a smaller on-site PV installation because the energy demand is also lower than for the food store, despite having double the building area. The GHG emissions reduction and payback time are shown in Figure 4.

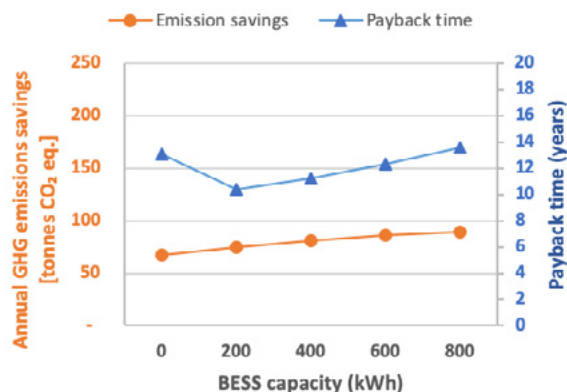


Figure 4. GHG emissions reduction and payback time for the warehouse.

The annual GHG emissions savings increase with increased BESS capacity. The largest GHG emission savings are linked to the reduction of grid mix electricity consumption and the increase in BESS capacity. Because the warehouse has a much smaller energy consumption, the PV installation in this case can better support the energy demand of the building, while also having a surplus at certain times of the day and year to charge the battery, and this in turn could supply the EV fleet, over and above the building demand. The surplus generated in this installation is responsible for the decrease in payback time when a BESS is used, as it will reduce the electricity consumption from the grid, both for the building and the EV fleet (i.e. with a BESS capacity of 200 kWh).

The energy consumption from the grid in the warehouse, shown in Figure 5, is significantly reduced both for the building (46% of reduction) and for the EV fleet (11%) when there is a PV installation in place and a BESS with a capacity of 800 kWh. A BESS capacity of 800 kWh is considered the optimum installation, because it provides the largest GHG emissions saving without significantly increasing the payback time.

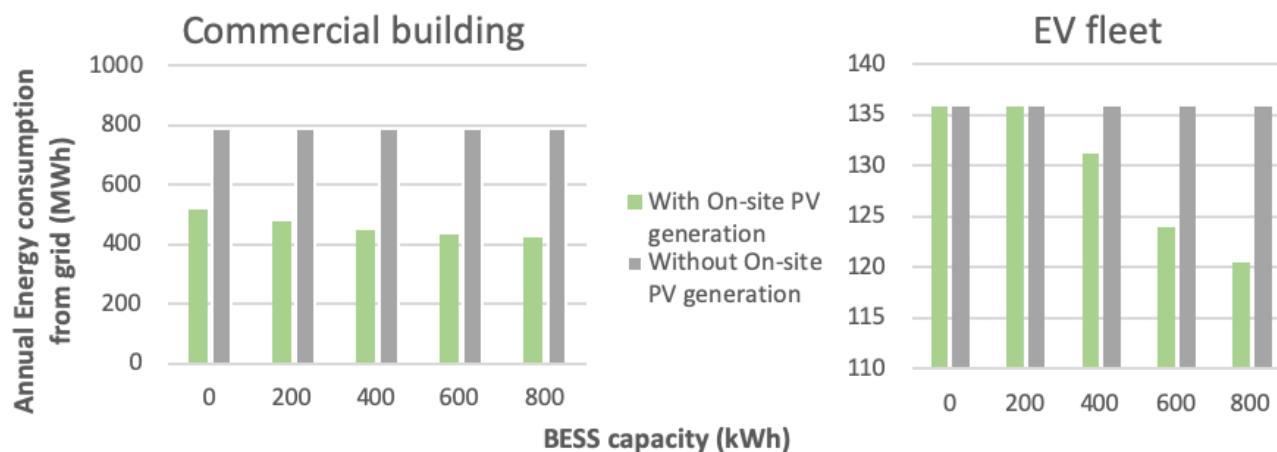


Figure 5. Annual energy consumption from the grid for the commercial building (left) and on the EV fleet (right) in the warehouse, with and without on-site PV generation.

This is a significant difference with the food store, where there was no incentive to install a BESS. In this case, for the warehouse and its relatively reduced energy consumption, the installation of a BESS would be useful in reducing the grid dependency of the EV fleet as well as the building. Furthermore, if the number of PV panels installed are increased to the maximum capability (i.e. 12,000 PV panels), the annual dependency from the grid both for the building and for the EV fleet would be further reduced, 77% and 46%, respectively. However, the payback time would rise to 28 years.



Conclusions

The reduction in dependency from the grid is greater for the warehouse than for the food store when the on-site PV installation with BESS is adopted. This is the case even though the area of the warehouse is double the area of the food store studied and it is linked to the reduced energy consumption per unit area. In the food store, the solar energy goes directly to the building leaving no surplus to charge the EV fleet, that is completely dependent on the grid. Thus, in this scenario, having a PV installation would not reduce the emissions of the EV fleet if compared with the scenario in which the electricity to charge the EV fleet comes from the grid.

With an on-site PV installation at a warehouse, the payback time increases slightly but the dependency on the grid and the annual emissions are halved when compared to the food store. In addition, in the warehouse, the EV fleet stops being fully dependent on the grid. If the number of PV panels were increased for the warehouse, the dependency of the EV fleet on the grid would be further reduced. According to the results in this study, this type of building could benefit from an on-site PV installation with BESS for EV fleet mass charging.

It should be noted that the well-to-wheel (WTW) impact of the EV fleet has not been analysed in this study. However, if the EV fleet is charged at the warehouse, the WTW impact would be lower when compared to charging at the food store. This is because the warehouse has a BESS greater than 200 kWh, and part of the demand of the EV fleet is covered by solar energy. In both scenarios, even if only the grid is used to charge the fleet, the adoption of an EV fleet seems to be beneficial when the WTW impact is considered if compared with an ICEVs fleet (EEA, 2018). The highest impact from both types of fleets, EVs or ICEVs, comes from the use phase. Thus, the greater the use of renewable energy to charge the EV fleet, the lower the impact of the EV fleet.

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FOSSIL-FREE FUELS FOR FREIGHT AND LOGISTICS: A LITERATURE-BASED STUDY

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Introduction

Business trends mirror the requirements of customers and development of technology of the current age. The growing awareness of the impact human activities have on the environment has led customers, businesses, and governments to shift mindset resulting in changes in market trends, business operations and government involvement as described in European Commission's 2018 report A Clean Planet for All (European Commission, 2018). In the supply chain context, the increase of logistical activity has increased dramatically with the globalization of economies thereby increasing stress for creating and implementing sustainable business practices across all actors within the logistics industry (Centobelli et al., 2017). In the European Union, road transportation is consistently responsible for the majority of the transportation industry's environmentally negative effects (ie CO₂ emissions, material waste), so stakeholders have focused on methods to minimize these effects (Pieters et al., 2012). These methods have been labelled differently over time but have lately been referred to as Green Logistics Practices (GLPs) (Jazairy & von Haartman, 2020). Although the climate challenges may take center stage in certain debates, GLPs promote a wider understanding of environmental sustainability.

Transportation is still reliant on fossil fuels. As stakeholder opinions change, abandoning fossil fuels for fossil-free fuels is of particular interest in creating environmentally sustainable supply chains (European Commission, 2018). The purpose of this study is to summarize the research currently represented in published literature discussing green practice options in freight transport and logistics exploring the possible implementation of fossil-free fuels.

With this background and current challenge, the researchers posed the following research questions:

- (RQ1) Which GLPs are used and suggested for designing more environmentally sustainable logistics systems?
- (RQ2) Based on the identified GLPs in literature which challenges, and opportunities lie in the use of fossil-free fuels for increasing the environmental sustainability of freight transport?

The remainder of the paper structure is as follows: methods, an overview of the literature group, a literature analysis, discussion including interviews to aid in beginning to understand the challenge(s) discovered in the literature and conclusions with suggestions for future research.

Methods

A mixed-method approach was applied to answer the RQs. The researchers began by conducting a systematic literature review to understand the research landscape and gain a better grasp of the challenges in the field. After an analysis of the literature, the researchers were not able to respond entirely the research questions so additional information was gathered from interviews.

While rigorous in structure, the results of a systematic literature review enable researchers to confidently describe the current research and justify that knowledge is missing. The researchers chose to follow the six steps designed by Durach et al. (2017), as visually displayed in Figure 1, to structure the process. Inclusion and exclusion criteria (Table 1) were applied to streamline the literature selection resulting in the final collection of literature. The following search string was compiled and performed in Scopus in March 2021:



TITLE-ABS (freight OR transport) AND TITLE-ABS-KEY (transition* OR adopt* OR shift* OR challeng* OR drive* OR motivat* OR implement* OR enact* OR switch*) AND TITLE-ABS (sustain* OR green OR environment* AND logistics)

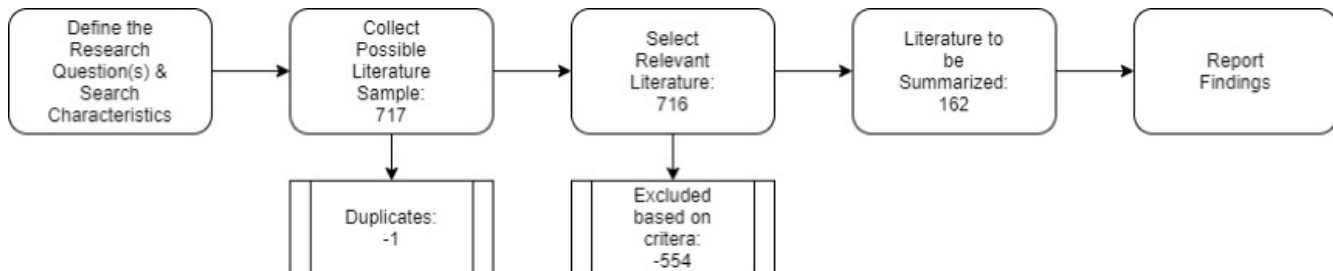


Figure 1 Six Steps of a SLR & literature selection progression (Durach et al., 2017)

Inclusion	Exclusion
Peer-edited journal articles	Documents and reports from governments or organizations that have not been peer-edited
Articles written in English	Articles written in other languages
Studies focusing on actions and practices to create more environmentally sustainable freight transport	Studies focusing on humanitarian logistics, food perishability, tourism, public health, agriculture, passenger vehicles and public transportation, city and urban planning

Table 1 Literature Inclusion & Exclusion Criteria

The findings of the articles were categorized into 4 different categories of GLPs, inspired by (Castelein et al, 2019), and was the result of iterations between the authors. Each category was analyzed separately, responding to RQ1. Biomethane was chosen as a focal alternative fuel due to its regional importance for the research group located in East Sweden and the research group's conjoining project. To support that discussion, two exploratory, semi-structured interviews were held with stakeholders. The interview results were discussed among the researchers and analyzed in relation to a wide range of GLPs as well as a supply chain context, in response to RQ2.

Literature Overview

Literature Landscape

The 162 articles included from the literature search span a period of 25 years displaying spurges in publications correlating with the dates of international climate summits such as the Kyoto Protocol and Paris Climate Accord. Most of the articles were published between 2016 and 2020. While there is research representing all continents, Europe is the largest contributing continent.

Methods Utilized

Both qualitative and quantitative studies are represented in the literature sample. This broad range of methodology enables a multitude of topics, viewpoints, and results to be reported, allowing the researchers to understand the problem on a deeper level. Case studies and simulations were the most common methods utilized. The methods differ among the case studies with the majority as multi-case studies. Literature reviews hold a good representation in the sampled literature. Two included literature reviews discuss alternative fuels but from the producers' perspective (Gold & Seuring, 2010; Roddy, 2013), none of the found literature reviews investigate implementation and subsequent challenges of fossil-free fuels in the supply chain.

Literature Analysis on GLPs and Fossil-Free Fuel

Green Logistical Practices

Four groups form each to be discussed at a greater detail. Formation of these practice groups stem from their function or actor enforcement. The four groups are as follows: Business Strategies, Logistics System, Social, and Energy & Emissions.

Business Strategy GLPs: The GLPs allotted in this group have the main purpose to promote a more successful overall business with the unintended benefit of creating a more sustainable system. These practices can be broken down further into two smaller groups: Competencies and Business Models and Tools.

Competencies: These GLPs lean towards the service provided to their customers, managing the customer relationship and brand promotion with a sustainability perspective.



- Competencies and collaborate experience (Sallnäs & Huge-Brodin, 2018)
- Conducting Research on target market (Rakhmangulov et al., 2018).
- Sustainable pricing and labor management (Kumar et al., 2017)
- Workplace culture and support (Rodrigues & Kumar, 2019).

Business Models and Tools: As more businesses are moving towards more environmentally friendly business practices, trends of certain models and tools aiding businesses to create more sustainable business performance have emerged.

- Just-In-Time and Lean practices (Rodrigues & Kumar, 2019)
- 4PL (Mehmann & Teuteberg, 2016)
- Circular Economy and sharing economy business models (Khandelwal, 2020)
- Logistics Performance Indices (LPI) (Anser et al., 2020).
- Decision Support Systems (DSS) (Qaiser et al., 2017)

Logistics System GLPs: The practices included in this category target one or multiple aspects of the logistics system with the goal of creating a holistically more productive system while reducing its environmental impact. Three subcategories have been identified within this group, each of which will be discussed further: Modes & Vehicles, Infrastructure & System Design, and Minimization & Optimization.

Modes & Vehicles: These practices either encourage a modal change or adjustments in the transport vehicles attempts of reinventing certain modes to become greener.

- Investigation into efficiency of dry ports (Demir et al., 2019).
- Truck Platooning (Pajk & Cyplik, 2020).
- Longer Heavier vehicles (Rodrigues et al., 2015)
- Drones (Kirschstein, 2020).

Infrastructure & System Design: GLPs that fall into this category change or modify an aspect of the current infrastructure or network design.

- General Modernization of existing infrastructure (Kayikci, 2021)
- Freight villages and inland container terminals (Merlak et al., 2019)
- Reverse logistics and centralized logistics (Yuchi et al., 2019)

Minimization & Optimization: This category addresses the practices that concern methods in which the transport mode utilized can be minimized or optimized in some manner.

- Route optimization (Zhu et al., 2014)
- Horizontal collaborations/ Pooling (Tiwari et al., 2021)
- Crowdfunding (Gatta et al., 2018)

Social GLPs: These practices are put into effect by actors that typically have little supply chain knowledge and are connected to a separate larger body such as government or international legislation. The two practices categorized as Social GLPs are: Policies and Taxation.

Policies: The focus of many policies is the greenification of road transport.

- Reluctancy to adopt policies (Jaller et al., 2019)
- Trend of addressing private or public transportation (Stelling, 2014)

Taxation: As taxation is typically included in the enactment of policies, little is researched about the role of taxation in the efforts of creating more sustainable logistics practice norms making it difficult to separate the two.

- Alignment of taxes across the supply chain (Henkow & Norrman, 2011)



Energy & Emissions GLPs: Practices included in this category have the goal of minimizing emissions emitted and introducing a long-term sustainable manner to conduct business. Many of these practices are a result of technical or innovative progression of previously discussed GLPs. Three subgroups have emerged and will be discussed further: Overall System Solutions, Mode Specific Solutions, and Alternative Fuel Sources.

Overall System Solutions: Practices that lie in this group attempt to bring attention towards the importance of decreasing pollution, conserving energy and decarbonizing logistical activities.

- Propose strategy or models rather than concrete solutions (Vasiliauskas et al., 2013)
- Carbon Emission Reports (Kalenioja et al., 2011)

Mode Specific Solutions: Every mode utilized in transport carries advantages and disadvantages to its use, these practices attempt to maximize advantages while minimizing disadvantages.

- Low carbon emitting vehicles (Dioha & Kumar, 2020)
- Greener road transport highlighted (Athena et al., 2014)

Alternative Fuel Sources: Over the years, research has provided multiple alternatives to fossil fuels. These practices are investigations into which fuels can successfully replace fossil fuels on in the transport industry.

- Sustainable jet fuel (SJF) (Smith et al., 2017)
- Wind powered electricity (Poulsen & Hasager, 2016)
- Electrification of fleet (Watrobski et al., 2017)
- Bio-based fuels i.e. biomass, torrefied biomass, biogas/biomethane (Crawford et al., 2016; Rehl & Müller, 2011; Thrän et al., 2016)

Among the GLPs mentioned above, the last group addresses the fuel question directly, and the results mirror the relatively low interest for this question in earlier research. Albeit the question of fossil-free fuels - as any other part of the logistics system - cannot fully be understood in isolation. Other GLPs are closely or indirectly connected to the fuel-issue, which will be addressed below.

Discussion

Fossil-free fuels is discussed in many forms, most commonly, the electrification of transports. However, the interviewed stakeholders agree that we will need to use all available sources to replace fossil fuels. Biomethane is an alternative fuel created through the anerobic digestion and refining of organic waste of farms, fisheries, paper mills and households. The broad potential for possible sources from which biomethane may be produced allows for regions despite climate and population density to implement biomethane (Ersson et al., 2013). The Swedish government announced an initiative of a vehicle fleet independent of fossil-fuels by 2030 as part of the country's larger 2050 carbon neutrality goal which run parallel to the European Union's targets allowing for the already existing biomethane industry to expand (European Commission, 2018). Östergötland county has been at the forefront of Sweden's shift to fossil-free fuels with multiple biomethane plants and large agricultural sector as organic input for these plants (Ersson et al., 2013).

Two interviews were conducted with high-level managers from two companies located in Östergötland: a publicly owned forwarder and governmentally owned producer of biomethane. The interview focused around the GLP categories previously mentioned, to deepen understanding GLP choice of the organizations, proposing biomethane as a possible industry-wide solution. Both participants speculated over future energy options for the transport sector and three major topics arose: Market Trends, Sustainable Actions and Biomethane.

Market Trends: Despite working with different clientele, the two organizations see similar trends in service demands. Stakeholders, whether haulers, local government, or final consumers, demand greener transport and the use of fossil-free fuels. The motivation and extent of the sustainable requests vary. Regardless, the demand exists forcing businesses to change behavior and method (Dai et al., 2021). Large vehicle manufactures have announced that they will stop producing cars driven on fossil fuels signaling that the market and mindset has changed forcing consumers to switch.

Sustainable Actions: Comparisons and predictions of electric, hydrogen and biogas fueled vehicles were made. While electric vehicles take center stage in media and amongst politicians as the green alternative for the future, both interviewees agreed that while electric vehicles aid in reducing carbon emissions their use may not be suited for all sorts of transport. Electric vehicles are best suited for last-mile and passenger transport, biomethane or hydrogen-fueled vehicles are best for long-haul freight transport (Skytte et al., 2017). Switching as an industry to a greener fuel source will take time and resources that currently are not accounted for at the level in which they should.



Biomethane: The biomethane provider sets a price for the fuel based on production cost. During the pandemic, other fuel prices fluctuated greatly causing financial issues for transporters. The set price and source of biomethane would allow businesses to accurately determine prices offering the quality service regardless of fuel price. Competencies and infrastructure still lack in biomethane provision system (Franco et al., 2021). The utilization of biomethane is broad and not limited to transport vehicles but can replace fuel in industrial machines allowing for a supply chain network switch to greener energy.

The two organizations interviewed has created a workplace culture that supports moving towards greener business practices through creating organizational missions and sense of a common goal. Similarly, the biomethane producer has been successful in engaging households that produce organic waste that later becomes biomethane as a contributor towards a greener community and participant in a circular economy. Adoption of fossil-free fuels requires adjustments in infrastructure, among the possible fuel alternatives biomethane may require the fewest changes to the existing system.

Conclusions & Future Research

Responding to RQ1, the literature review identifies four major groups of GLPs. The Energy & Emissions GLP group is more progressive in tactic and innovation compared to the other groups. These practices inspire companies to enable a reduction of carbon emissions pushing towards climate neutral goals from multiple governing bodies. While the implementation of these practices yields less carbon emission, the costs of implementation are great.

Responding to RQ2, the literature review revealed few examples of fossil-free fuels among the GLPS. The semi-structured interviews revealed knowledge and infrastructure costs of switching entire systems to fossil-free fuels, such as biomethane, are among the highest. As organizations move towards these practices on a large-scale, these high switching costs can be interpreted as beneficial long-term investments. Marketing, customer service and efficient supply chains are marked as important competency for the development of biomethane.

This literature review and complementary interview study provides both managerial and research implications. From a managerial point of view, this research begins to identify the challenges in introducing and implementing fossil-free fuels, as that relates to many different GLPs. More research is required to go deeper into each facet of implementation preferably amongst different geo-political situations as this study is based in Sweden. This study collects and attempts to bring clarification to the different GLPs allowing researchers to understand the status of research in the field. Future research may include further investigation into switching costs and logistics network design post-biomethane adoption. In future research the green bullwhip effect may aid in analysis, displaying the magnitude of different stakeholder pressures (Michel et al., 2016).

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OCEAN LOGISTICS: PEOPLE, PROCESSES, TECHNOLOGIES AND THE ENVIRONMENT



5G ENABLED FREE PORTS: A CONCEPTUAL FRAMEWORK

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Abstract

This paper proposes a conceptual framework that depicts a generic freeport model underpinned by 5G technology. The framework is based on the early findings from a 5G testbed and secondary 5G use cases from both practice and academia. The current state of a UK port was established which forms the basis for the conceptual articulation of the 5G enabled freeport concept. Following this a 5G-enabled freeport protocol was developed, outlining the underlying areas where 5G can add value. Our research is one of a few early academic studies that offer valuable insights about the application and impact of 5G on port operations and its implications for freeports. Our research also has important policy implications, given the UK government's recent announcement and roll out of eight freeports across the UK.

1. Introduction

5G, the fifth generation of mobile telecommunications technology, is said to be a revolutionary leap forward in terms of data rates, latency, massive connectivity, network reliability, and energy efficiency, when compared with its predecessor, 4G (Shafi et al., 2017). 5G has the capacity to support innovative new services, via autonomous vehicles and smart cities, and increase efficiency through smart agriculture, factory robotics and healthcare applications such as remote surgery. The logistics and freight transport sectors are two of the industries that are actively exploring 5G's potential to improve visibility, enhance operational efficiency and accelerate automation.

This research investigates the particular use case of 5G applications in ports and aims to explore how 5G capabilities can support the freeport concept to enhance efficiency and productivity to port operations, allow real-time location tracking of individual items, and replace low value, manually intensive processes with 5G enabled autonomous systems. We particularly focus on freeports, given the UK Government proposals for their development, in response to both Brexit and the economic impacts from COVID-19 (Webb and Jozepa, 2021). While exact definitions vary between countries, freeports can be considered designated areas of a country which are outside of customs purposes and located near a port area (Serwicka and Holmes, 2019). Eight locations in the UK have been awarded this status, and are expected to start operations in late 2021.

The multidisciplinary research team is part of a UK government funded 5G testbed programme with the aim of determining the policy implications and business benefits of adopting 5G in a port setting especially with regards to its potential support of freeport operations. The freeport use case was co-created by a consortium of public and private organisations, including two academic institutions, a port operator, technology service providers, a value adding manufacturing site within the freeport zone and a haulage company. Multiple data collection methods are used including interviews, regular information exchange meetings, archival documents (such as government policy documents) and secondary publications. The method adopted is inductive in approach including the development of descriptive and prescriptive models.

2. Literature Review – 5G in ports

The first major use cases of private 5G networks in logistics have tended to be at logistics hubs such as seaports, airports, and warehouse complexes. Major seaports around the world, including Singapore, Rotterdam, Busan and Shanghai, are investing aggressively on digitalisation to transform themselves into smart ports and meet future challenges. Smart ports will need to utilise digital solutions to address the current and future challenges faced by seaports including spatial constraints, pressure on productivity, fiscal limitations, safety and security risks and sustainability (Berns, et al., 2017).

5G is seen as a key enabler to the smart port concept and the only wireless technology currently capable of connecting every container, vehicle, crane, and other assets used, both indoors and outdoors, at a major port complex. This intensive real time connectivity with low latency by 5G, if integrated with other technologies such as Artificial Intelligence (AI) and edge computing, provides insights into a port's condition and operations. It affords a port the ability to control and optimise its operations safely and securely and make decisions in real time (Connected Places Catapult 2020). It also powers innovative concepts such as digital twins, an important pillar of a smart port. Precise representation of digital twins is dependent on real-time connectivity between the physical asset and its virtual representation. Given the complexity of modern ports and increasingly automated logistics facilities, collecting, transferring, and visualising



the data in a one-to-one dynamic virtual model has been limited by the capabilities of existing wireless networks. The top three challenges to the advancement of digital twins in logistics are cost, precise representation, and data quality. 5G and next-generation wireless could provide solutions to the latter two challenges (DHL 2020).

Various 5G use cases in ports are emerging, with nine cases identified through the literature, including Port of Livorno in Italy (Mattei 2020), Port of Zeebrugge in Belgium (Port of Zeebrugge, 2020) and Port of Qingdao, China (Ericsson, 2021). Private 5G networks are the dominant infrastructure among trials and implementations. The main efforts of exploring the value generation from 5G largely lie in port automation, intelligent decision making and real time control of cargo movement and other operations. The reported benefits tend to concentrate on port productivity gains (e.g. reducing transit time of goods in the port, improved efficiency in quays and yards operation, saving on labour costs and easing service flow), improved safety and security as well as environmental benefits.

The Port of Livorno stands out due to its deliberate efforts in assessing how the benefits (using both quantifiable and qualitative measures) enabled by 5G could contribute to the development of a smart and sustainable port and UN sustainable development goals (SDGs). For instance, there has been an 8.2% reduction in associated CO2 emission per terminal operation, a 20% average cost reduction per year through optimising vessel berths as well 20-25% increased productivity with automated quay cranes. 5G technologies are mainly used to augment and enhance existing port and terminal operations, rather than enabling new business models and more radical innovative practices. Our paper attempts to bridge the latter and explores how 5G could enable the concept of freeport as discussed earlier in this section.

3. How Would Freeports Operate with 5G?

The current perception of freeports is mixed. There are clear advantages of trade that are well studied and reported as discussed in the literature, but there are also concerns and a certain level of distrust from the general public about the ability of freeports to generate value (Serwicka and Holmes 2019). To make freeports operate in a smart and sustainable way, digitisation is inevitable. Every transaction needs to be automated and monitored by people and software applications empowered by technologies such as AI. Currently, to the best of our knowledge, the use of 5G as key enabling digital infrastructure to support the freeport concept is rare. Therefore our use case will provide valuable insights as to how a freeport could utilise 5G to capture the full value of connectivity and thus demonstrate tangible economic, social and environmental benefits.

Our freeport use case is aiming to create digital geofencing within the port that will allow real time goods tracking within every section of the port. The digital geofencing will play a key role in monitoring of goods as well as guaranteeing the path of trucks from different free zones, thus assuring a valid transfer and legal compliance. The first step is to enable 5G radio and deploy a virtualized core network that will enable the development of precise location tracking utilizing 5G. The 5G network will interconnect sensors that will be installed over each truck to enable real time condition monitoring of goods. Moreover, sensors will allow additional security to goods transfer and generate automated stock check via long range RFID.

Generating and transferring real-time data from sensors in containers and truck fleets (which can feed into IoT solutions, AI, machine learning (ML) and robotics for future automation) requires significant network and cloud capacity. 4G networks lack such capacity to deal with this level of data at scale, a task which 5G is capable of handling. Computing and storing huge quantities of IoT data is also a challenge across standard communications networks and clouds. A private 5G network with local processing (through Mobile Edge Computing) provides an environment where services can run efficiently onsite, limiting ingress bandwidth to the core and cloud, and improving responsiveness.



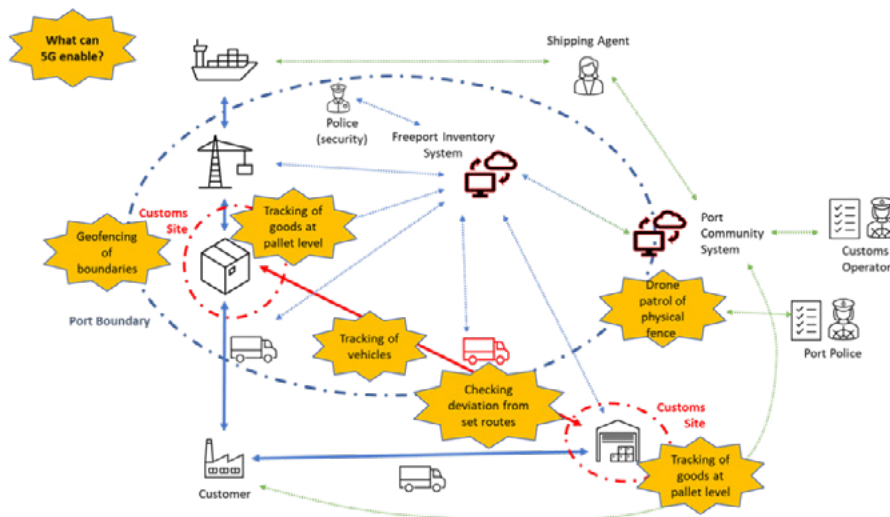


Figure 1: A conceptual framework of areas where 5G could add value to the freeport concept (source: authors).

There are multiple expected benefits of this use case. For haulage companies, this means faster freight release through port gates, implying lower costs for haulers serving the terminal by reducing the waiting time at the port. For the Port operator, the savings on manpower in controlling and securing the designated cargo is one key benefit. The streamline of information flow also means better control of import/export cargo by Customs and other related government agency.

Figure 1 is a generic model of a freeport and also serves as a conceptual framework highlighting areas where 5G could add value to the free port concept.

- Geofencing of boundaries: Creating a geofence (i.e. a virtual boundary) of a free port could potentially eliminate the need to establish a physical boundary as goods can be tracked in real time and any deviation from the designated areas would trigger an alert to the control system at the port and possibly notifying Customs agency for security monitoring purpose.
- Tracking of goods at item, pallet level and consignment level: Goods equipped with RFID tags and containers with IoT sensors enable the real time control and monitoring, not only the location of the goods, but also the condition of the cargo. The precision of location as well as the contextual awareness data generated by the IoT sensors offer increased visibility to related stakeholders regarding the consignment, so that interventions could be taken timely when the state of cargo is deteriorating. This is of particular value to refrigerated containers of perishable products e.g. fresh, frozen and pharma products.
- Drone inspection: it will add enhanced security and situation monitoring of cargo and people movement by transmitting large volume of image and voice data to the port security department, providing continuous monitoring and reducing the need of human inspection and patrol on the ground.

4. Conclusion

A conceptual framework that depicts a generic freeport model underpinned by the 5G technology is developed. The framework is based on the early findings from the 5G testbed and secondary 5G use cases from both practice and academia. The current state of a UK port was established which forms the basis for the conceptual articulation of the 5G enabled freeport concept and areas where 5G could add value. Our future research would examine in more depth whether the expected benefits can be operationalised in practice and explore the barriers and challenges of deploying 5G in ports at scale. Our research is one of the early academic studies that offer valuable insights about the application and impact of 5G on port operation and its implications for freeports. Our research also has important policy implications, given UK government's recent announcement and roll out of eight freeports across the UK following Brexit (Gov.uk 2020).

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HOW INFORMATION FOR OPERATIONAL DISRUPTION MANAGEMENT AFFECTS THE PORT HINTERLAND FREIGHT TRANSPORT EFFICIENCY – SIMULATION OF A SWEDISH DRY PORT CASE

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Introduction

Freight transport volumes via ports have increased significantly over the last decades with increased volumes. The increase in trade volumes combined with increase in vessels' size has generated a need to focus on the functionality of ports' hinterland transport. The hinterland is broadly defined as those places that can be served by the port cheaper than from other ports (van Klink and van den Berg, 1998). Most hinterland transport in Europe is made by road transport (Frémont and Franc, 2010). A common approach for use of other modes of transport to and from the hinterlands via dry ports, which are used as the ports' interface in the hinterland (Roso et al., 2009). A dry port in this paper follows the definition of "...inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardised units as if directly to a seaport." (Roso et al., 2009, p. 341). Surveyed literature has focused on lowering environmental impacts of transport by establishing use of dry ports in the hinterland (Lättilä et al., 2013; Roso, 2007). As dry ports have been identified as an alternative option for hinterland transport, a shift is found in the literature towards employing dry port solutions to relieve volume pressure from the port.

Managing operational disruptions, such as built-in uncertainty with high probability of occurrence and low impact, in transport operations has been recognised as an important aspect that influences the operational performance of intermodal transport (Hrušovský et al., 2021) and hinterland transport (Li et al., 2018). Operational disruptions in hinterland transport have mainly been studied for port operations (Pant et al., 2011) in the interface between sea transport and port operations (Zhou et al., 2018) as well as in the interface to hinterland transport for rail (Xie and Song, 2018) and road (Li et al., 2018). Nevertheless, few articles have considered operational disruptions in the hinterland part of port transport. The management of operational disruptions benefits from information support (Meyer et al., 2014), which, in turn, has been put forward as a key component to improve hinterland transport (Wiegmanns et al., 2018). The use of information is important for the timing of disruption management (Sheffi, 2015), such as early detection, which is desirable to predict and mitigate impact from a disruption (Wide, 2020). Information that is continuously updated, which will be referred to, from now on, as real-time information, supports operational disruption management (Hrušovský et al., 2021). However, the effects that information has on the management of operational disruptions in hinterland transport with a dry port have not been included in previous studies. Instead, previous focus has been on combining the concept of real-time information and port interface, such as truck arrival time to port (Li et al., 2018) or ship arrival time to a port connected to hinterland rail transport (Elbert and Walter, 2014). Therefore, the purpose of this paper is to investigate the operational efficiency effects of information for operational disruption management in hinterland transport with a dry port setup, to facilitate efficient intermodal hinterland transport. This is done through the development of a simulation model of a real-world case of a hinterland transport chain with a dry port connecting the modes of rail and road.

Frame of references

The use of information to manage operational disruptions has been highlighted in previous hinterland transport studies. Zhou et al. (2018) simulated the coordination between lighter operations and trucks arriving at a port. In the paper, the strategies of no coordination (all trucks arriving around the same time), with coordination (trucks' arrivals are spread out) were investigated. When including coordination and a spread-out arrival for the trucks were included, the cycle times for both the lighters and trucks were lowered. Li et al. (2018) highlighted the arrival of trucks to a port and considered disruptions for trucks outside the port (referred to as land-side disruptions). The connection to disruption management is made through information about the different punctuality of the trucks arriving to the port, viewing how different strategies manage low turn-around times for non-punctual trucks. The authors proposed four strategies for serving arriving trucks of First-Come-First-Served (FCFS), priority depending on punctuality of arrival time, serving trucks picking up the container closest in the yard (maximise port equipment utilisation) and a mix between the priority and closest container strategies. The results showed that best improvements in truck turn-around times were found with the strategy that mixed priorities and maximised port equipment utilisation. However, for environmental improvements, the strategy of maximising port equipment utilisation showed best results. Elbert and Walter (2014) provided another example of the use of information for managing operational disruptions, by information about Estimated Time of Arrival (ETA) for ships arriving at a port. The authors build a simulation model considering the capacity utilisation of a hinterland rail connection from a port. The simulation included scenarios with and without the ETA of a container to port, highlighting that more containers went through the port operations, yards and transshipments, when the ETA was known, compared to when not known.



A common approach in evaluating container flow through a terminal (such as a dry port) is in connection to a port and by considering the performance measures connected to congestion in the terminal generating the congestion, for example for trucks arriving to a port (terminal) (Zhou et al., 2018) or for intermodal hinterland flows, for sea barges (Caris et al., 2012). Commonly used performance measures for this congestion are turn-around time in the terminal (for example for a truck) (Zhou et al., 2018; Caris et al., 2011), number of trucks at the terminal (Zhou et al., 2018; Caris et al., 2011; Roso, 2007) and waiting time for trucks at the terminal (Caris et al., 2011; Caris et al., 2012), which can be used connected to CO2 emissions (Li et al., 2018). While these time measures influence the total transport time for a container, another important measure for the actors buying the transport service is the delivery precision (Lammgård and Andersson, 2014). Lastly, the performance measure of utilisation of resources capacity has been highlighted. Elbert and Walter (2014) considered the output of containers on trains to evaluate the resource utilisation of the trains. Caris et al. (2012) focused on the resources at a terminal to evaluate the capacity utilisation.

To sum up, hinterland transport disruptions have been studied primarily with a focus on the connections to port operations, whereas information has been studied with various approaches but not for the hinterland transport with dry port settings. Therefore, the hinterland transport literature is lacking insights into managing operational disruptions by using information in hinterland transport with a dry port setup and how this information influences the operational disruption management. To address these missing links, this paper sets out to explore operational disruptions in connection to a dry port in the hinterland transport. This is investigated through the development of a simulation model that represents a case demonstrating hinterland transport via rail to a dry port and road transport, serving as the link between the dry port and receiving warehouses. The information is represented by providing different information to the model in three different scenarios.

Simulation model

Discrete event simulation has commonly been used to study operations in intermodal transport chains (for example, Caris et al. (2011), Lätttilä et al. (2013) or Roso (2007)). The studied case is an intermodal transport chain that includes one specific train that runs between a port and a dry port. The train carries containers mainly from Asia, that arrive to a port in Sweden. Transport between the dry port and the receivers is through road transport. The dry port has a storage area, where the containers can be stored before moving them to the receiver. The same actor is responsible for both the dry port operations and road transport. The containers on the train have different destinations in around 20 receivers. A late arriving train to the dry port impacts the predetermined plan for dry port operators and the haulier. If containers on the train are indicated as prioritised by the receiver of the containers, the dry port operator aims to deliver these containers first. If there is no information about delays for the arriving train, the haulier has to wait until the containers arrive, which negatively influences their efficiency. However, with this information, the receiver can make decision to transport containers at the dry port until the train arrives. The simulation model is built around the arrival of the studied train at the dry port. The containers arriving with the train are unloaded by dry port operators and can either be stored in the dry port storage area or directly transported to the receiver. Some containers on the train are prioritised containers, for example, due to holding urgent products in the container that need fast delivery or the costs of the container rent, which need fast handling. These prioritised containers should be the first to be transported to the receiver after the train arrives and when these have been delivered to the receiver, the containers in the storage area can be transported.

To cover the purpose, three different information scenarios affecting the management of an operational disruption on the train were derived from the case. Firstly, it has been argued that information allows for a quicker detection, leading to actions with fewer impacts from disruptions (Sheffi, 2015). Li et al. (2018) and Elbert and Walter (2014) indicated that information about late ships or trucks to a port could improve hinterland and port operations. Nevertheless, to the best of our knowledge, no investigations on information for late trains to a dry port can be found in the literature. Therefore, three scenarios are deployed. If the train is late and information is not available (scenario 1), no disruption management is possible. The trucks will stand and wait for the train, as they want to transport the prioritised containers on the train first. If the dry port receives the information about the delay (scenario 2), the disruption can be managed, and re-plan decisions can be made (via coordination with the receiver) to take a container from the storage area on the dry port and transport to the receiver. Scenario 2 should lead to resource utilisation improvements for the trucks, as they are not waiting for the train to arrive but can work with containers that are in the storage area. For the information to support earlier detection of a disruption, reliable information is important (Wiegman et al., 2018) to provide more possible alternatives (Sheffi, 2015; Wide, 2020). Scenario 2 is only valid if the information about the delay is reliable, that is, if the prediction of the delayed arrival time is valid. Therefore, the third scenario is based on information being given about the train being delayed, for example, 30 minutes (50/50 division) or 20 minutes (33/66 division), but the actual delay is longer (total delay of 60 minutes), leading to a later information update about the actual delay. The disruption management is then assumed to include that the trucks are waiting for the late arriving train to start with the prioritised



containers, but after the update realise that they are wasting time and decides to start with non-prioritised containers from the dry port storage area. The logic of the simulation model can be seen in Figure 1. In the model two sources of containers are available, either via the arrival of train or via a storage area, which is made once per simulation run or via an assigned initial value of 40 containers at the storage area (yard) for each run. Figure 1 does not include dry port operators unloading non-prioritised containers and put them in the storage area when trucks are busy delivering.

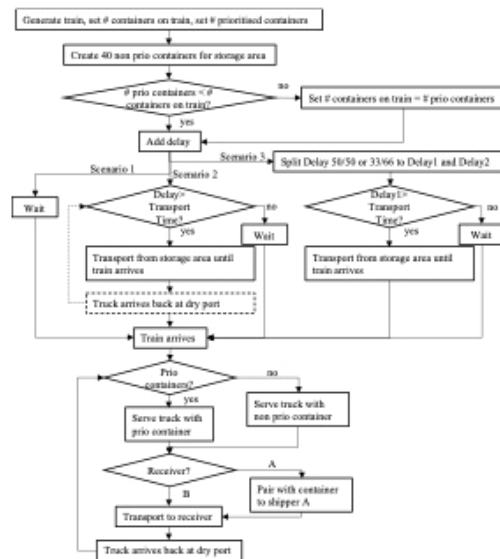


Figure 1. Flow chart of the logic for the simulation model.

As there is no capacity problem for trucks at the dry port, the time spent at a terminal is not the focus of this study. For example, compared to a port that has a high number of trucks arriving at the same time as a ship arriving at a port (Zhou et al., 2018), the dry port is not suffering from the same scale issue when the train arrives. To evaluate time output, the two following outputs being considered are how fast the priority containers are delivered (time between arrival at dry port and delivery at receiver) and how much time the priority containers spend at the dry port (elapsed time between when a priority container arrives and leaves the dry port). Furthermore, considering the problem of the dry port providing container delivery services during the operational disruption of a delayed train and its different information inputs, the scenarios will differ in the utilisation of the resource's trucks, which, therefore, is of interest to evaluate.

Input data to the simulation model

Real-world data were used as input from the empirical case to the simulation model. The real-world data from the dry port system were given for the time period of 01-2020 to 01-2021. The data accounts for 314 trains during the period (including extra trains that were added during extra demand) carrying 12,908 containers, excluding an outlier of one train that was removed, as the train consisted of more containers than the feasible capacity of the train. The number of containers on each train was received through dry port system data. As the model represents when a train with prioritised containers is delayed, the number of containers per train was derived only for the trains carrying prioritised containers. In total, during the given historical data of one year, 203 trains with prioritised containers were present, carrying in total 8,962 containers. (Notable, during this time period there were 314 trains in total, of which 111 did not include any priority containers and one additional train was an outlier.) These data were analysed in the ExpertFit program, but no statistical distribution was found to be suitable for the empirical data. Therefore, empirical distribution from the software was used as input for the model. The empirical distribution consists of a probability function that includes each value represented in the given data. The data for the number of containers having any priority was retrieved for the same period (01-2020 to 01-2021) and included 881 priority containers (on 203 trains) with a priority notion (from a total of 12,908 containers). The number of prioritised containers on each train (with prioritised containers) was derived and analysed through the ExpertFit program. The simulation model additionally needed input data that were not available. In these cases, a common approach is to use system expert input to create a triangular distribution for the needed data. For this purpose, the CEO of the case dry port operator and haulier as well as the transport manager at the main receiver provided their expert input.



Validation and verification of simulation model

For the research study, the framework to ensure research quality of the discrete-event simulation from Manuj et al. (2009) was considered to be an overall guide in the research process. The simulation model of the dry port was built in the AutoMod simulation program, for a base model (without any train delay) and the three scenarios with delays. The conceptual model for the simulation model was based on dialogues with the system experts. The use of empirical input data, when available, provides validation that the input to the model is a valid copy of the real-world. Additionally, a base model was used for validation purposes to compare the simulation outputs with given estimations from system experts (event validity). Systematic walkthroughs of the model (Sargent, 2010) were used for verification to ensure that the model was working as expected. In this case, the built-in debugger was used to follow the code and model animation at the same time. Additionally, dummy variables were used in the model to ensure that it was working as expected. To verify used input data, the output of the base model was used to compare the match with given empirical input data. Different outputs were analysed for 100 runs of all scenarios to check that no infeasible values were generated.

Results

100 runs of each scenario were performed in the AutoMod analysis tool AutoStat. To evaluate the time of the prioritised containers in the system, all prioritised containers needed to be delivered to the receivers during the snap length, therefore runs with another snap length of 8 hours were executed. Additionally, the 8-hour period corresponds well to the simulation of one workday. The following results are presented as the mean of min and max of 95 % confidence intervals for the 100 runs.

The results of the number of delivered containers for both prioritised and non-prioritised containers, indicate low differences between the scenarios in delays below 60 minutes, as illustrated by the mean of confidence intervals (95%) in Figure 2. This is in line with the set rule of when delays are smaller than the mean transport time the trucks should wait, except from scenario 3, which waits for the first indicated delay then sends out non-prioritised containers. When the train is delayed between 90 minutes and 180 minutes, scenario 2 performs best. After 180 minutes of delay, scenario 3 acts in a similar way as scenario 2, as the first delay is equal to 90 minutes or more, and the trucks will then not wait for the train as in previous delays.

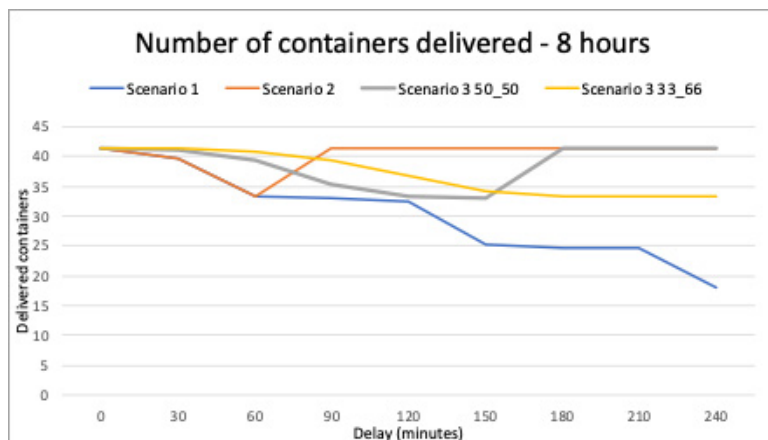


Figure 2. Comparison between scenarios 1-3 for number of delivered containers and varying delays.

The mean of the confidence intervals (95%) for the mean time of the prioritised containers in the dry port are presented for scenarios 1-3 in Figure 3 for different delays. Figure 3 shows that the prioritised containers spent the least amount of time in the dry port in scenario 1, which is understandable considering that the trucks are waiting for the late arriving train to directly serve the prioritised containers. In the two other scenarios, the trucks are not available at the dry port when the train arrives, since they are transporting non-prioritised containers from the storage area. The differences between scenarios 1 and 2 are only present when the delays are smaller than the mean transport time (90 minutes), as scenario 2 will have trucks wait for delayed trains with a smaller delay than the mean transport time. The difference between scenarios 2 and 3 is due to the extra waiting time before delivering non-prioritised containers from the storage area in scenario 3. It can further be seen that the time in scenarios 2 and 3 is dependent on the match between the delay and the transport time cycle.



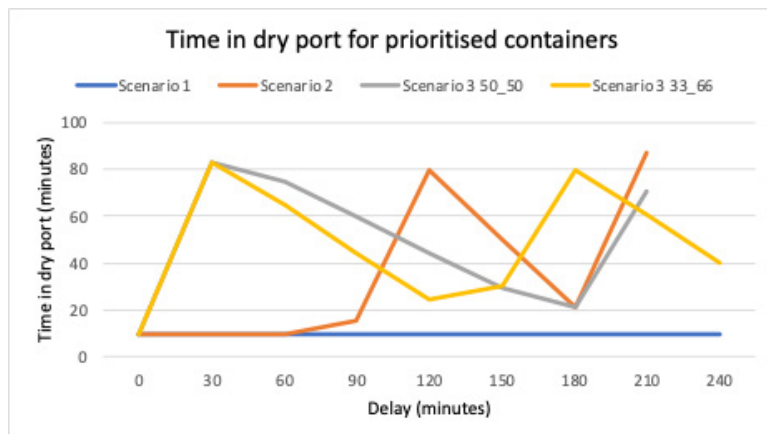


Figure 3. Comparison of scenarios 1-3 for time in dry port for prioritised containers.

The mean confidence intervals (95%) for the time it takes after the prioritised containers arrive at the dry port until delivery at the receiver are presented for the three scenarios in Figure 4 (the y-axis is in minutes). Similar to the time spent at the dry port, the scenarios represent the time to delivery for the prioritised containers, with scenarios 2 and 3 generating the longest time until delivery and first scenario being the fastest to deliver the prioritised containers.

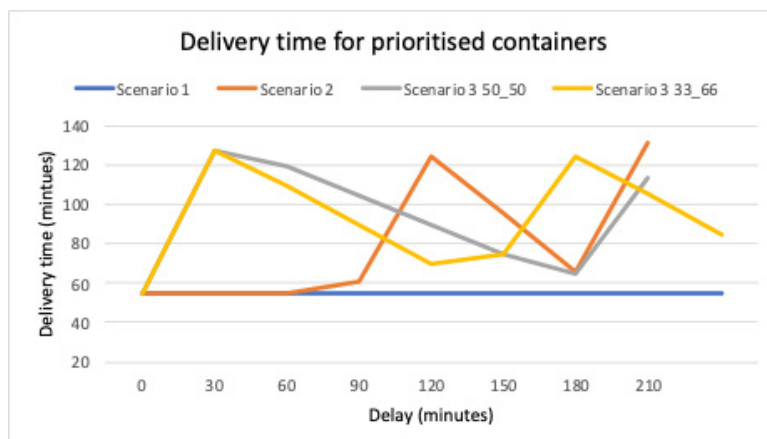


Figure 4. Comparison between scenarios 1-3 for delivery time of prioritised containers.

The confidence intervals (95%) for the trucks' resource utilisation are presented for the three scenarios in Figure 5. The resource utilisation is derived from the modelled resource truck, which has a capacity of 6, is based on the queueing theory and is the fraction of the resource's capacity that the loads utilised. This is calculated by dividing the average number of loads that claimed the resource by the resource capacity (Banks, 2004). As expected, scenarios 2 and 3 provide a higher resource utilisation for the trucks than scenario 1. Scenario 1 gained a quick handling of the prioritised containers at the expense of resource utilisation for the trucks. Scenario 3, with lower a first delay (33-66) generates a constant fall of resource utilisation, while the case with a longer first delay (50-50) reaches the fixed transport time and, therefore, sends out non-prioritised containers instead of waiting. This can be seen in the difference between the two cases after a 150-minutes delay time.



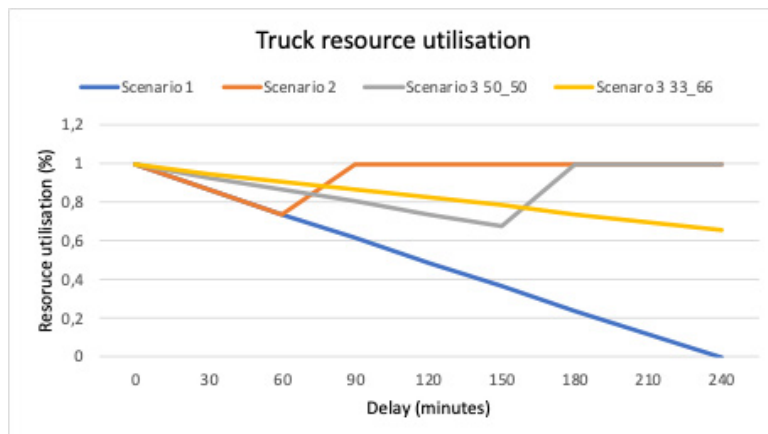


Figure 5. Comparison between scenarios 1-3 for resource utilisation of the trucks.

Discussion

The simulation model investigates the efficiency effects for three information scenarios when an intermodal hinterland transport, the rail mode in this case, is delayed at a dry port. The results of the simulation model show that no information (scenario 1) satisfies the receiver demand of delivery of priority containers the fastest but at the expense of lower resource utilisation. Accordingly, the information of the delay cannot make the priority containers arrive quicker in the studied system, providing better results for quick deliveries without any information, as trucks are waiting for the delayed train in this scenario. In the attempts to manage the disruption by utilising the resources of the trucks instead of waiting, the time to delivery for the prioritised containers becomes longer (in scenarios 2 and 3), as the trucks are used for non-prioritised containers until the delayed train arrives. Furthermore, correct predictions of the delayed arrival of the train (as information in scenario 2) provide quicker deliveries when the train arrives compared to information matching incorrect predictions (scenario 3). The improved efficiency effects for scenario 2 show the value of reliable prediction information (Wide, 2020), in making timely re-plan decisions (Sheffi, 2015) in the hinterland transport context. Information with precise predictions for the arrival of delayed train provides the higher resource utilisation and with shorter times for prioritised container deliveries than incorrect predictions (scenario 3).

The simulation model investigates different magnitude of the train delays. The effects on efficiency from the different delays are mainly influenced by comparing the delay magnitude is in relation to the mean transport time. There will be tensions for the decision, when deciding between delivering a non-prioritised container from the yard or waiting for the prioritised containers on the delayed train. If the delay is less than the mean transport time, the simulation model is instructed to wait, where in reality a planner could have decided to transport a container from the storage area. The transport time is contextual for this case and origin from the transport time. Nevertheless, these insights about the demonstrated impacts on transport operations in connection to the transport time add to the intermodal freight transport literature, which has mainly have focused on extended delays in intermodal transport networks (Hrušovský et al., 2021; Burgholzer et al., 2013), in which delays that were over 2 hours in length impacted the network. In a case where the distance is longer between the dry port and the receivers, the option of sending non-prioritised containers is first feasible when delays are larger, thus matching the transport time between the dry port and the receiver. As the studied dry port is smaller in scale than the connected port, the efficiency issues arising do not completely corresponding to the previous hinterland transport literature with a port perspective. Instead of having issues with truck delays (Li et al., 2018), truck turn-around times (Caris et al., 2011), or rail capacity (Elbert and Walter, 2014), the studied dry port highlights the measures for issues when operational disruption occurs when aiming to deliver prioritised containers at the same time as the truck's utilisation should be kept high.

Conclusions

The aim of this paper was to investigate the operational efficiency effects of information for operational disruption management in hinterland transport with a dry port setup to facilitate efficient intermodal hinterland transport. The presented study provides insights into the efficiency effects depending on three different information scenarios for management of a train delay in a hinterland transport chain with a dry port solution. Few previous intermodal hinterland studies have touched upon disruptions in hinterland freight transport, thus this study contributes by investigating the efficiency effects of three information scenarios for managing a delay of a train to a dry port terminal. Additionally, the represented dry port solution provides a contribution to hinterland efficiency effects of delivery time for prioritised containers, truck utilisation and number of delivered containers due to an operational disruption, thus adding to the identified effects in the hinterland transport literature connected to ports, such as turn-around time. The study contributes



by illustrating how information affects the management of operational disruptions in the studied hinterland transport, including what actions can be taken and at what times. These insights broaden the discussion in the hinterland transport literature about information as support to managing operational disruptions by not limiting the view of information as leading to actions but rather that different actions can result from different information. Furthermore, this study highlights the differences between information about reliable predictions (scenario 2) and incorrect predictions (scenario 3) about a train delay on the impacts on the dry port operations and transport operations to receivers. The study provides practical contributions to dry port managers and transport managers, as well as logistics managers at receivers, on what information they should aim to acquire to obtain the desired benefits from resource utilisation or quick delivery of priority containers. Furthermore, managers can obtain an understanding on how to steer the existing contradictions between these two performance measures. The limited system boundaries for the simulation model of dry port and transport to receivers influence the re-plan options and limit the implications of the output. By including a broader system scope of the hinterland transport in future studies, possibilities for evaluation of more re-plan decisions are provided.

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SPECIALISED SUPPLY CHAINS, SUPPLY CHAIN FUTURE, THEORY AND INNOVATION



THE DETERMINANT OF A FIVE-STAGE DOWNSTREAM OIL SUPPLY CHAIN THE GHANAIA CASE

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1. Introduction

The downstream oil industry contributed over \$4.01billion to Ghana's GDP in 2016 and house over 7000 players. The astronomical growth in the industry is mainly attributed to the government's introduction of strategic policies like the local content policy and participation regulation in 2013, the deregulation policy in 2015 among others (Acheampong, Ashong, and Svanikier, 2016; Tawia, 2018). The downstream oil industry exhibits similar operational features (Hussain, Assavapokee, and Khumawala, 2006; Mbuguah, Kibuine, and Kahuthia 2019). Ofori (2015) concluded that product responsiveness and cost are the critical determinants required to improve the supply chain between oil marketing companies and bulk distribution companies in Ghana. That of Tawia (2018) touched on determinants (traffic flow, buying area, accessibility, visibility, etc.) that affect fuel retailing sectors in Ghana while Boison, Asamoah, Addison, and Asiedu (2018) work also touched on the fuel retailing sector. They identified the location as the key determinant that influences sales volume. These works focused mainly on determinants that affect two players within the whole downstream oil industry. However, the metamorphic nature of the industry powered by technological advancement, new policies, new oil well discoveries among others raises urgent needs to reassess the determinants of Ghana's downstream oil supply chain. Besides, useful downstream oil determinants today may not influence the industry's performance tomorrow. Hence, this paper studies the determinant of a five-stage downstream oil supply chain the Ghanaian case. The aim stated is achieved by answering these questions: what are the determinants of the entire downstream oil supply chain? What is the impact of the identified determinants on the downstream oil supply chain performance?

2. Literature Review

Extensive research investigating downstream oil determinants is still ongoing. Shobande (2018) investigated the determinants of downstream oil performance in Nigeria. Using panel data spanning from 2000-2016, he found that market structure is the critical determinant determining a firm's competitiveness. Amponsah and Opei (2017) explored supply chain challenges facing the downstream petroleum industry. They used questionnaires to collect their data and SPSS to analyze the data. Their result suggests that government interference, government inability to pay under-recoveries, government indebtedness to players, inadequate infrastructure, and inconsistencies in refining crude oil by TOR are the key determinants slowing the industry progress. Attah-Kesson (2013) examined the factors driving the youth job expectations in an emerging oil hub, Western Region. He found that socio-cultural, political, economic factors and lack of knowledge regarding local content policy hinder youth job expectations. That of Boison et al. (2018) looks at the factors influencing sales performance and a fuel station siting. They found that the fuel station location, branding, pump pricing, promotions, and service quality correlates with sales performance. A critical retrospection on the empirical review revealed that intensive literature is available on the downstream oil industry. However, the literature focus is the primary determinant of a specific player within the downstream oil industry (Ofori, 2015; Bioson et al., 2018; Attah-Kesson, 2013; Amponsah and Opei 2017). This study deviates from such and rather investigates the determinant affecting the whole downstream oil supply chain.

Figure 1 exhibits the crucial activities in a five-stage downstream oil supply chain, from suppliers to manufacturers, distribution centers, retailers, up to filling stations. The five-stages is seen as the five players who ensures that customers have access to the oil industry. These activities include; supplying of crude oil and refined petroleum product (RPP), transportation and distribution of RPP, an environmental problem with refinery of the oil, human capital receiving and accounting for RPP, government intervention, economic stability, stakeholder participation, customer satisfaction, tanks maintenance, dependency nature of the chain, etc. These activities give rise to the determinants (government interference, human capital, collaboration, transportation and distribution issues, environmental issues, maintenance issues, customer satisfaction, stakeholders, and economic issue) that affect the five-stage downstream oil supply chain industry.



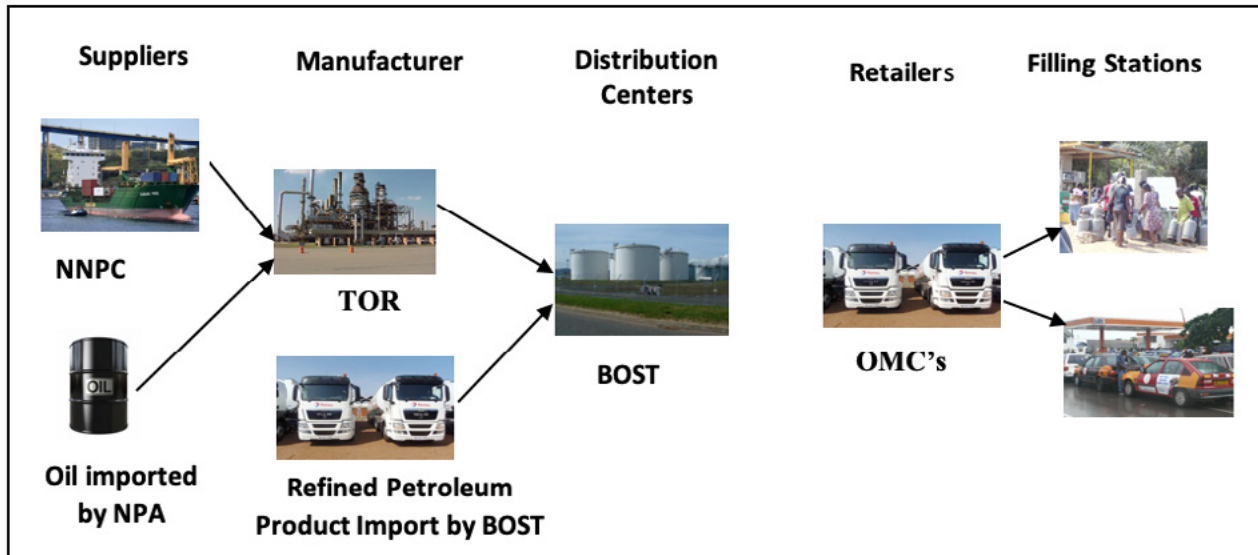


Figure 1: A Five-Stage Downstream Oil Industry
Source: Authors' Construct

The dependent variable performance was defined by Luogon (2013) as “the ability to provide a product as or more effectively and efficiently than relevant competitors.” A firm’s performance can be measured using either its financials (return on asset, equity, or sales, Liargovas and Skandalis, 2010) or non-financial (innovation, timely delivery, service, etc. Omar, Waweru and Rimiru, 2015). This paper measure performance using a non-financial measure, timely delivery of products. The independent variables government interference, human capital, and collaboration were molded using three theories (resource-based suggests view theory, political economy theory, and stakeholder’s theory). The political economy theory suggest that it will be challenging to admit Ghana’s downstream oil industry is devoid of government interference. Amponsah and Opei (2015) concluded that government interference leads to disequilibrium in the demand and supply of refined petroleum products, delays in the payment of under-recoveries, and indebtedness to the downstream industry. Government interference is captured in this study by abuse of power, political stability, perception, expansion of industry growth, and industry risk.

The stakeholder’s theory was used to review Section 17 of Ghana’s Local Content Policy. It was clear that human capital growth was one of the core visions of Ghana’s Local Content Policy which the downstream oil industry cannot neglect. This claim is supported in The Ministry of Energy’s (2011, cited in Arthur & Arthur, 2014) work that Ghana’s local content can develop based on these four essential pillars education, development of skills (training), transfer of technology, and active research and development. Therefore, in this study, we measure human capital with the educational level of workers, regular training of workers, training programs been relevant, training programs increase workers’ motivation, and training based on performance appraisal. The application of resource dependency theory without collaboration in the five-stage downstream oil industry results in each player’s goals increasing the bullwhip effect of the downstream oil supply chain. Hudnurkar et al. (2014) identified 28 factors that affect the collaboration of the supply chain. Upon this background, this study adopts four (trust, information sharing, enable technology, and incentive alignment) of these factors to analyze the downstream oil industry collaborations in Ghana. The conceptual framework is presented in Figure 2.

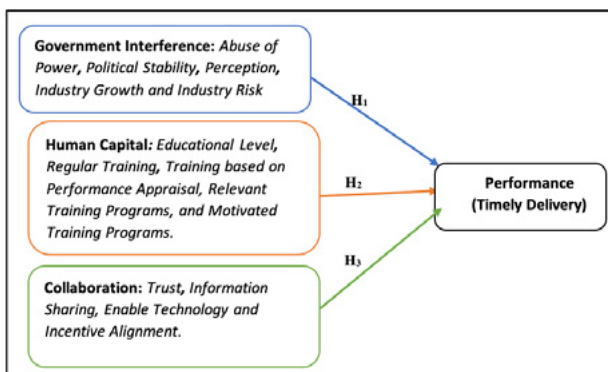


Figure 2: Conceptual Framework
Source: Authors' Construct



3. Methodology

This study's research approach is the mixed method, making the researcher collect data using qualitative methods (interview, questionnaires, etc.) and further analyzing it with quantitative techniques. The study population consists of over 7000 key players, a purposive sampling technique was employed (Saad et al. 2014, cited in Ofori, 2015) and a sample size calculator was used to calculate the total sample size (191) with a confidence level of 95%, and an interval of 7%. Primary data was collected using a closed-ended questionnaire. The primary data collected was screened, coded, and compiled using Microsoft Excel and uploaded into statistical package for social science (SPSS) software version 20. The data investigation commenced by checking the reliability using Cronbach's alpha with an overall Cronbach's alpha greater than 0.70 better (Zhu, Sarkis and Lai, 2008). Furthermore, we run the one-way analysis of variance (ANOVA) to aid with the validity of data. The logistics regression develops by Berkson in 1994 was used to regress each determinant factor against a dichotomous performance. Logistics regression strength lies in: not needing any pre-assumptions, achieves better accuracy compared to linear discriminant analysis, and shows asymptotic characteristics (Lee et al. 2015). The logistics regression is formulating as follows:

$$z_i^* = \beta_0 + \sum_{i=1}^m \beta_{ij} X_{ij} + k_i \quad (*)$$

where z_i^* represents a latent variable (dichotomous performance) that is unobserved $z = 0$ (Likert scale from 1 to 3, implying downstream oil performance is decreasing), and observed $z = 1$ (Likert scale from 4 to 5, meaning downstream oil performance is increasing). X_{ij} is a set of explanatory variables, β_{ij} are coefficient to be estimated, and k_i is an error term. The error term is supposed to follow a logistic distribution as defined in equation (1). Equation (2) represents empirical logistics model (where $p_i = \text{prob } z_i = 1$ and the logit or the log odds ratio correspond to the left-hand side), and the final model for each determinant factor (government interference, human capital and collaboration) are shown in equation (3), (4) and (5) respectively.

$$F(q_i) = \frac{\exp(q_i)}{1 + \exp(q_i)} \quad (1)$$

$$\log \left\{ \frac{p_i}{1 - p_i} \right\} = \beta_0 + \sum_{i=1}^m \beta_{ij} X_{ij} \quad (2)$$

$$\log \left\{ \frac{p_i}{1 - p_i} \right\} = \beta_0 + \beta_1(\text{gen}) + \beta_2(\text{sec}) + \beta_3(\text{AoP}) + \beta_4(\text{PS}) + \beta_5(\text{IPe}) + \beta_6(\text{EIG}) + \beta_7(\text{EIR}) \quad (3)$$

$$\log \left\{ \frac{p_i}{1 - p_i} \right\} = \beta_0 + \beta_1(\text{gen}) + \beta_2(\text{sec}) + \beta_3(\text{EL}) + \beta_4(\text{RT}) + \beta_5(\text{ToAP}) + \beta_6(\text{TPaR}) + \beta_7(\text{TPiM}) \quad (4)$$

$$\log \left\{ \frac{p_i}{1 - p_i} \right\} = \beta_0 + \beta_1(\text{gen}) + \beta_2(\text{sec}) + \beta_3(\text{Tru}) + \beta_4(\text{ISQA}) + \beta_5(\text{ET}) + \beta_6(\text{IA}) \quad (5)$$

4. Results and Discussions

A total of 200 questionnaires were distributed to downstream oil and gas industry players out of which 186 (representing 93%) were returned and 94% of the targeted total sample size. The overall Cronbach's alpha test is 0.790 and the one-way analysis of variance (ANOVA) used to test the mean pairwise comparison between the variables was 242.82 (p-value 0.000) significant at a 95% confidence level. The following Tables (1, 2, and 3) touch on the impact of the investigated determinants on downstream oil supply chain performance. All the Tables reported significant positive values confirming that participants in the various industries of the downstream oil supply chain agree that performance is consistent within the oil supply chain.

Table 1 reports on government interference impact on downstream oil supply chain performance. The diagnostics test showed that the Omnibus test and Hosmer and Lemeshow's test were both significant, signifying that the prediction model fit well with the data, and the overall classification analysis measuring the logit regression accuracy rate was average 69.9% (unobserved performance 0 (52%) and observed performance 1 (82%)). The result suggests that political stability (PS) decreases downstream oil supply chain performance. As political stability deteriorates, it results in poor performance in the downstream oil supply chain. This result correlates with (Mohen 2014, cited in Mbuguah et



al. 2019) assertion that industries thrive under good political stability. Meaning political stability in Ghana is a catalyst to the downstream oil supply chain growth. On the other hand, the government's consistent effort to expand the downstream oil supply chain (EIG) may increase the downstream oil supply chain performance. This result supports Government of Ghana (GOG) timely policies (like local content, deregulation, participation regulation) are yielding the intended performance improvement of the industry (Arthur and Arthur, 2014; Acheampong et al. 2016; Tawia, 2018).

Human capital impact on downstream oil supply chain performance is shown in Table 2. The diagnostics test for predicting the model fitness was significant when tested with Omnibus Test and was rejected by Hosmer and Lemeshow test, with an accuracy of classification of 69.4%. The result revealed that the educational level of sector workers within the downstream oil supply chain decreases performance. That is, as workers working within the downstream oil supply chain improve on their educational level, downstream oil supply chain performance may rise. The results affirm (Khan and Afzal, 2011; Ndulue, 2012) studies that any organization with a strong educational level enjoys strong organizational performance. Besides, training program relevancy also showed a decreased impact on downstream oil supply chain performance. Indeed, training plays a crucial role in the human capital development of any organization, however, if the training program content is not relevant to the core needs of the job it creates financial losses. This is why the Government of Ghana has partnerships partner with international organizations and downstream supply chain operators to improve the industry training content (Ministry of Energy 2010, cited in Kazzizi and Nouri, 2012).

Finally, collaboration impact on downstream oil supply chain performance displayed in Table 3. The diagnostics test revealed that the model prediction fitness was significant using the Omnibus test and Hosmer and Lemeshow test, with an average (68.8%) classification accuracy. All the factors adopted were not significant with downstream oil supply chain performance. Implying that collaboration benefits enjoyed by downstream oil supply chain players will elude the industry (Walter 2003, cited in Hudnurkar, 2014; Dyer and Singh, 1998; Eichman 2000). Additionally, it presupposes that industry players reject, trust, information sharing, enabling technology and incentive alignments in their operations. Posing a difficult challenge on the industry aims achievements and the stagnation nature of the industry. The results suggest that downstream oil supply chain players reject cooperative strategy among members.

5. Conclusions

Various studies have extensively considered downstream oil supply chain determinants but mainly focusing on determinants that affect a player in the supply chain (Ofori, 2015; Tawia 2018; Bioson et al. 2018; King et al. 2018; Hussain et al. 2006; Mbuguah et al. 2019). This paper looks at the determinant of a five-stage downstream oil supply chain in the Ghanaian case by answering these questions what are the determinants of the five-stage downstream oil supply chain and what is the impact of the identified determinants on the downstream oil supply chain performance. The preliminary result indicates that the questionnaire was reliable (Cronbach's alpha > 0.7) and valid (ANOVA 242.82 with a p-value of 0.000). It was found that the determinant that affects the five-stage downstream oil supply chain includes government interference, human capital, collaboration, transportation and distribution issues, environmental issues, maintenance issues, customer satisfaction issues, stakeholders, and economic issues, which addresses the first question of the paper. The second question was answered by regressing three (government interference, human capital, and collaboration) determinants against downstream oil supply chain performance. The results reveal that most of the downstream oil supply chain industry player agrees that the sector's performance is steady within the entire chain. However, government interference factors (political stability and expand industry growth) significantly affect downstream oil supply chain performance. Besides, two factors of human capital (educational level and training program relevancy) had a significant decreasing impact on downstream oil supply chain performance. Finally, none of the collaboration factors adopted had any significant impact on downstream oil supply chain performance. This result was very intriguing, presupposing that downstream oil supply chain players neglect trust, information sharing, enabling technology, participants' and incentive alignment in their operations.

The paper recommends that: the GOG should constantly improve on its political stability index since its betterment impacts the industry performance positively, the GOG should regularly review the training content and educational requirement of the downstream oil supply chain industry, and downstream oil supply chain players should embrace trust, information sharing, enabling technology and incentive alignment in their operations. This research comes with these limitations' poor participants enthusiasm, difficulties in reaching downstream oil supply chain players, and lack of funds to reach most participants. Further research should look at other determinants identified impact on the entire downstream oil supply chain and collaboration factors should be tested again.



Variable	Parameter Estimate (β)	Standard Error	Wald Statistics	Odd Ratio (e^{β})
GEN	0.258	0.342	0.571	1.295
SEC	0.388***	0.110	12.358	1.474
AoP	-0.182	0.173	1.110	0.833
PS	-0.407**	0.192	4.504	0.665
IPe	-0.074	0.148	0.249	0.929
EIG	0.331*	0.185	3.190	1.393
EIR	0.037	0.151	0.061	1.038
Constant	0.133	0.979	0.018	1.142

Omnibus Test 28.252 (0.000); Hosmer and Lemeshow Test 8.482 (0.388);

Overall Classification 69.9% (unobserved 0 (52%) and observed 1(82%)).

Table 1: Government Interference and Downstream Oil Supply Chain Performance

Where ***, **, and * represent significant level at 1%, 5% and 10% respectively.

Variable	Parameter Estimate (β)	Standard Error	Wald Statistics	Odd Ratio (e^{β})
GEN	0.210	0.343	0.373	1.233
SEC	0.430***	0.110	15.229	1.538
EL	-0.735**	0.309	5.657	0.480
RT	0.399	0.347	1.327	1.491
ToAP	0.267	0.203	1.734	1.306
TPaR	-0.466*	0.272	2.930	0.672
TPIM	0.317	0.271	1.372	1.373
Constant	-0.455	1.439	0.100	0.634

Omnibus Test 30.533 (0.000); Hosmer and Lemeshow Test 17.362 (0.027);

Overall Classification 69.4% (unobserved 0 (49.3%) and observed 1(82.9%)).

Table 2: Human Capital and Downstream Oil Supply Chain Performance

Where ***, **, and * represent significant level at 1%, 5% and 10% respectively.

Variable	Parameter Estimate (β)	Standard Error	Wald Statistics	Odd Ratio (e^{β})
GEN	0.073	0.330	0.048	1.075
SEC	0.425***	0.107	15.907	1.530
Tru	-0.053	0.235	0.052	0.948
ISQR	0.136	0.254	0.287	1.145
ET	-0.129	0.195	0.437	0.879
IA	0.009	0.235	0.001	1.009
Constant	-1.132	1.210	0.874	0.322

Omnibus Test 18.982 (0.004); Hosmer and Lemeshow Test 8.726 (0.273);

Overall Classification 68.8% (unobserved 0 (44%) and observed 1(85.6%)).

Table 3: Collaboration and Downstream Oil Supply Chain Performance

Where ***, **, and * represent significant level at 1%, 5% and 10% respectively.

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AN EMPIRICAL INVESTIGATION OF SUPPLY CHAIN RISK MANAGEMENT: THE ROLES OF GUANXI AND INFORMATION SHARING

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1. Introduction

In recent years, various manufacturing practices (e.g. outsourcing, globalization, lean manufacturing, just-in-time) has brought uncertainty to product quality and cause additional quality considerations to the components or final product. Failure to cope with quality risks in the supply chain could lead to a series of repercussions for firms, such as increased inefficiency, inferior product quality, conflicts with stakeholders, loss of firm's reputation, manufacturing distribution problems, and decrease of firm's share price (Tse et al., 2021).

Supply chain risk management (SCRM) has been proposed to identify, assess, treat, and monitor risks in supply chain with the purpose of reducing their vulnerability, thus ensuring their profitability and maintaining their competitive advantage (Fan and Stevenson, 2018). Unfortunately, academic studies to date have not provided firms with a full array of insights about the ways to minimize the negative impact of production quality risk (Tse et al., 2019). Therefore, this study will aim to help contribute to filling this gap by gaining greater insight and understanding of quality risk in SCRM. This paper aims to contribute to this body of knowledge to provide insights on the synergy results from four key SCRM practices, e.g. risk shifting, supplier development, risk avoidance and risk assessment, which are advocated as being adopted simultaneously to best proactively handle supply chain risks.

Grounded on previous research which argues that adopting SCRM requires the orchestration of complementary organisational resources, this study posits that depending on the context of examination Guanxi and Information Sharing (IS) will have a greater or lesser significance in performing SCRM process. In so doing, the objective of this study is to address these research gaps and to identify appropriate strategies i.e. Guanxi and IS, which can help mitigate supply chain risk. We build on a sample of 468 survey responses from managers in Chinese firms, and we examine the effect of Guanxi and IS on four dimensions of SCRM. Then we take the possible synergy effect between dimensions into consideration and apply a novel methodology fsQCA to attain the combinations that facilitate different SCRM dimensions.

2. Literature review and hypotheses setting

2.1 Supply chain risk management dimensions

According to Tse et al. (2019), handling quality risk through proper management practices is particularly important for the firm's competitiveness and survival in the market, thus, one of the tough challenges for all researchers in this domain is to build quantitative models and of information related to quality risk in the area of supply chain management process research. In reviewing and consolidating articles from existing literatures, this study will focus on four distinctive dimensions we advocate: risk shifting, supplier development, risk avoidance and risk assessment. Risk shifting refers to the way that focal firms transfer, manage and mitigate known or foreseeable risks with suppliers involved (McDermott and Hayes, 2018), supplier development is the efforts made by the industrial buying firm with the purpose to improve supplier's capability and performance (Krause, Handfield and Scannell, 1998). Risk avoidance represents a set of preparedness actions which ensures the readiness of an organization to forecast, take precautionary measures and respond to risk (Christopher, Liljelund and Mitchell, 2001), and risk avoidance is the assignment of probabilities to risk bearing events in the system assessment of uncertainty (Tuncel and Alpan, 2010). These four dimensions are selected as this study focus on the antecedent activities that take place before risks occur, and these activities cover main strategies to prevent the quality risk in the supply chain.

2.2 Guanxi and SCRM dimensions

Guanxi refers to a subset of relationships that work according to norms of reciprocity between suppliers and buyers, which also generate a social network that contains implicit mutual obligations, assurance and understanding (Burt and Burzynska, 2017). The development of Guanxi places strong emphasis on the relationships between business partners for achieving mutual benefits, and involves the use of personal and/or inter-firm connections to secure favours in the long run. Existing studies do not consider the potential importance of Guanxi in the adoption of SCRM practices. So, this study opens a new avenue of research by proposing the role of Guanxi in the adoption of different SCRM practices. We argue that the application of Guanxi can mitigate the risk of SCRM process, since it provides a strong motivation for establishing strategic partnerships with suppliers (Lee and Humphreys, 2007). The key reason is trust can be raised by developing Guanxi



between the buyer and supplier thereby solving the conflict goals buyers and sellers may have and enhancing their level of cooperation. Mutual trust not only enable buyers reduce their expenditure from preventing suppliers' opportunism, but suppliers save cost by decreasing the penalties they may have received for defective products. Besides, the development of Guanxi facilitates good communication and relationship between buyer and suppliers, which not only makes it easier to establish an explicit inspection mechanism, but also makes the implementation of inspection activities less obstructive. Last but not least, Guanxi can enhance organizational activities in that it offers the "favour" of facilitating transactions by allowing access to limited resources/information, preferential treatment in business dealings, and protection from external threats (Lee and Humphreys, 2007). According to this line of reasoning, we postulate the following hypotheses:

H1a: Guanxi positively affects risk shifting;

H1b: Guanxi positively affects supplier development;

H1c: Guanxi positively affects risk avoidance;

H1d: Guanxi positively affects risk assessment.

2.3 IS and SCRM dimensions

IS refers to the situation in which supply chain partners share critical and proprietary information that may facilitate the other party's activities (Li et al., 2015). When applying IS in SCRM processes, different members (i.e., suppliers, manufacturers, distributors, logistics service providers, wholesalers and retailers) work jointly in an effort to ensure supply chain safety, while organizations which are able to appropriately prevent, detect, respond and recover from risks show their resilience to ensure sustainability (Speier et al., 2011). IS enables supply chain members to identify possible vulnerabilities in the supply chain as well as making corresponding contingency plans, thus firms can respond rapidly when actual risks occur. Meanwhile, IS can provide accurate and timely data which increases the accuracy of evaluation, which helps the focal firm keep track of who did what and when at every stage of production. In addition, IS contributes to coordination in supply chain in several levels, from only sharing demand data that suppliers received directly from customer to complete information that support the specific cases, which include activities like production status, production and inventory costs, quantity discounts, transportation availability and so on. IS also provides more opportunities for members to communicate, thus enabling them to establish a more efficient inspection system. Last but not least, high supply chain visibility which is brought about by IS reduces the information asymmetry between the buyer and supplier, so that the buyer can mitigate the imperfect observability in the supplier's quality and improve the risk perceptions of the supplier's product quality, as well as helping the firm identify possible accidents (Speier et al., 2011). This leads to the following hypothesis:

H2a: IS positively affects risk shifting;

H2b: IS affects supplier development;

H2c: IS affects risk avoidance;

H2d: IS affects risk assessment.

2.4 Guanxi, IS and SCRM dimensions

As mentioned, Chinese businesspeople are usually involved in multiple networks, and the most remarkable benefit of participating in the network is the development of Guanxi and IS (Murray and Fu, 2016). Given that both Guanxi and IS are closely relevant to different SCRM processes, this raises the question of how best to apply Guanxi and IS in supply chains. In this study, we argue that in the case of Chinese firms, Guanxi and IS should be applied simultaneously to mitigate risks in different steps of supply chain management. When used in this way, Guanxi and IS can each compensate for the limitation of the other, it is suggested. Specifically, IS can operate as the complement of Guanxi when the aims are to achieve different SCRM processes. When applying SCRM processes, the buyer emphasises that the supplier should bear the main responsibility for the quality of the product, and this behaviour will greatly affect the trust between them if the buyer is unable to prove the exact mistake was the fault of the supplier. While, IS facilitates sufficient supply chain visibility and traceability, which is vital for identifying risks, and providing concrete evidence of who should be the person responsible for the risk (Fu, Han and Huo, 2017), thereby reducing the suspicion and mistrust between buyers and suppliers. Besides, buyers can show strong trust to suppliers by involving themselves in various activities to help suppliers perform better when a good Guanxi is developed in supply chain, while excessive participation of buyers in the supplier activities might cause suppliers to misunderstand that buyers do not believe in them. In this situation, the supplier's concern can be dismissed by IS for its ability to show specific evidence which is part of the requirement the work of the supplier does not meet and why the supplier needs help. With the complexity of supply chains increasing,



the increased number of relationships making it difficult to develop strong relationships, the multiple links and exchanges make it hard to forecast, aggregate, and share accurate and timely information. Against this, the Guanxi factor can affect the information flow and the interaction between the buyer and supplier firms in the Chinese business environment. And we posit that the complementary effect of Guanxi to IS are also applicable regarding SCRM processes.

H3a: The use of guanxi and IS will function simultaneously in promoting risk shifting

H3b: The use of guanxi and IS will function simultaneously in promoting supplier development

H3c: The use of guanxi and IS will function simultaneously in promoting risk avoidance

H3d: The use of guanxi and IS will function simultaneously in promoting risk assessment

3. Method

3.1 Data

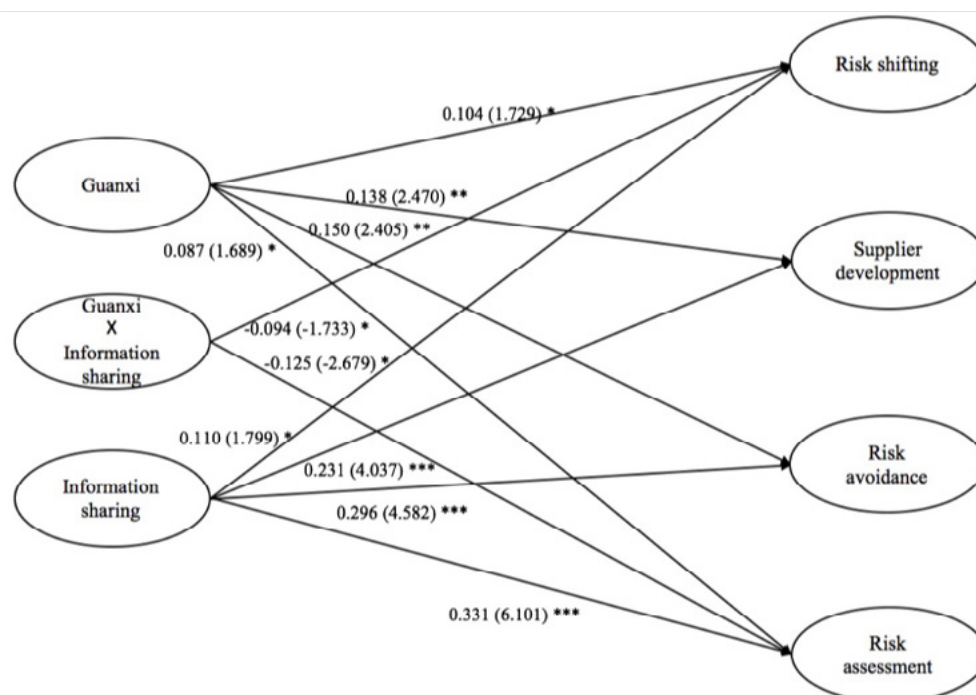
To examine the degree of significance of factors to the effectiveness of SCRM approach, a survey instrument was developed and administered to key informants within firms. The target respondents of this study are supply chain managers and senior managers from the manufacturing sector in Chinese firms because being Chinese they practice Guanxi and they are the decision-makers who can assess strategic information about SCRM. To test the model, a mailing list of approximately 2440 manufacturing companies based in China was used. In total, 468 valid responses were obtained, an effective response rate of 9.5% per cent. To operationalize concepts and constructs, a 7-point Likert scale is used to evaluate how effective their firm is in developing Guanxi and IS to support each of the aforementioned dimensions of SCRM (1 – Not effective at all, 7 – Highly effective). It is necessary to consider the potential problem of common method bias (CMB) (Podsakoff et al., 2003), thus we run a Harmon one-factor on the main variables of our study, and the outcomes showed that there was no uni-factor solution because the maximum variance explained by any one factor was 24.509%, which indicates the absence of CMB. In addition, a common latent factor test was adopted to reinforce the results of the CMB test. Twenty-four question items were formed as a single factor, and the model fit ($\chi^2/df = 7.499$, CFI = 0.451, IFI = 0.455, GFI = 0.569 and RMSEA = 0.162) for the single factor model showed a poor model fit, which indicated that the single factor model was not acceptable, thus, the CMB problem was not a concern for this study.

3.2 Structural model

To assess the construct reliability, a two-step procedures suggested by Narasimhan and Jayaram (1998) was adopted. Firstly, we ran exploratory factor analysis (EFA) to check the unidimensionality of the constructs. The EFA was conducted using the principal component method with varimax rotation and without specifying the number of factors, and the result of EFA indicates that the data was suitable to proceed with factor analysis. Then this study applied confirmatory factor analysis (CFA) to confirm the unidimensionality. By using SPSS AMOS 23, it was found that the model fit indices obtained all indicated an excellent fit for the measurement model ($\chi^2 = 597.333$; $df = 256$; $\chi^2 / df = 2.333$; $p\text{-value} = 0.000$; CFI = 0.941; GFI = 0.908; RMSEA = 0.053; IFI = 0.942). In addition, to assess the discriminant validity, this study used the average variance extracted (AVE) and inter-construct correlations comparison method. In this study, all six constructs' discriminant validity is confirmed because each of their square root of AVE is greater than their correlations with other constructs.

Regression weight p-value: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$





Model Fit Index: $\chi^2 / df = 2.333$; $p\text{-value} = 0.000$; CFI = 0.941; GFI = 0.908; RMSEA = 0.053; IFI = 0.942

Figure 1. Structural model.

Table 1. Results of hypotheses H1abcd, H2abcd, and H3abcd using SEM

Path	β	t-value	p-value	Hypothesis support
Main effects				
Guanxi - > Risk shifting	0.104	1.729	0.084*	Supported
Guanxi - > Supplier development	0.138	2.470	0.014**	Supported
Guanxi - > Risk avoidance	0.150	2.405	0.016**	Supported
Guanxi - > Risk assessment	0.087	1.689	0.091*	Supported
Information sharing - > Risk shifting	0.110	1.799	0.072*	Supported
Information sharing - > Supplier development	0.231	4.037	***	Supported
Information sharing- > Risk avoidance	0.296	4.582	***	Supported
Information sharing- > Risk assessment	0.331	6.101	***	Supported
Interaction effect				
Guanxi x Information sharing - > Risk shifting	-0.094	-1.733	0.083*	Supported
Guanxi x Information sharing - > Supplier development	0.025	0.505	0.614	Not supported
Guanxi x Information sharing - > Risk avoidance	-0.024	-0.440	0.660	Not supported
Guanxi x Information sharing - > Risk assessment	-0.125	-2.679	0.007***	Supported

Notes: The entries in the table are standardized path coefficients. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$



In order to explore the interaction of Guanxi and IS through structural equation modelling (SEM), the method suggested by Hair et al. (2010) to test the interaction was adopted. The interaction construct was not only added into the proposed model, but also tested with other constructs of SCM strategies. This study used SPSS AMOS 23 to run SEM for assessing the support of the conceptual model and hypotheses. Fig.2. exhibits the results of the structural model and the standardized regression weights of all the entries. Overall, the model fit indices obtained all met the requirement of good fit benchmark, and proved that the fit of the structure model (Fig.2.) was acceptable.

The model was assessed by examining the variance explained (R^2) of the endogenous construct or dependent variables and the intensity of the path coefficients (β). The maximum value of R^2 is 18 per cent for risk assessment and the minimum was 5 per cent for risk shifting. H1a, H1b, H1c and H1d hypothesis positive relations between Guanxi and risk shifting, supplier development, risk avoidance and risk assessment. The positive effects were on H1a ($\beta = 0.104$, $t = 1.729$), H1b ($\beta = 0.138$, $t = 2.470$), H1c ($\beta = 0.150$, $t = 2.405$) and H1d ($\beta = 0.087$, $t = 1.689$). The paths also support the relationships of H2a, H2b, H2c and H2d. This implied that IS was a critical predictor of risk shifting ($\beta = 0.110$, $t = 1.799$), supplier development ($\beta = 0.231$, $t = 4.037$), risk avoidance ($\beta = 0.296$, $t = 4.582$) and risk assessment ($\beta = 0.331$, $t = 6.101$). In addition, it was hypothesized that the interaction between Guanxi and IS was positively associated with four SCRM processes. However, the result indicated that the positive impact on supplier development ($\beta = 0.025$, $t = 0.505$) and risk avoidance ($\beta = -0.024$, $t = -0.440$) was not significant, and the impact on risk shifting ($\beta = -0.094$, $t = -1.733$) and risk assessment ($\beta = -0.125$, $t = -2.679$) were negative and significant. In addition, this study provided further evidence to resolve the uncertainty of whether Guanxi and IS should be applied as complements or substitutes for achieving risk shifting and risk assessment. As illustrated in Fig.2. and Fig.3., when IS was not widely used in firms, Guanxi had a positive effect on risk shifting and risk assessment, while with the high adoption of IS related activities, there was not much effect from Guanxi to risk shifting and even a negative effect from Guanxi to risk assessment, and the results showed that IS dampens the positive relationship between Guanxi and two SCRM dimensions, e.g. risk shifting and risk assessment. In fact, Guanxi encouraged firms to manage business by cooperating with goodwill and trust and allow parties to interact with focal firms and communicate about the potential supply chain risks directly. While the development of IS could break the mode that Guanxi operates because it relies more on data collection from multiple sources to identify vulnerabilities. Given the fact that effective IS could also help to identify and communicate information about supply chain threats, the role of Guanxi became less vital when firms leveraged good IS activities. Thus, the results of our empirical study rejected H3a, H3b, H3c and H3d, and surprisingly offered completely different views to that of Guanxi and IS literature.

4. Fuzzy-set Qualitative Comparative Analysis

To determine what combinations of organizational resources were most important in the attainment of performance for firms operating in varying contexts, this study employed a fuzzy-set Qualitative Comparative Analysis (fsQCA). This method is particularly relevant to the case of SCRM dimensions since depending on the areas insight generation is targeted, the factors that are core contributors to them can vary significantly. Based on the method proposed by (Ragin, 2009), the first step of the fsQCA analysis is to calibrate dependent and independent variables into fuzzy or crisp sets, so the original values collected from survey were transformed into the values ranging from 0 to 1. Crisp sets are best suited in categorical variables that have two, and only two options. For example, firm size was categorized into large firms with 250 or more employees and small-medium enterprises (SMEs) with fewer than 250 employees. On the other hand, Fuzzy sets may range anywhere on the continuous scale from 0, which denotes an absence of set membership, to 1, which indicates full set membership. According to the procedure, the degree of set membership is based on three anchor values including a full set membership threshold value (fuzzy score = 0.95), a full non-membership value (fuzzy score = 0.05), and the crossover point (fuzzy score = 0.50). Since this study used a 7-point Likert scale to measure constructs, we followed the process described by Ordanini, Parasuraman and Rubera (2014) to transfer them into fuzzy sets. Full membership thresholds were set to values greater than 6, crossover points to 4.5, and full non-membership scores to 3. The reason for setting full non-membership of 3 rather than 2 was due to the distribution of values, which was based on the basis of respondents answering that they strongly agreed.

FsQCA 3.0 was used to analyse of configurations leading to high SCRM dimensions (Ragin, 2009). FsQCA sorts all the 468 observations into each of these rows based on their degree of membership of all the causal conditions. The next step is to reduce the number of rows according to two conditions: (1) a row must contain a minimum number of cases, this value was set to a frequency threshold of 5 cases (Ragin, 2009); and (2) we selected rows which achieve a minimum consistency level of 0.90. Four separate fsQCA analyses were formed and four dimensions of SCRM processes were set as dependent variables separately. Only risk assessment and risk avoidance results have been shown in fsQCA, while the results for supplier development and risk shifting were not generated, as the matrix was empty. Thus, the results presented in Table 2 provide the best configurations for risk avoidance and risk assessment. The black circles (●) indicate the presence of a condition, and crossed-out circle (⊘) denotes the absence of one.



Core elements of a configuration, which is refined as those casual conditions for which the evidence indicates a strong causal relationship with the outcome of interest, are marked with a large circle, whereas peripheral elements, which refer to those for which the evidence for a causal relationship with the outcome is weaker, are recorded with small ones. Blank spaces mean “don’t care”, in which cases the causal condition maybe either present or absent.

Table 2. Configuration for achieving high level of risk avoidance and high level of risk assessment.

Configuration	Solution				
	Risk avoidance				
	1	2	3	4	5
Risk shifting			⊗	●	●
Supplier development			⊗		●
Risk assessment	●	●	●		●
Guanxi				●	⊗
IS	●	●		●	
Large firms	●	⊗	⊗	⊗	●
SME enterprises	⊗	●	●	●	⊗
Consistency	0.919	0.896	0.879	0.934	0.997
Raw coverage	0.322	0.501	0.251	0.254	0.084
Unique coverage	0.244	0.136	0.013	0.013	0.006
Overall consistency	0.855524				
Overall coverage	0.895338				

Configuration	Solution				
	Risk assessment				
	1	2	3	4	5
Risk shifting			●	⊗	●
Supplier development			⊗	⊗	●
Risk assessment	●	●		●	●
Guanxi				⊗	⊗
IS	●	●	●		
Large firms	●	⊗	⊗	⊗	●
SME enterprises	⊗	●	●	●	⊗
Consistency	0.937	0.917	0.939	0.935	0.935
Raw coverage	0.316	0.493	0.178	0.156	0.156
Unique coverage	0.240	0.273	0.012	0.01	0.006
Overall consistency	0.918151				
Overall coverage	0.834821				

The outcomes of the fsQCA analysis for achieving high level of risk avoidance produce five solutions. The first and fifth solutions applies for large firms. Solution 1 indicates that large firms that operate under conditions of high risk avoidance, provided they have developed risk assessment and IS. Solution 5 also applies for large firms who operate under conditions characterized by an absence of Guanxi. This solution is the only one in which all other three dimensions of SCRM process are accompanied in which they all should apply together with risk avoidance, while neither Guanxi nor IS are necessary conditions in this case. Particularly, Guanxi should not be present in this configuration. Solution 2, 3 and 4 are suitable for SME enterprises and suggest that under condition of an absence of risk shifting, supplier development, risk assessment, Guanxi or IS, while the supplier development are not present in all of them, which suggest that the efforts focal firms made to improve supplier’s capability and performance is not a necessary condition for achieving good preparedness actions to forecast, measure and respond to risk. A separate analysis is performed to determine configurations of conditions that lead to high level of risk assessment. Solutions 1 and 5 are similar to those that are result in increased risk avoidance, and they suggest that for large firms, the impact of Guanxi, IS and other dimensions of SCRM processes on both risk assessment and risk avoidance is realized under the same specific conditions. The absent of Guanxi reflects that large firms avoid developing strong Guanxi network with its partner. Large firms usually implement complete SCRM strategies which could effectively avoid risks, while the adoption of Guanxi has the potential to induce partner to behave opportunistically and trigger undesirable accidents. As for SME enterprises, Guanxi is not a necessary condition in all the solutions of risk assessment. The results of solution 2, 3 and 4 are all under conditions characterised by a lack of supplier development and Guanxi.

5. Discussion and conclusion

This study offers several important theoretical implications for researchers and practitioners. Firstly, this research offers a comprehensive understanding of using different components of SCRM to deal with quality risk. Specifically, four important SCRM processes that firms adopt before risk occur provided a well-grounded standard of what SCRM strategies can be considered to prevent quality risks occurring. The items for each dimension based on the literature are helpful guideline for future research to understand the specific processes of SCRM. Secondly, the findings of this study make important contributions to the impacts of Guanxi and IS on improving different dimensions of SCRM. Thirdly, this study differs significantly from existing literature in the area of SCRM by looking into how specific dimensions are interdependent to each other. We added to the existing literature by scrutinising the complementary effects of different dimensions of SCRM and also provided additional information about how Guanxi and IS could influence the synergy of those processes. Hence, this study provided new evidence suggesting that different SCRM dimensions need to be considered concurrently and the synergy effects between them could be used to enhance a particular SCRM strategy.

From a managerial perspective, this research provides feasible suggestions to practitioners in several ways. This study answered the question by presenting the definition of four SCRM dimensions that can help managers to accurately understand the specific meaning of each dimension in order to take the appropriate actions. And managers could use the questionnaire items as a check list of SCRM processes for company’s risk management planning. Secondly, this study provides some interesting insights for managers with regards to the adoption of Guanxi and IS for different SCRM dimensions. The results show that Guanxi and IS have direct positive impact on all four SCRM



dimensions. Meanwhile, only one of the Guanxi and IS practices should be adopted at one time, rather than being applied simultaneously. Our results for the interaction effect between the Guanxi and IS emphasise the need to operationalise them individually in most of cases. Accordingly, we advocate for the use of Guanxi and IS separately as a means to improve the overall adoption of SCRM. Thirdly, this paper considers that the selection of appropriate SCRM processes from different dimensions could be an effective way to achieve SCRM, which could significantly lessen specific risks to a firm and even the risk disruption to the whole supply chain (Lei et al., 2021). And the fsQCA analysis provides concrete suggestions for companies to design these dimensions in a complementary manner, so that managers can follow the suggestions of any configuration which are appropriate for them.

Despite its contributions, this study is constrained by a few limitations that need to be considered for future research. Firstly, when taking into account the different typology of SCRM, future research will be benefit from exploring other SCRM processes that firms can adopted after risks happen. Secondly, future research could be further improved by collecting data from multiple respondents and from firms' different sections. Thirdly, the scope of generalization of the results is limited and future studies could solve it by replicating the survey in a large range of countries (both developing and developed).

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STEERING THE ROAD FREIGHT SECTOR: TOWARDS A ZERO EMISSIONS STRATEGY GIRO-ZERO



UNDERSTANDING ENERGY USAGE OF AN ELECTRIC REFUSE COLLECTION VEHICLE FLEET IN AN URBAN ENVIRONMENT

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1. Introduction

The process of implementing electrified powertrains as fully-developed consumer products (Denton, 2016) has been significantly accelerated around the world by economic and environmental zone-specific regulations (Pasaoglu et al., 2016). The UK has been particularly proficient in effectively applying swift measures in this direction due to the UK government's position regarding the reduction or net cancellation of greenhouse gases (GHGs) in a short timescale (Reiner et al., 2020), as well as the forthcoming 2030 ban on sales of petrol and diesel-powered cars. These policies, particularly the UK DfT's Road to Zero strategy (Reducing emissions from road transport: Road to Zero Strategy - GOV.UK), combined with the creation of low/zero emission zones (Ballantyne and Heron, 2020), aim to achieve the emission reduction targets, partially through quick and reliable implementation of electrified powertrains as means of powering all categories of vehicles, including refuse collection vehicles (RCV).

The popularity of electric vehicle (EV) technology is growing and it is significantly facilitating the mass adoption process of EVs for all types of automotive powertrains (Noori and Tatari, 2016). Model-based software simulation solutions for automotive applications have also gained popularity, due to their ability to accurately simulate various types of complex electric powertrains (Hammadi et al., 2012). Whilst some research solutions exist, there appears to be a lack of literature concerning real-life applications and examining the impact of electrified powertrains in economic and environmental contexts. Moreover, there is a lack of meaningful data regarding energy use when heavyweight powertrains are considered, for example, electric local delivery vans, delivery trucks or Refuse Collection Vehicles (RCV). Thus, understanding the energy-related impact of EV implementation is critical for public sector-related logistics fleets to address energy usage and CO₂ emissions in the commercial transport sector.

This paper aims to examine the implications of implementing a fully electric RCV fleet in a specific urban environment (Sheffield, UK), by performing a quantitative investigation of energy usage and carbon dioxide emissions. The process consists of observing and analysing energy usage of one RCV, then upscaling the figures of interest to fleet-level, ensuring full analysis coverage throughout all refuse collection routes. It also presents potential solutions concerning the charging and maintenance of the vehicle fleet, as well as a basic cost estimation concerning vehicle charging of the proposed electric vehicle fleet system.

The presented analysis provides the public sector, other private EV fleet users, and EV manufacturers with baseline energy usage figures for an eRCV fleet operating in an urban environment. Additionally, the research has developed a robust methodology and system cost analysis that will consist as reliable and comprehensive starting points in the design or optimisation processes of electrified heavyweight powertrain fleets.

2. Methodology

The multivariate analysis presented in this document has been tailored to reflect the refuse collection capabilities of the Sheffield City Council. Currently, the refuse collection company in charge of waste management operates a fleet comprising of 26 diesel-powered RCVs and together with the Sheffield City Council is looking at the feasibility of implementing a fully electric fleet of such vehicles. Furthermore, Sheffield is a particularly exhaustive testing area for such vehicles (and simulations of such operations) since the local topography features significant variations in altitude. The developed model accounts for this together with other factors that significantly affect energy usage of such vehicles.

The system modelling has been particularly tailored to reflect the real-life scenario and challenges posed by the scale of the fleet in Sheffield, based on both the refuse collection routes, as well as the topology of the area the refuse collection routes cover, as seen in figures 1a and 1b. Similarly, the energy usage prediction and the related analysis has been performed in such a way that considers real-life technical functional parameters provided for the eRCV prototype, with some reasonable approximations and assumptions that are not expected to significantly change the results. The conclusions provided by the energy usage figures computed and presented later in the document are contextualised such that they can be correlated with the available opportunities of interfacing the fleet with other energy production sources usable by the Sheffield city council.



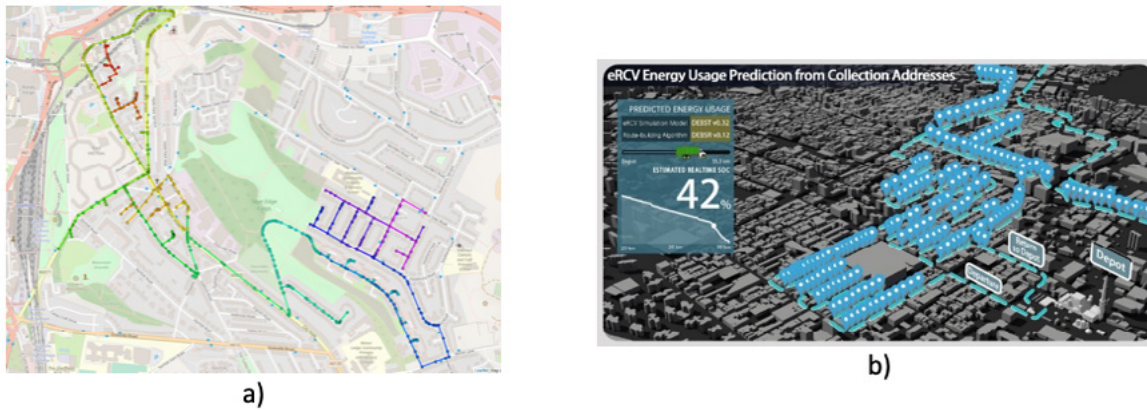


Figure 1. a) Mapped Example of Sheffield area refuse collection route, b) Visual conceptualisation of predicted energy usage

2.1. Vehicle Modelling

The vehicle model used for this study is currently set up to simulate the physical parameters and physics of an electric refuse collection vehicle (eRCV). The employed modelling approach has been presented extensively in previous research material (Zhao et al., 2020). The drivetrain topology is a simple single data processing pipeline consisting of Battery-DC Motor-Gearbox-Aerodynamic model, as seen in figure 2.

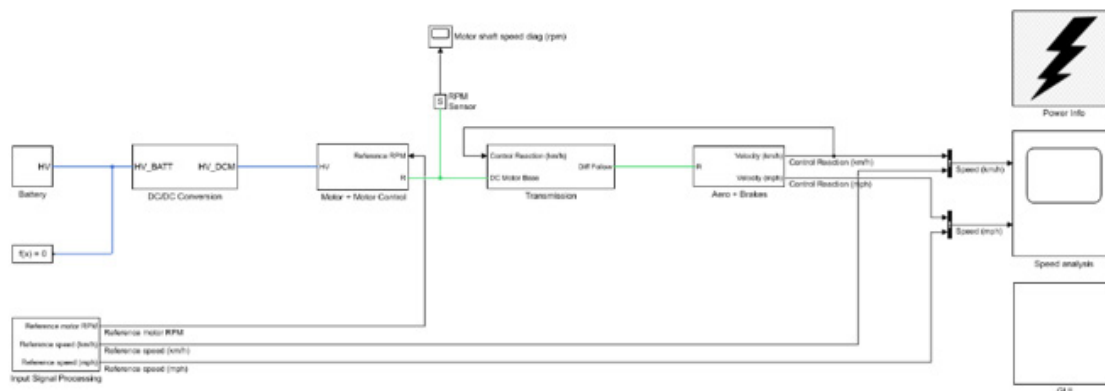


Figure 2. eRCV software model. System diagram.

Power delivery is controlled using an ideal PID controller that maps power supply capability to power demand (input speed/time, or speed/distance data), that handles torque in the motor module, which is set to work in current-control mode. The controller also handles braking power and aims to create a power delivery profile that maximises energy regeneration potential through braking while maintaining a maximum system responsiveness to input data telemetry, as seen in figures 3a and 3b.

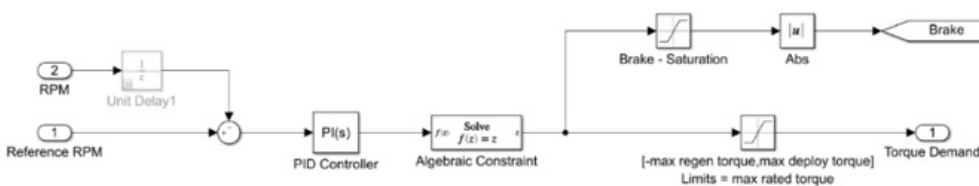


Figure 3a. PID control module.



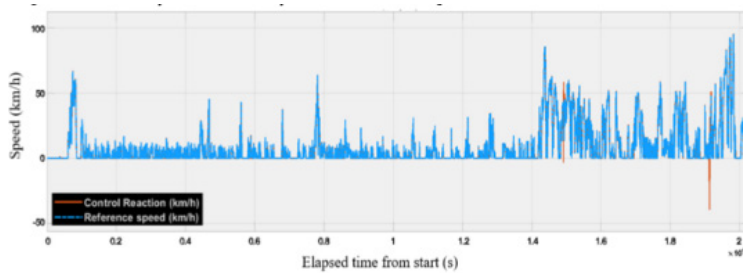


Figure 3b. Vehicle speed control.

The model is also able to simulate an approximation of the power demand created by the auxiliary power consumers in the vehicle, ranging from commonly used systems such as AC cooling, to more specific systems (such as refuse compressor systems) that have their power consumption modelled as a continuous power consumption set at an average value recorded in real datasets. These auxiliaries have been modelled as special, separately controlled resistors, placed in parallel with the battery cell network, and hence provide a realistic steady drain on the battery system when the vehicle is in use. Finally, the model can provide real-time, unit-by-unit measurement of parameters of interest of the powertrain, such as instantaneous power at battery and motor level, motor and gearbox RPM, as well as mechanical stress, but also battery losses and SoC estimation, a key indicator that indicates energy usage dynamics. The model capabilities mentioned can be seen illustrated in figure 4.

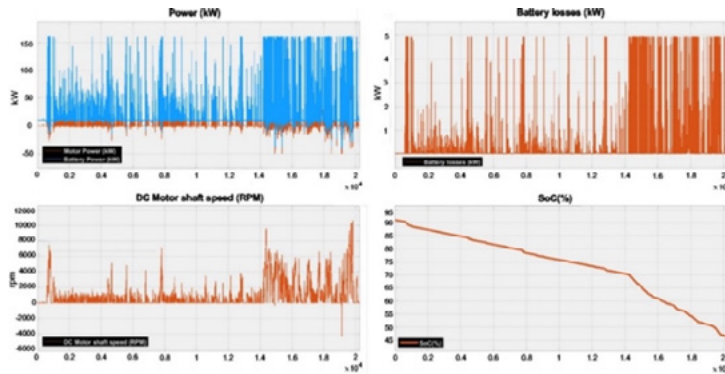


Figure 4. Power information output. Model output example. TL – Power @ Motor & Battery (kW), TR – Battery losses (kW), BL – Motor RPM, BR – SOC

In order to ensure the software model simulates results homogenously, some reasonable assumptions had to be made with respect to the technical specifications and key performance characteristics of the modelled eRCV.

Firstly, a lack of resolution in different monitored variables has been observed in the provided data. It was derived that the recorded real data may have an error in a worst-case scenario of $\pm 1\%$ compared to the real-life vehicle data logs, considered as reference points. This may have a snowball effect on the accuracy of the data generated by the presented vehicle model and its results must be adjusted to account for this lack of resolution in input data. Similarly, the provided specifications point out that the vehicle mass can vary between the base vehicle weight and the maximum rated weight, depending on the amount of refuse collected per driving cycle. For ease of result understanding, all runs have been simulated with a vehicle weight set as the midpoint of the weight boundaries. While this approach may exhibit large variations in results over small datasets, the provided data creates a big simulation dataset which significantly attenuates any potential data outliers. The aerodynamic subsystem part of the model allows for externally defined mass in various ways, including as step and ramp functions. Furthermore, the auxiliary systems power draw has been derived based on the available data in the provided vehicle logs as well as value-tuning during the validation phase.

2.2. Description of analysed dataset

The aims of analysing the dataset are based around understanding energy usage if eRCVs with a given custom specification were to be deployed to perform refuse collection on the same routes the contracting company is currently using. Based on energy usage, recommendations can be given whether routes should be managed differently based on a selection of criteria (such as collection area type, or day of week). Understanding energy usage can also provide an insight towards the feasibility of deploying a fully electric RCV fleet for rubbish collection. The environmental and financial impacts of such a fleet may be further enhanced with use of other renewable systems that would be able to charge it. Secondly, the analysis should also give some insight into whether the vehicle batteries could be integrated into the energy



grid and be used as “extra energy tanks” in the form of a Battery Energy Storage System (BESS) that would help ease electricity grid stress during peak times. Such systems may also be used to provide long-term investment attenuation, by integrating them with the energy grid so that they may be able to give energy to the system during peak demand hours.

Finally, to efficiently simulate the entire received bin and route data, a custom-spec simulation routine parallelisation procedure has been used. The dataset upon which the routine has been applied consists of GPS and vehicle data logs of all refuse collection routes throughout a 2-week period, amassing to 752 hours, 9 minutes and 23 seconds of effective vehicle running. These have been processed and simulated by the parallelised simulation environment loaded with the software EV model in 7482 seconds.

3. Results

To achieve the proposed aims, the simulated data has been grouped with respect to different selection criteria in order to perform a multivariate analysis. Firstly, energy usage throughout the entire output dataset has been interpreted regardless of any classification factors, so that a baseline energy usage per bin collection route can be determined. When considering all the 229 driving routes recorded throughout two weeks of refuse collection operations, the average driving cycle lasted for 11824 seconds and used 24.6% of the specified battery capacity, which translates into an absolute energy usage of 74.38 kWh. The minimum energy usage per driving route has been found to be 20 kWh, while the maximum energy used in one cycle is 163 kWh. The total energy used throughout the cycles is 17034 kWh.

Secondly, routes have been grouped by the type of collection they represent (Clinical – collection of medical waste from hospitals and other care centres, Dom (Domestic) – urban residential house neighbourhoods, Dom Rural (Domestic Rural) – a blend of urban and rural residential house neighbourhoods, and Weekly Flats – a selection of routes that collect rubbish from a group or block of flats on a weekly basis). This classification aims to indicate the most common types of refuse collection zone the fleet is concerned with and understand the differences in performance indicators between them. Similarly, the routes have also been classified by the day of week on which they are performed. This has been done to determine an average energy usage figure throughout every day of the week independent of collection area type and should give clues related to the current route management scheduling efficiency. For every classification type, in addition to energy usage in relative battery level (%) and absolute energy usage (kWh), the total and average timing of every route grouping has been calculated. Plots of every grouping can be seen in figures 5-7.

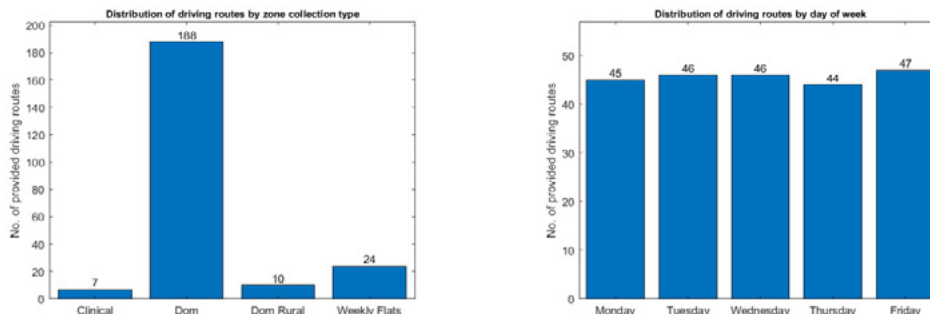


Figure 5. Distribution of driving routes. Left – Type of refuse collection zone, Right – Day of week

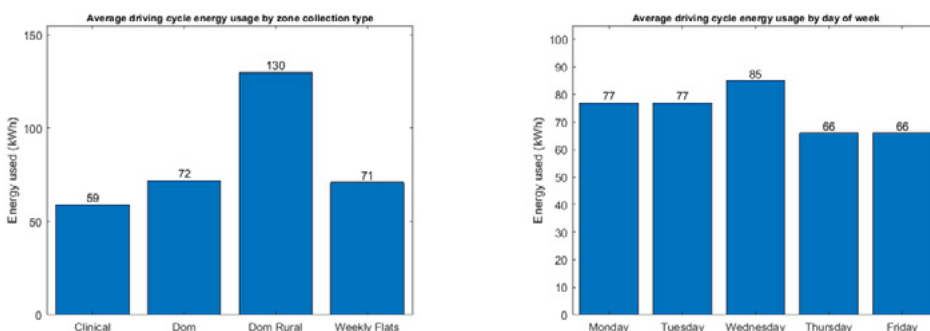


Figure 6. Average energy usage per driving cycle. Left – Type of refuse collection zone, Right – Day of week



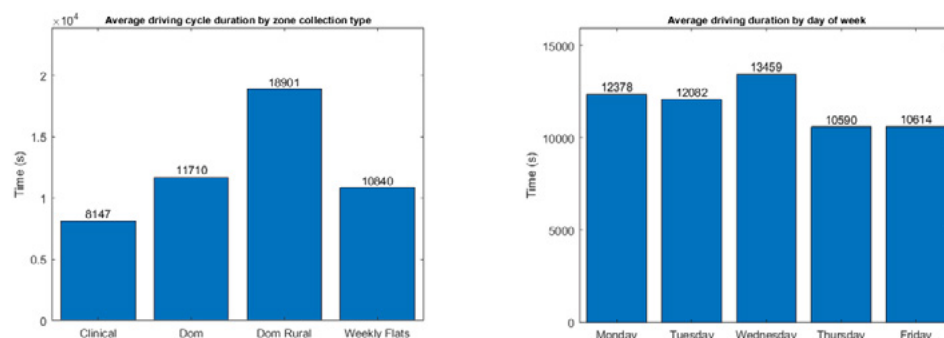


Figure 7. Average driving cycle duration. Left – Type of refuse collection zone, Right – Day of week

It can be observed that the Weekly Flats routes are particularly inefficient, this may be due to the route characteristics (plenty of collection points relative to other collection zone types, therefore many start-stop cycles) or a general imperfect approximation of the driving style generated by the data processing sections of the model. To improve energy consumption on every route especially this one, economic driving techniques such as predictive driving and lift-and-coast are suggested.

Additionally, the figures related to the classification of input data by day of week suggest a reasonably well distributed energy usage on average, albeit this could still be further improved. Driving route durations on average vary by almost an hour of effective route collection running between the busiest day (Wednesday) and the slackest day (Thursday). Similarly, this correlation is also suggested by the average energy usage by day bar graph, under figure 6.

To further improve the distribution of energy usage throughout the week, driving routes can be re-organised based on the guidelines and priority list presented previously. Another potential solution that may aid towards this can exist in splitting some of the longer driving cycles into smaller bits so that the average daily usage can be smoothened out. Optimising the energy usage distribution across the entire week is a desirable concept as this simplifies the design choices (by only needing to consider one reliable energy usage figure) that may arise when conceptualising renewable energy systems at base that would help attenuate the charging costs of a 100% deployed eRCV fleet.

Similarly, it can be seen from the processed output data that the average number of rubbish collection vehicles deployed on a given day ranges from 24-26. Assuming the minimum (24) of this range, a summarised analysis can be performed to understand the daily energy usage regarding a fleet of eRCVs. Assuming that every vehicle has the battery size provided by the eRCV manufacturer (300kWh) and using average energy usage and average driving cycle duration on a daily basis, together with a set start date for rubbish collection at 08:00 and only one route shift, it can be derived that the rubbish collection shifts will end on average at 11:50, at this point the available energy storage capacity for grid support could be calculated at 5000 kWh, assuming for other losses and rubbish collection vehicles that fail to make it in time by the average end shift date, implying an approximate total figure of 1900 kWh of energy used by all vehicles for one day. This opens plenty of opportunities to interface the vehicle energy storage with the grid and other energy generators the contracted rubbish collection company may have, to charge the eRCV fleet during low-demand hours but also have them support the energy grid during peak energy demand hours, effectively using the vehicle batteries as a modular energy storage system that can adapt its needs and capabilities in a versatile manner. A detailed day-by-day analysis concerning average shift end times and total remaining energy in all vehicle batteries is presented in table 1.

Day of week	Avg. shift end time	Total remaining energy (kWh)	No. of RCVs deployed (est.)
Mon	11:26	5856	24
Tue	11:21	5849	25
Wed	11:44	5645	24
Thu	10:56	6140	24
Fri	10:57	6130	26

Table 1. Average performance indicators – day of week classification



4. Potential reduction in CO₂ emissions and fleet costs

By utilising the abovementioned energy usage figures and noting the gross thermal calorific value of pump-ready diesel, we can provide some estimates regarding the current carbon dioxide footprint caused by the RCVs in use and the potential reduction in these emissions if a full-electric fleet replaces the diesel-powered vehicles.

From the energy usage previously presented, it is noted that as an estimate, all-classifications-considered energy usage average is rated at 71 kWh. Based on this figure and the estimated number of driving cycles performed daily (or number of RCVs deployed, if a 1:1 factor is attributed), it can be derived that the average energy used on a weekly basis is 9126 kWh. This value can then be multiplied with the gross calorific value of diesel (World Nuclear Association, 2021) to calculate an estimated weekly carbon dioxide footprint that revolves around 1360 Kgs of emissions every week, which, if extrapolated, results in approximately 36.5 tonnes of carbon dioxide gas emitted yearly (This is an estimation for illustration only based on the assumption that the eRCV and the RCV have similar efficiencies – this is unlikely in practice, but better approximations could be made with more data input from the fleet operator). The carbon dioxide footprint is likely to be bigger than expected, since diesel-powered powertrains have a significantly lower system efficiency, so the real energy usage will be higher than what a full-electric RCV would exhibit. Furthermore, the emission estimate precision can be further improved if actual fuel consumption figures for the diesel RCVs in use is provided. The same calculation can be performed for other greenhouse gases (GHGs), such as NO_x, if desired. To fully understand the potential reduction in carbon emissions as well as what costs potential solutions may incur, the aspect of vehicle charging needs to be considered. To do this, 2 scenarios have been considered.

4.1. Scenario 1: Off-grid vehicle charging system

The first scenario implies an off-grid charging system that works independently of the national energy grid. The contracted local waste management company currently operates a biomass refuse incinerator with an output rating of 1MW. When comparing this figure with expected energy usage, it can be deducted that the entire fleet is realistically able to be charged from the power output of the incinerator, offering the opportunity for creating an off-grid charging system which also provides the benefit of having to consider less electric grid regulations, therefore more flexibility in terms of charging performance and cost of system design and maintenance.

Finally, since the incinerator is required to operate constantly independently of the eRCV fleet, all the energy given out by the system is “free” from a vehicle standpoint. This means that if the eRCVs are charged off-grid from the incinerator, a theoretical 100% decrease in CO₂ emissions generated by the fleet operations can be achieved. However, this scenario will be more prone to failure from a system design perspective since there is only one system energy source.

4.2. Scenario 2: On-grid charging system

The second possible scenario of charging the electric fleet in question is represented by having the charging energy supplied by an on-grid system, which takes the energy from the national grid. In this context, the carbon dioxide emissions can be determined by looking at the share of renewable energy production in the UK national grid, which is currently set at 40.2% (DUKES – Energy Trends, Department for Business, Energy and Industrial Strategy, 2020). This is also the effective potential reduction in the CO₂ footprint in this scenario.

The major benefit of this scenario is that the user can benefit from energy price mechanics, such as peak/off-peak price variations. Therefore, a strategy involving buying (charging) energy at low price and selling vehicle leftover battery energy (supporting the grid) at high price. Based on the previously presented conclusion regarding the possible feasibility of charging the eRCV fleet with on-grid chargers, charging patterns need to be considered as well. Given that one driving cycle on average depletes only 24% of the vehicle battery capacity and the shift times are reasonably predictable, with all shifts occurring during the day, it can be safely suggested that vehicles be charged overnight to benefit from the significantly lower off-peak energy costs. A full battery charge during off-peak times is predicted to cost approximately 40-55 GBP (according to consumer-specific UK economy7 tariffs, however this could be higher or lower when considering business rates), accounting for a 90% charging efficiency, and can be achieved with reasonable margin during the time of day with off-peak tariffs by employing 50-60 kW fast charging stations. Additionally, due to the aspect that after every day there is a significant amount of energy left in the vehicle batteries, once the RCVs end their respective shifts, they can be connected to the grid and have the leftover energy be used as a grid support BESS as required, to provide grid support during peak energy demand times, thus reducing the net cost of system implementation and maintenance on the long-term through having the ability to “sell” the available energy to the national grid during maximum demand. Finally, if the second scenario is not a desirable feature, the specified battery capacity could be reduced, making the cost of an eRCV lower and slightly more efficient due to the vehicle being lighter.



5. Conclusions & Future aims

The presented simulation results suggest that both energy usage and carbon dioxide emissions can be significantly reduced by implementing an eRCV fleet for refuse collection in an urban environment. Furthermore, the financial and environmental impact of the fleet can be further enhanced by implementing vehicle charging systems that take advantage of local energy production. The analysis and calculations performed in this study can be further extended for larger, more complex fleets, such as for bus route systems in the Sheffield area. Similarly, other urban areas can also benefit from these conclusions, by using a reasonable degree of result extrapolation depending on the topography area in question. Such vehicle fleets may bring bigger savings in terms of maintenance and operation costs, as well as more meaningful reductions in the carbon footprint of the public logistics sector around Sheffield and beyond.

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ENERGY USAGE AND SUSTAINABILITY PREDICTION FOR ELECTRIFIED PUBLIC SERVICE VEHICLES (PSVS) – A CITY-DISTINCTIVE PRE-DEPLOYMENT SOLUTION

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1. Introduction

As shown in the statistics published by the U.K. government on March 2021, in the year 2020, the U.K. transportation sector produced 97.2 million tonnes of carbon dioxide which accounted for 29.8% of all territorial CO₂ emissions in the country (National Statistics, 2021). Although Public Service Vehicles (PSVs) are only a limited proportion of the 32.9-million vehicles registered in Great Britain (Wagner, 2020), the significance of Greenhouse gas (GHG) emissions from PSVs have been amplified due to the significant increases in new battery-electric cars (Wagner, 2020).

Diesel-fuelled internal combustion is a tried and tested vehicle propulsion technology, used by PSVs across the U.K. and around the world. However, achieving progress towards net-zero greenhouse gas emissions (Shankleman, 2019) necessitates its demise. To reduce the environmental impacts introduced from municipal public services, PSVs powered from an alternative energy source, such as Compressed Natural Gas (CNG) and hybrid hydraulic, have been introduced. Although the deployment of CNG-PSVs in the U.S. is rising (Vock, 2014), PSVs in the U.K. are still rarely powered by natural gas. While literature shows that the tailpipe emission of a CNG-PSV is, in fact, higher than a diesel vehicle since the fuel efficiency of a CNG engine is significantly lower than a diesel-powered Internal Combustion Engine (ICE) (Zhao et al., 2017).

Electric motors have an extended history than ICEs, over the last decade, there has been a significant increase in the adoption of Electric Vehicle (E.V.) powertrains (Canter, 2008). These are shown to be less polluting with a smaller carbon footprint when compared to their traditional ICE counterparts, and the growth of renewable energies means that the GHG emissions relating to electricity generation are also dwindling. In addition to their environmental benefits, the electric vehicles could also offer significant financial benefits due to their limited operation cost. Published articles indicate that operating electric PSV (ePSV) fleets could produce a daily fuel reduction of 100,000 litres for certain services such as waste collection (Nickels, N.D.), while the economic significance could become increasingly apparent with higher levels of fossil fuel prices (Little, 2018). In addition to a reduced operation cost, initial infrastructures such as charging stations will also become cheaper, further emphasising the cost benefits when operating electric-powered fleets.

However, large scale applications of ePSVs remain rarely seen on the market. On the one hand, an all-electric PSV can be three times the price of a conventional diesel PSV (Zhao et al., 2017), mainly caused by its expensive battery pack and corresponding management system. On the other hand, word-wide research shows that an electric vehicle is generally four times the weight of a similar ICE vehicle, mainly due to its onboard energy storage components. Therefore, a considerable amount of energy is consumed to operate the vehicle itself (with its heavy onboard battery) to maintain traction (Zhao et al., 2017). Hence, for an electric PSV, optimising and reducing the weight of its onboard energy storage system could significantly improve its fuel economy while reducing its initial procurement cost.

To moderately optimise the battery capacity, the energy required to operate the targeted service routes is preconditioned but generally unavailable due to the nature of proposed pre-deployment analyses. Even though pre-defined driving cycles are commonly used for measuring tailpipe emissions and fuel economy of small-sized passenger cars (Environmental Protection Agency, N.D.), the public service orientated vehicle, commonly working under ideographical conditions such as low speed and frequent stop-start cycles, expected to produce arguable results when tested or simulated under these driving cycles. Meanwhile, the street characteristics and urban terrain has been recognised as another critical factor for driving energy calculation (Brundell-Freij, 2005), where these characteristics trends to be distinctive among cities. Thus definitive studies and analyses using vehicle-distinctive simulation module and city- distinctive route and road data are necessary.



2. Research target and proposed methodology

Like any typical PSV, a Refuse Collection Vehicles' (RCVs) energy consumption and corresponding emissions are equally significant, therefore used in the paper as an example PSV. An RCV generally operates a low-speed duty-cycled profile on restricted residential areas, due to its start-stop manoeuvres, low average speed and considerably high payload, the RCV consumes significantly more energy even compared with a typical PSV. Meanwhile, refuse collection has varieties of structural advantages, making it suitable for electric transition, especially when compared with other human-mobility oriented public services. On the one hand, an electric RCV that is purely powered by battery technology won't generate tailpipe emissions hence keeping pollution away from the urban area. On the other hand, its start-stop nature can be easily achieved when driven by electric motors. However, refuelling a diesel RCV clearly requires far less time than charging an eRCV. Hence, to dispel the range anxiety as well as demonstrating robust serviceability, most of those eRCVs are fitted with a large battery packs, resulting in a vehicle that is able to double-shift without recharging (Digi Greenwich, 2017). However, this over-weighted energy storage component causes additional energy consumption during the standard collection period and significantly increases the procurement cost.

In this paper, to effectively analyse the energy usage of a desired ePSV fleet, comprehensive analyses and calculations, driven by both geographic data and service routes, are presented. The approach proposed in this paper can be classified into two stages, converting addresses to a simulated drive route, and then calculating the energy usage an ePSV will be needed to cover this simulated route. To begin with, a proposed methodology is proposed to produce a simulated driving route, representing an electric PSV's departure from the depot, operating the service routes, and finally driving back to the depot. Next, a vehicle designated model which calculates the energy usage from the previously generated drive route is provided. By combining the algorithm of route generation with the model of energy usage calculation, this paper demonstrates how the exact amount of energy to operate a given service route is predicted.

3. Research review

Several existing methods for energy consumption prediction are mostly based on computing instantaneous energy usage and adding the results over time. Newer approaches such as metaheuristic algorithms are also used in combinatorial optimisation, but introduced additional complexity. Simple techniques such as the voltage monitoring approach (MpowerUK, N.D.) converts instantaneous measured voltages to a relative SoC based on the battery's voltage-SoC discharge curve. While other meta-heuristic techniques have been applied to the energy usage prediction (Abousleiman, 2015), In this research, the coulomb count method (MpowerUK, N.D.) has been selected. While also known as the current integration, the coulomb count method takes advantage of the exponential time-dependency of charge respecting to current to calculate accurate energy consumption. Although errors can be accumulated due to the continuous nature of the integration operation, the coulomb counting method has been deemed sufficient and has been successfully integrated into the software drivetrain model.

Meanwhile, while most frequently chosen algorithms towards automated route plan, such as TDS, A* or Dijkstra, is able to generate solutions that are reliable among time, these can be further improved in the context of route planning for electric vehicles. Especially given their different driving characteristics compared to traditional ICE powertrains, such as instant maximum torque delivery and limited range that is significantly influenced by road and weather features (Abousleiman, 2014).

4. Address driven energy prediction

Conventionally, the local council holds a large number of locations to be visited for any specific PSVs. Using RCV as an example, with the increasing number of areas that need to be visited, the collection schedule becomes more solidified. When introducing electrical waste trucks to the collection fleet, the risk of service interruption is therefore of significant importance. As illustrated in (Magnetic, N.D.; Smulian, 2018; Veolia, 2018), empirical data presented in various articles demonstrate that most eRCV providers were advancing a large, in terms of capacity, battery as the credential for robust service availability. However, the weight of eRCVs' onboard energy storage device, the battery, is not proportional to the amount of energy stored, hence carrying an oversized battery could significantly undermine the eRCV's advantage of sustainability. In this section, a methodology will be presented to model the energy utilisation of an eRCV, thereby predicting the energy usage for any given refuse collection route. The overall objective being to determine the optimal SoC strategy for each vehicle, to reduce the battery capacity and thus, reduce the vehicle's kerb weight.

Through a novel address analysis process, the schedule addresses for a given day provided by the local authority can be converted into a dataset. This dataset consisted of all geographic coordinates correlating to the exact locations of the bins to be collected. In order to gain a complete route that is able to be used for the total energy usage calculation, the depot of the RCV fleet is also added and set to be the origin and termination point for the



collection route. Based on these addresses and coordinates, together with other requirements and regulations, such as the RCV can only collect bins on a downhill cycle, an imitated route that potentially represents a real-world driving route can be generated, hence providing the same data as the data recorded from a positioning-logging device installed on a PSV. With the information provided by the virtual route data, a novel vehicle model solution has been implemented, which shows the energy drained through the cruise and collection activities from the battery, through power electronic converters of the vehicle, to the main drivetrain and other auxiliary components such as in-cab air conditioner. The simulated energy figure focuses on both the overall usage of a given route and instantaneous power consumption in a one-second average interval. A simplified system topology is shown in Figure 1, which indicates its three main subsystems: address decode, route simulation and energy usage prediction.

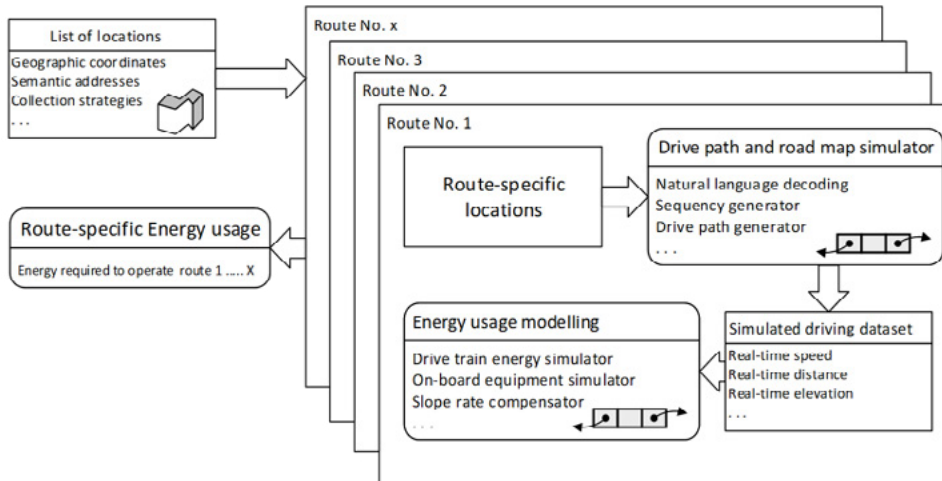


Figure 1. System topology of the proposed address-driven energy prediction methodology.

Utilising this methodology, all planned address groups can be analysed and produce a cluster of figures that hold energy usages data of being what theoretically could refer to the energy required to collect each group of addresses. Based on these route-level energy figures, optimisation to the onboard battery can therefore be conducted. First, through re-constructing the address group, the route with salient energy consumption can be modified. Secondly, a dedicated battery pack can be designed so that its stored energy could match the requirement of the waste management operator while maintaining a limited weight.

5. Evaluation and results

In order to validate the effectiveness of the proposed address-driven energy prediction methodology, the energy consumption model is firstly evaluated using real-life data, but in two stages. First, real-life driving routes are used to evaluate the efficacy of the proposed modelling methodology. The results obtained from the proposed model is compared with the real-life SoC figure collected together with the driving route. During the evaluation, driving cycles have been chosen at random from provided data sets and having its behaviour observed for over 130 kilometres of driving cycles in total. Throughout this evaluation stage, the average error rate with outlier marker attenuation (i.e. the difference in SoC percentage at the end of the simulation between real-life data and simulation) can be found to be 5.8%. A comparative histogram showcasing several of these error rates per cycle is presented in Figure 2.

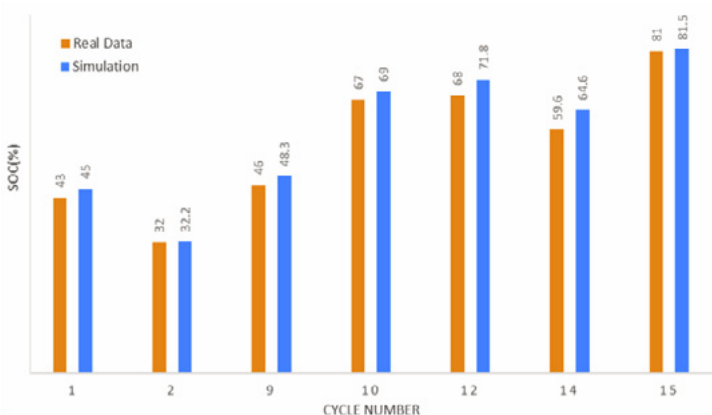


Figure 2. Comparison between real-life and simulated end-of-collection SoC using real-life driving route.



To evaluate the proposed algorithm, data has been randomly selected from the address book provided from the local authority. The data used for evaluation has been plotted in the following Figure 3.



Figure 3. The plot of the sample data used for evaluation.

Utilising the proposed algorithm, as shown in Figure 4, the proposed algorithm successfully generated a virtual driving route that covers the entire targeted addresses while achieved a minimised repeating section.

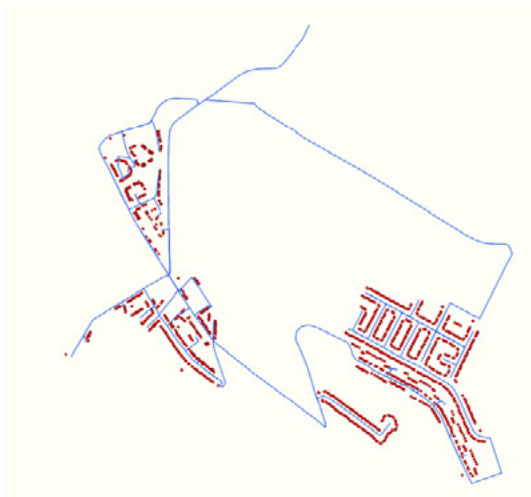


Figure 4. Simulated virtual driving route for the select sample address set, utilising a given road structure.

Figure 5 showing a comparison between the virtual driving route and the driving route logged from an in-service vehicle, which demonstrating a negligible difference between the real and simulated path.

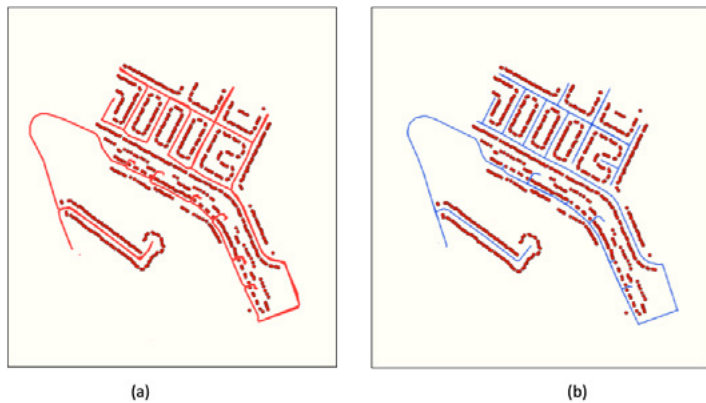


Figure 5. Comparison between real (left) and simulated (right) driving route (section).



Using the simulated driving route showing above, a speed profile could be then generated. As shown in Figure 6, the speed profile can be split into cruise sections and collection sections based on its speed characteristics.

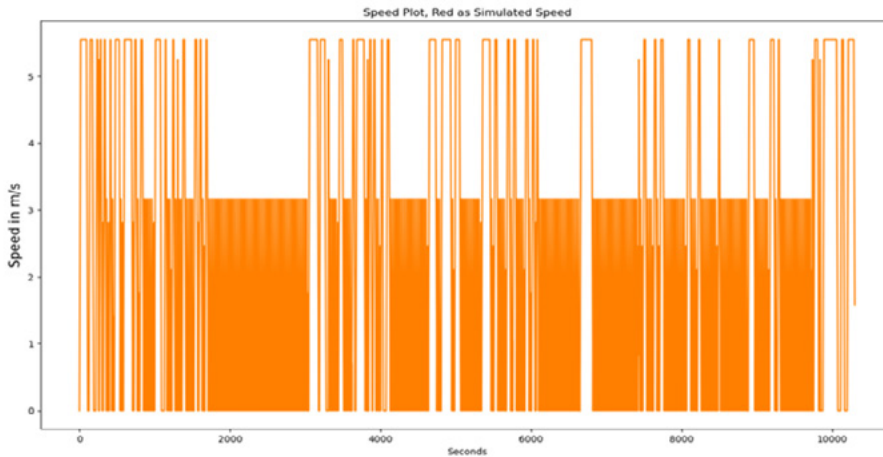


Figure 6. Generated speed profile.

The integrated system was therefore evaluated, which primarily focused on the collection stage, where the vehicle uses most of its energy. As can be seen from Figure 7, simulated drive path has been generated so that fed into the proposed energy simulation model. Results are compared between the real-life energy usage and the energy usage predicted from the generated drive route.

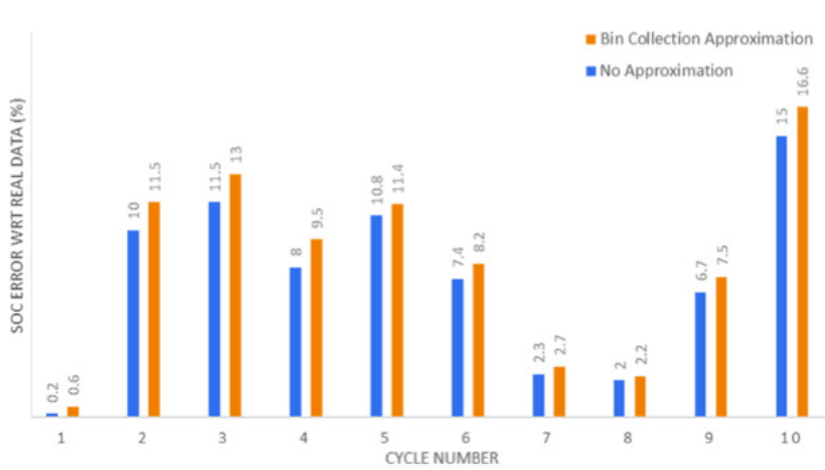


Figure 7. Comparison between real-life and simulated end-of-collection SoC using simulated driving route.

As can be seen from the above evaluation, the results have successfully demonstrated the consistency and accuracy of the proposed drive route simulation algorithm and energy prediction model. Hence validates the efficacy of the proposed address-driven energy prediction methodology.

6. Conclusions & Future aims

Public services play a vital role in contemporary communities and require an increasing number of vehicles to accomplish. To reduce noise pollution and GHG emission, ePSV market share is rapidly increasing. However, off the shelf ePSVs are equipped with heavy batteries which are consistently oversized to relieve range anxiety. However, research has shown that the battery contributes the majority of the vehicle's kerb weight, and thus carrying an oversized battery could crucially jeopardise eRCV's significance of efficiency and cost. Optimally, the battery capacity should be custom-designed to minimise its weight and cost. However, it requires a vehicles' in-route driving data, which is challenging to obtain before deploying vehicles. Hence, a novel methodology to provide city-distinctive energy prediction and customise ePSV's battery before deploying the fleet is required and critical for public sectors to achieve improved sustainability and investment efficacy.



The solution presented in this paper takes waypoints as input. Through a novel two-stage analysis, the energy required for a PSV carrying out giving commissions in a targeted city can be calculated. The methodology and analysis presented are augmented by a novel, customisable energy prediction model, which is backboned by a state-of-the-art PSV virtual driving and route-finding algorithm, while the results have successfully validated the proposed solution. Furthermore, through calculating all planned routes and services, the cluster of energy figures obtained can then be used to customise the battery capacity required for a designated ePSV fleet. Using this suggested battery capacity, the public sector and E.V. manufacturers could therefore optimise the battery size before production. Furthermore, the environmental contribution could also be progressively obtained, providing a means for urban authorities to strategically assess carbon footprint planning and charge station distribution in any designated area.

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SUPPLY CHAIN RESILIENCE



RESILIENCE STRATEGY OUTCOMES, MEDICINE SHORTAGES, AND THE PHARMACEUTICAL SUPPLY CHAIN (PSC)

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Purpose

This study aimed to identify the outcomes of the resilience strategies adopted by supply chain actors to mitigate the impact of medicine shortages and supply chain disruptions.

Research Approach

An exploratory mixed methods design that involved qualitative and quantitative research inquiry was used. The qualitative data were first gathered through 23 semi-structured interviews with key supply chain actors across the PSC in the UK to explore their experiences. Secondly, the findings from these semi-structured interviews were used to develop a survey distributed to a broader spectrum of supply chain actors where the final sample from the survey was (n=106). Thirdly, Structural Equation Modelling was used to analyse the data generated from the survey. Finally, the data were triangulated to discuss the research findings.

Findings and Originality

The study found that supply chain actors employed both recovery and resistance strategies to reduce the impact of medicine shortages. However, due to the nature of the PSC, which includes limited suppliers, complex production processes and stringent regulations, these strategies sometimes had detrimental effects. For instance, when product flexibility was employed to address medicine shortages, the SC of alternative products was threatened due to the limited number of suppliers. Also, information sharing, to a large extent, increased the behavioural uncertainty of PSC actors. However, resource sharing through strategic alliances increased resilience strategies impact.

Research Impact

This work contributes to the building body of supply chain resilience research by providing empirical evidence into how supply chain resilience strategies mitigate the impact of medicine shortages and the outcomes of these strategies. In addition, the study shows and advocates for a holistic approach to developing resilience strategies when addressing medicine shortages due to the detrimental effects of some strategies, such as partner dissatisfaction and behavioural uncertainty.

Practical Impact

The findings provide practical insights into how managers can implement supply chain resilience strategies by identifying the possible impact of specific strategies. Thus, it emphasises the need for a systemic approach where the impact on supply chain partners is considered when developing resilience strategies in the PSC.

Keywords

Pharmaceutical Supply Chain, Resilience Strategies, Medicine Shortages, Supply Chain Disruptions.

Introduction

Medicine availability is critical for effective healthcare operations (Chen et al., 2020). In recent years, the global pharmaceutical industry has witnessed substantial growth, with the global market valued at about \$1.2 trillion in 2019 (Mikulic, 2020). However, there is global interest in the rising rates of medicine shortages (Phuong et al., 2019). For instance, the UK and the US recorded 178 and 166 new cases of medicine shortages in 2019 (Rees, 2020; ASHP, 2021). Medicine unavailability has had a detrimental impact on supply chain (SC) actors as it has restricted patients' care, hindered participating firms' operations and financial performance, and, in some cases, resulted in the death of patients (Phuong et al., 2019). Globalisation, manufacturing issues, natural disasters, and the complex interface between the pharmaceutical supply chain (PSC) and regulatory requirements have been identified as some of the factors challenging medicine availability (Tucker et al., 2020; Vann Yaroson et al., 2021). The dynamic nature of medicine shortages thus raises concerns about how best to address them.



Proponents of supply chain (SC) resilience strategies advocate for its propensity to mitigate the impact of disruptions (in this case, medicine shortages) (Aldrighetti et al., 2021; Katsaliaki et al., 2021). SC resilience requires organisations to develop timely and cost-effective strategies to prepare, respond and recover from a disruption (Scala and Lindsay, 2021). These strategies include flexibility, visibility, and collaborative practices and can either be recovery or resistant. The concept of SC resilience hinges on the idea that if inherent SC weaknesses (vulnerabilities) are addressed, the impact of disruptions may be reduced (Hendry et al., 2019).

Medicines differ from other products due to their pertinence for survival in most cases. The costly nature associated with its manufacturing and distribution process also limits the number of suppliers in the PSC (Paplexi et al., 2020). In addition, the PSC requires safety and reliability in delivering healthcare products while meeting consumers' needs (Chen et al., 2020). A medicine must be proven safe and effective in fulfilling its intended purpose. This stems from the metabolic processes in the body following medicine consumption understood by limited specialised individuals (Paplexi et al., 2020). To this end, a PSC is a highly regulated and complex SC, made up of multifaceted procedures and operations that facilitate medicine discovery, development, manufacture, and distribution. The peculiarities of the PSC may not permit the effective building of resilience. For instance, SC actors may be unable to engage in flexible operations due to the limited number of suppliers. Moreover, approaching SC resilience as a systemic concept that requires interactions and decision-making processes among SC actors (Vann Yaroson et al., 2021) may affect possible outcomes in the PSC.

Few empirical studies examine the potential and outcomes for resilience in the PSC (Tucker et al., 2019; Vann Yaroson et al., 2021). Thus, our study attempts to identify what resilience strategies SC actors employ when they encounter shortages and the impact of these strategies. We adopt a systemic approach to achieving our research objectives by examining PSC actors' experiences, activities, and strategies. Our findings contribute to existing SC resilience and medicine shortages literature by providing empirical evidence and practical implications on applying proposed resilience strategies when addressing shortages. The section following this presents an overview of the literature on the research phenomenon, followed by methodology, analysis, discussion, and conclusion sections.

Literature review

Our study explored the outcomes of resilience strategies in the PSC when addressing shortages. In order to achieve the research objectives, this section provided the literature on the concepts of resilience and medicine shortages.

Supply chain disruptions: Medicine shortages

Due to the dynamic nature of medicine shortages, discrepancies exist on what constitutes medicine shortages among supply chain actors (Miljković et al., 2020). Some studies focus on manufacturing abilities, reference to pharmacies (ASHP, 2021), or timing (Miljković et al., 2020). Further, the causes of medicine shortages are multifaceted, ranging from manufacturing issues to pricing fluctuation and reimbursement, regulatory policies, natural disasters, pandemics, shortage of raw materials, and the list goes on (Phuong et al., 2019). These causes can be categorised as anticipated (such as quota systems) and unanticipated (natural disasters). These issues hinder the ability to determine practical strategies to curb the impact of medicine shortages (Vann Yaroson et al., 2021). The above-identified factors denote the need to address medicine shortages from a supply chain management perspective which has received limited scrutiny in prior studies.

Supply chain resilience

The premise of SC resilience is its adaptive capacity to continue operations in the presence of disruptions (Shekarian and Parast, 2020). SC resilience entails responsive and/or recovery strategies. However, differences exist on what constitutes resilience among the various SC resilience proponents. Some studies have concentrated on only the recovery elements of supply chain resilience which is the capacity of the supply chain to return to or respond to normal operations after a disruption has occurred. The shortfall may be the costs associated with these strategies. Also, some recovery strategies may not be timely and may be unable to manage the impact of the disruption, which may lead to adverse effects, as in the case of PSC, which may lead to the death of the patient. The resistance elements of SC resilience are the capability to recognise, anticipate and defend against the changing shape of risks before adverse consequences occur (Sa et al. 2019). Adopting these strategies provide the supply chain with the capacity to recover from or resist disruption by containment or avoidance. There are, however, limited empirical studies to identify when supply chain resilience strategies are either recovery or resistant strategies (e.g. Hendry et al. 2019).

Essential ingredients of SC resilience, as identified by prior literature, include flexibility, visibility, and collaborative practices (Sabahi and Parsast, 2020). Flexibility refers to a firm's ability to adjust to the needs of stakeholders and the environment with minimum effort and reduced time. In most cases, this may entail speeding up production processes, ramping up supply and reduced lead times. Flexibility has been emphasised as the critical driver in SC resilience (Fayezi et al., 2017). However, the supply market configuration (number of suppliers, buyers, competition



among suppliers) may not make this strategy effective. SC collaboration requires firms to work successfully together for mutual benefits. This strategy encourages trust, information, resource sharing, and joint decision-making. Empirical evidence, however, suggests incorporating collaborative practices as resistance strategies to reap its efficacy (Hendry et al., 2019). SC visibility entails sharing information across the SC and is emphasised as an outcome of collaborative efforts (Vann Yaroson et al., 2021). Visibility may imply that manufacturers have complete information about the position of their assets within an SC environment to guide in mitigating unproductive decisions in the event of risks, unnecessary interventions, and in most cases, overreactions.

Despite a body of SC resilience literature presented, limited studies exist when addressing these strategies' outcomes, and our study contributes to this aspect of SC resilience literature (Tukamuhabwa et al., 2017). We achieved this by addressing the research questions i) what resilience strategies do supply chain actors employ in mitigating the impact of medicine shortages? ii) what are the outcomes of these applied resilience strategies? The following section provides an overview of the methodology employed in answering our research questions.

Methods

This study explored the outcomes of adopting resilience strategies to address medicine shortages. A mixed-method approach was used to achieve the research questions posed in this study. It involved a sequential two-phased exploratory research process of qualitative and quantitative techniques in collecting and analysing the data. This approach to the research was conducted under the pragmatism paradigm, which posits that social reality can be explained based on information (Creswell and Poth, 2016). By gathering information from multiple sources, the current underlying outcomes of resilience strategies were explored and explained.

The first phase of the study employed a qualitative approach to collect data from 23 key actors at various UK PSC levels using semi-structured interviews. A protocol designed from existing studies guided the data collection process at this stage. The protocol contained questions around medicine shortages, disruptions, vulnerabilities, and resilience strategies. The inter-views lasted between 30-60 mins. Digitally recorded and subsequently transcribed data were analysed using thematic analyses following a six-step process by Braun and Clarke (2014). First, the lead researcher generated the initial themes, which were validated by multiple researchers across Pharmacy and Operations Management disciplines. This process minimised bias and enhanced the study's validity (Corbin and Strauss, 2014). Second, these developed themes supported by established literature was used to design the quantitative phase's survey instrument.

The quantitative phase, the second phase of this study, confirmed the findings from the qualitative stage of the interview. The survey instrument that measured constructs such as flexibility, visibility, and some aspects of collaborative practices identified from the qualitative phase was used to collect the data. Ten experts conversant with the UK's PSC pre-assessed the reliability and validity of the survey instrument. Data were collected from 106 actors at various stages of the PSC and then analysed using a two-step approach on SPSS and SmartPLS. First, simple statistics such as frequencies and cross-tabulation identified the patterns and outliers of the data. The Cronbach's alpha, composite reliability and Average Variance Extracted (AVE) were used to assess the measurement models in the study. Second, the discriminant validity test (heterotrait-monotrait ratio (HTMT) approach) was used to validate the identified structural paths. Our structural model analysis was done using the partial least square method (PLS: PLS-SEM), a variance-based predictive approach employed, deal with complex models (Sarstedt et al., 2020). Data were triangulated using meta-inferences, where theoretical statements offered holistic explanations of the research phenomenon from the qualitative and quantitative findings (Venkatesh et al., 2016). Our findings and analysis are presented in the next section.

Results and analysis

Qualitative phase

This study explored resilience strategies outcomes when employed in mitigating medicine shortages using a mixed-method approach. At the qualitative phase of the study, 23 key research respondents in charge of making decisions at various levels of the PSC were selected to participate in the research. This comprised five manufacturers, one pre-wholesaler, two logistic service providers, five hospital pharmacists, six community pharmacists, one pharmacist working in a GP practice and three participants representing various regulatory bodies. The nature of the sample was also based on the design of the PSC in the UK. The rationale for conducting interviews across the various levels of the PSC was to examine and determine the interrelatedness of resilience strategies across the PSC.



Our study found that PSC actors adopted both recovery and resistance resilience strategies to mitigate the impact of medicine shortages at the qualitative phase of the study. To this end, flexibility, visibility, and joint decision-making were the strategies often used after a medicine shortage had occurred to recover from the disruption. On the other hand, resource sharing through strategic alliances were in place before a medicine shortage happened; thus, PSC actors could plan for the shortage. Table 1 provides a summary of the outcomes of the resilience strategies used in addressing medicine shortages.

Regarding flexibility, respondents often mentioned their need to seek alternative products (product flexibility) when a shortage occurred, either in form, volume, or presentation (Tablets/injections). At other times they sought alternative suppliers (supplier flexibility). Flexibility strategies also differed at various levels in the PSC. For example, the Community and hospital pharmacists (patient-facing PSC actors) demonstrated flexibility by substituting alternative medicinal products, while manufacturers sought alternative suppliers. However, the respondents reiterated that although these strategies were often effective at meeting patients demand, they were sometimes costly and encroached on the substitutes supply chain.

Table 1 Outcomes of resilience strategies in addressing medicine shortages.

Antecedents of PSC resilience	Identified strategies	Positive outcomes	Negative outcomes
Flexibility	Product flexibility	Ability to meet patients demand.	Adverse drug reaction Stress on alternative PSCs Increased PSC complexity Stress on human resources
	Supplier flexibility	Ability to recover from a shortage and meet patients demand	A limited number of suppliers Increased prices Costly alternatives.
Joint decision-making	Joint meetings and collaborative strategies	Ability to ramp up production. Delegation of strategies Source for alternatives	Panic buying Imposing quotas Conflict Partner dissatisfaction
Visibility	Product visibility	Ability to plan for medicine shortages	Panic buying
	Information visibility	Ability to prepare for and recover from the shortage	Panic buying Behavioural uncertainty Unethical business practices Absence of trust Information quality and timing.
Resource sharing	Strategic alliances	Information sharing Infrastructure sharing Buffer stock Increased use of technological infrastructure	Power display Monopolistic behaviour

The respondents also explained that all PSC stakeholders participated in collaborative decision-making processes after a medicine shortage had occurred. The goal of the joint meetings was to decide on the appropriate strategies for addressing the issue, such as ramping up production or importing and delegating responsibilities. However, some supply chain actors complained that due to stringent regulations and long lead times, it was often challenging to ramp up production capable of meeting demand. Even though this approach had positive outcomes as it provided solutions to ensure operations recovery, it led to other negative outcomes. For instance, the patient-facing PSC actors engaged in stockpiling while manufacturers/wholesalers adopted the rationing/quota approach, resulting in conflicts and partner dissatisfaction. All PSC actors argued that they engaged in such practices to ensure patients treatment continuity.

Product and information visibility were the two forms of visibility used in the PSC as identified from our analysis. These strategies involved information sharing and the use of information technology (IT) platforms. Respondents explained that pending information about shortages was often shared through various websites, joint decision-making meetings and conference bulletins. According to our respondents, the notice and the quality of information were insufficient and efficient to plan effectively. The IT platforms permitted PSC actors to view where their



products were in the supply chain, thus enabling them to plan for and respond to a disruption. However, information sharing was sometimes detrimental to building resilience strategies because it could also lead to members of the PSC engaging in unethical business practices such as stockpiling. Detrimental outcomes such as stockpiling generated mistrust and hindered future sharing of information. Our findings also identified resource sharing facilitated through strategic alliances as a PSC resilience strategy. These alliances permitted infrastructure sharing such as warehouses and technological know-how. It was evident here that trust existed between supply chain partners as they were permitted to stockpile. However, due to the limited number of suppliers in the PSC, forming strategic alliances led to monopolistic behaviours where smaller individual firms suffered.

Quantitative phase

This phase of the study sought to confirm the results from the qualitative phase. The survey was used to collect data from 106 respondents within five categories of respondents of the PSC. Thus, ten manufacturers, five pre/wholesalers, four regulators, 57 secondary care and 30 primary care pharmacists participated in the study. The disparity in SC actors' responses was expected since there are fewer manufacturers and regulators than primary and secondary care pharmacists in the PSC. Simple and descriptive statistics such as mean, frequencies and percentages were used to determine the data characteristics and statistical properties. This finding corroborated the findings from the qualitative phase of this research. Based on the findings from our interviews, we identified measurement models and structural paths examining the outcomes of resilience strategies. Resilience strategies were measured using recovery and resistance variables. The outcomes were measured using partner dissatisfaction (PDS) and behavioural uncertainty (BU). All the outer loadings were above 0.60, as suggested by (Hair et al., 2017). The Cronbach's alpha, composite reliability, and AVE reflect the reliability and validity of the measurement model used in this study. All the correlation values for the HTMT are below 0.95, confirming the identified structural paths in the model. The structural model was tested using the SmartPLS, and the results are presented in Table 2.

Table 2 Structural model examining supply chain resilience and outcome.

Structural path	Direct effect	T value
Behavioural uncertainty -> Partner dissatisfaction	0.798	16.148***
Product design -> Recovery strategies	0.534	6.965***
Product design -> Resistance	0.463	3.953***
Recovery strategies -> Behavioural uncertainty	0.295	2.259***
Recovery strategies -> Partner dissatisfaction	0.003	0.033
Resistance -> Behavioural uncertainty	0.015	0.103
Resistance -> Partner dissatisfaction	-0.254	2.113***

Significance ***p < .01, **p < .05, *p < .10

From Table 3, the structural path results confirm some of our qualitative phase findings. We find a relationship between recovery strategies and behavioural uncertainty, positive and statistically significant. There is also a negative and statistically significant relationship between resistance strategies and partner dissatisfaction; and a positive and statistically significant relationship between product design and resilience strategies (recovery and resistance). These findings depict the influence of PSC product characteristics in developing resilience strategies. It also shows that recovery strategies increase the level of behavioural uncertainty in the PSC while resistance strategies reduce partner dissatisfaction.

Discussion and conclusion

Our study sought to examine the outcomes of resilience strategies when managing medicine shortage using a mixed-method approach. We found several outcomes that may have practical implications. First, we found that PSC actors adopted both recovery and resistance strategies to manage medicine shortages. However, these strategies had positive and negative impacts. For instance, using product flexibility impacts substitutes SC's and incurred additional costs, defeating the purpose of resilience and possible explanations to partner dissatisfaction (Tukamuhabwa et al., 2015). Thus, flexibility strategies such as product flexibility in the PSC may be a temporary departure from practice as a short-term solution and may not be sustainable, as Fayezi et al. (2017) argued. Also, the threat of an adverse reaction from SC actors to information shared on impending shortages restricted the timing and quality of information shared. This action created a potential barrier to information visibility, as vulnerable firms could regard



the release of information as a threat to their survival (Katsaliaki et al., 2021). This provides possible explanations for the behavioural uncertainties of PSC actors. Also, strategic alliances, formed from long-standing relationships among SC partners, increased trust, alignment of goals and satisfaction with partners and could mitigate the impact of medicine shortages. These findings confirm the assertions in the SC resilience literature (Hendry et al., 2019).

Finally, closer scrutiny of the analysis showed that in most cases, PSC resilience resulted from SC actors' interactions and decision-making processes in response to medicine shortages. These interactions suggest developing resilience strategies systemically (throughout the supply chain) and not in parts (individual firms) (Sa et al., 2019; Vann Yaroson et al., 2021). Also, the decision of a PSC actor to build resilience strategies in response to disruption could result in further exposure of the PSC to the impact of disruption. These non-linear responses to decisions by PSC actors were influenced mainly by the complex production process and stringent regulations of the PSC. In conclusion, this study identified two forms of resilience strategies used in mitigating the impact of medicine shortages. However, due to the non-linearity of the PSC, these strategies had detrimental effects. Therefore, our study contributes to the building body of supply chain resilience research by providing empirical evidence into how supply chain resilience strategies mitigate medicine shortages impact and the outcomes of these strategies.

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SUPPLY CHAIN DISRUPTION IN A HIGH RELIABILITY ORGANISATION

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Introduction:

The global economy is operating in an age of turbulence (Christopher and Holweg, 2011; Seville et al., 2015). Supply chain disruptions (SCD) are increasing in frequency and intensity (Sawyer and Harrison, 2019), compounded by the forces of globalisation along the dimensions of replenishment, time, sea-borne distance, technology, and climate change, that are accelerating beyond organisational adaptability (Christopher and Towill, 2002; Friedman, 2016). A resilience gap has arisen, where such turbulence is increasing faster than organisations are becoming resilient (Hamel and Välikangas, 2003). An estimated 75% of companies experience an SCD annually (Tukamuhabwa et al., 2015; Scholten et al., 2019a), the threat of which is the most critical concern of organisations operating in a global environment (DuHadway et al., 2019). SCDs result in severe stock and operating under-performance, human resource capacity issues, financial losses, and firm closures, and their mitigation should be a high priority for top management teams (Craighead et al., 2007). Supply Chain Resilience (SCRes) has emerged as the dominant perspective in responding to such disruptions, defined by Ponomarov and Holcomb (2009, p. 131) as 'the adaptive capability of the supply chain to prepare for unexpected events, respond to disruption and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structures and function'.

However, the concept faces organisational and theoretical challenges:

Organisational Challenges:

SCRes is a form of insurance, a trade-off between the cost of just in case and the lean nature of just in time, creating a tension between efficiency and effectiveness (Sheffi, 2001). The trade-off has not been properly assessed (Hosseini et al., 2019). An optimum solution for balancing the tension between efficiency and effectiveness has not been found (Linnenluecke, 2017), a dilemma that must be investigated further (Ali et al., 2017). This involves resilience-related investment in the capabilities to resist SCDs (Macdonald et al., 2018), capital investments that are difficult to define and measure in terms of long-term value (Carroll and Rudolph, 2006). This is perceived as competing with primary customer service and efficiency-based production performance goals that are focused on generating revenue streams, whose effects are immediately discernible (Jüttner and Maklan, 2011).

The skills and techniques required for balancing efficiency and effectiveness are considered to be in conflict, and successful SCRes strategies, measured in terms of decreasing frequency of SCDs, breed inertia and complacency and transfer focus away from ongoing threats (Carroll and Rudolph, 2006). Arrogance arising from success obstructs awareness of changing conditions, searching for innovative alternatives and diversion of resources to support strategic exploration that aligns cost-optimised operational excellence to episodic, crisis-driven risk management activities (Hamel and Välikangas, 2003). This leads to entrained, complacent thinking, where best practice is past practice (Snowden and Boone, 2007). Also, the implementation of SCRes strategies to mitigate dynamic non-events, through continuous and discreet adjustments that achieve transient control of SCDs, are without operator knowledge of what specifically creates reliability (Weick, 1987; Sawyer and Harrison, 2019).

Theoretical Challenges:

The SCRes Integrated Framework comprehensively described the phases, strategies, capabilities, and practices that lead to competitive advantage (Ali et al., 2017). However, SCRes is still in its infancy (Hendry et al., 2019; Sawyer and Harrison, 2019). There is no coherency in SCRes practices (Carvalho et al., 2014) and it lacks common understanding and consistency in descriptions and terminology (Biedermann et al., 2018; Sawyer and Harrison, 2019). Capabilities, for instance, are also termed as dimensions, elements, enhancers, and enablers (Ali et al., 2017). Many SCRes elements are paradoxically complementary and conflicting, such as collaborative relationships reducing flexibility (Stevenson and Busby, 2015; Tukamuhabwa et al., 2015). Terms such as robustness and flexibility are often contradictory, used inconsistently (Wallace and Choi, 2011), and are confused and unclear (Spiegler et al., 2012). Capabilities are all entwined, but one may be to the detriment of the other (Thomé et al., 2016) and elements, strategies and definitions are inconsistent (Stone and Rahimifard, 2018). It remains unclear how SCRes strategies inter-relate (Scholten et al., 2019a).

The Ponomarov and Holcomb definition describes a phased approach to SCRes, but with many variants and iterations found in the literature, there is a call for a more rigorous theoretical consolidation of the SCRes phases (Ali et al., 2017). SCRes remains sparse and fragmented (Linnenluecke, 2017; Stone and Rahimifard, 2018) with 10 perspectives and 56 related theories found in the literature (Biedermann et al., 2018). The term resilience is ambiguous and elusive



(Wieland and Wallenburg, 2013). SCRes research has not focused on how resilience is strategically achieved in the face of individual SCDs (Tukamuhabwa et al., 2015), and there is little guidance from SCRes theory on how to build proactive risk management processes (Scholten et al., 2014). There is a significant body of SCRes research but implementing the theory into practice is extremely challenging due to the dynamic nature of the turbulent operating environment (Datta, 2017). There is a lack of SCRes context-specific empirical research (Scholten and Schilder, 2015; Hendry et al., 2019; Sawyerr and Harrison, 2019). SCRes research has been context-dependent, and there are very few empirical studies of SCDs (Linnenluecke, 2017). Research has confined the concept to SCM strategies (Polyviou et al., 2019) and Scholten et al. (2019a) call for an exploration of perspectives outside Operations Management.

SCRes research focuses on large-scale powerful organisations with an abundance of tangible operational resources, such as financial, infrastructural, and technological, and neglects the contribution of intangible human resources to SCRes (Polyviou et al., 2019; Scholten et al., 2019a), such as the immense USD\$1trillion pharmaceutical industry (Zahiri et al., 2017). This is despite SMEs accounting for 99% of U.K. industry (Tukamuhabwa et al., 2015). The non-routine practices of SCRes must be 'bundled' with regular organisational activities, such as routine, predictable, co-ordinated, and sequential enactments (Tang, 2006; Craighead et al., 2007; Scholten et al., 2019b). Resilience is enacted at all organisational scales but there has not been an exploration of how the levels interact, a research opportunity (Linnenluecke, 2017), and the importance of top management commitment as a formative SCRes element is sparsely addressed (Sawyerr and Harrison, 2019).

High Reliability Theory (HRT):

The SCRes literature calls for an exploration of High Reliability Organisations (HROs) to address these challenges. HROs operate under cannot-fail conditions, but successfully maintain reliable performance regardless (Weick, 1987; Rochlin et al., 1987; La Porte and Consolini, 1991; Linnenluecke, 2017). Catastrophes in a HRO context include the 1984 Bhopal gas disaster in India and the NASA 1986 Challenger explosion (Swuste et al., 2020). There are considerable similarities between the formative elements of SCRes and the characteristics of HROs, and HRT is congruous to the aims of SCRes (Sawyerr and Harrison, 2019). There is a strong case for exploiting HRT to identify underlying factors to enhance SCRes (Wagner and Bode, 2006), and its effectiveness should be tested in a SCRes context (Ali et al., 2017) to determine if the less deterministic HRT elements can be transferred to SCRes (Sawyerr and Harrison, 2019). HRT has now emerged as the dominant theory on organisational resilience, and the conceptual comparisons that resolve the tension between HRT and the SCRes concept to enable cross-fertilisation and unification were unexplored (Linnenluecke, 2017), until Sawyerr and Harrison (2019).

HROs share the same budgetary pressures as business organisations, and balance reliability and efficiency, nuclear-powered naval aircraft carriers considered 'closest to the envelop' in that regard (Rochlin et al., 1987). However, similar to SCRes, HRT has also been criticised for forming theory based on abundantly resourced and politically important nuclear-powered naval aircraft carriers that enables substantial investment in high-reliability activities (La Porte and Consolini, 1991). Top management team (TMT) commitment is the most unique characteristic of the formative HRT cognitive infrastructure of collective mindfulness (Weick et al., 2008), and this has similarities to the internal social capital found to be key to SCRes in medium-sized organisations (Polyviou et al., 2019). Public-private short-term SCRes collaborations (Gabler et al., 2017) reflect epistemic nested authority systems found in HRT (La Porte and Consolini, 1991). A HRT premise is that cognitive processes of risk detection are routinised and repeated, and continuous variance is applied instead to production tasks that adapt to changing conditions (Weick et al., 2008). Another criticism of HRT was the study of safety in semi-simulation rather than safety in operational combat mode (Clarke and Short, 1993).

Complex, adaptive socio-economic, multi-scaled, non-linear, tightly-coupled SCM systems comprising complex interdependent interactions are evolutionary and self-organising in response to changing environments, and firms must balance anticipation and resilience to cope with the increased information exchange, communication and integration needed for decision-making during a SCD (Scheibe and Blackhurst, 2018; Sawyerr and Harrison, 2019). HRT literature demonstrates that this compares to technologically complex, tightly-coupled, interactive and interdependent HRO systems.

HRT Justification:

An SCM audience may have concerns about a HRO context that is focused on catastrophic events, but SCRes emerged from disasters such as '9-11', the 2008 global financial crisis and the 2011 Great East Japan Earthquake. From an ecological-symbolic interactionist perspective, categorising SCDs as crises or disasters, or determining their qualities, is sociologically insignificant in operating environments of complex interdependent exchange relations (Clarke and Short, 1993). The salient consideration should be the human response, such as evaluation and interpretation that gives meaning to it, through social constructionism shaped by structural and institutional contexts,



such as politics, personal interests, and conflicts (Clarke and Short, 1993). During a SCD, firms focus on effects rather than causes of SCDs (Carvalho et al., 2014). SCDs are characterised by their shape, duration, and magnitude, factors that have more importance than if the source was political, or environmental (Macdonald et al., 2018).

Research Questions and objectives:

This emerging part-time doctoral research responds to the SCRes literature calls for an exploration of High Reliability Theory by asking three research questions:

- How can the SCRes concept be advanced through the study of Supply Chain Disruption in a High Reliability Organisation?
- How do Supply Chain Management constituents across management scales in a High Reliability Organisation collectively approach Supply Chain Disruption?
- Is the HRT Cognitive Infrastructure of Collective Mindfulness an enabler of SCRes?

Four research objectives arise from these questions:

- Determine if SCM-HRO, as an interdependent organisational unit, enacts the HRT Cognitive Infrastructure of Collective Mindfulness, similar to its primary unit
- Determine if SCM-HRO has a phased approach to Supply Chain Disruption
- Determine the collectively mindful enactment and inter-relation of SCRes formative elements in a SCM-HRO context
- Determine the SCM-HRO process of balancing the tension between efficiency and effectiveness, whilst maintaining performance reliability

Literature Review:

Todd La Porte formed the 'Berkeley Group' at the University of California in 1987, together with Gene Rochlin and Karlene Roberts (Weick, 1987; Rochlin et al., 1987; La Porte and Consolini, 1991; Rijpma, 1997; Linnenluecke, 2017; Pillay et al., 2019) to explore and understand organisations that operate under cannot-fail conditions but manage to successfully maintain reliable performance regardless (La Porte and Consolini, 1991). The 'Berkeley Group' had considered Normal Accident Theory, whereby the criteria of tight coupling, response time and complexity in the system-design theoretically attributed to catastrophes, such as the 1984 Bhopal India gas disaster, the NASA 1986 Challenger explosion, the Chernobyl 1986 nuclear plant disaster and the 1989 Exxon Valdez oil tanker accident, but recognised a sub-set of these organisations that could have failed in dangerous environments, and nevertheless prevailed, categorising these as High Reliability Organisations (Roberts, 1990a; Roberts, 1990b; Linnenluecke, 2017; Agwu et al., 2019; Swuste et al., 2020). Collective mindfulness is the salient cognitive infrastructure of High Reliability Theory that enacts continuous re-accomplishment of reliability, through five common processes that reduce inertial tendencies (Weick et al., 2008):

- *Preoccupation with failure*: This is a collective recognition, and relentless, prideful (chronic) suspicion that all potential, as yet unseen, disruptions embedded in a system have not been exhausted or discovered (Weick, 1987; Weick et al., 2008)
- *Reluctance to simplify interpretations*: Simplification of tasks through standard frameworks, mindsets and procedures that are based on present, rather than future changing conditions, are potentially dangerous for organisations because they collectively restrict operators and decision-makers from noticing and searching for deviations that could accumulate and escalate to disruptions (Weick et al., 2008)
- *Sensitivity to operations*: This is the TMT big picture construction and maintenance of a cognitive map that enables remote observation and real-time, wide-lens, situational awareness of performance status (La Porte and Consolini, 1991; Weick et al., 2008)
- *Commitment to resilience*: Management of sudden disruptions concerns advance anticipation through prediction and prevention (Weick et al., 2008). When an actual event materialises, self-coping resilient containment, and reactive responsiveness are immediately enacted, learning from the absorbed change to return to operations (Weick et al., 2008)
- *Under-specification of structures*: enacting a flexible and adaptive garbage can of organised anarchy that culturally enables decisions to be made outside hierarchical authority structures, but with close TMT support, when unique situational problems require constant but variable structures of rapid and accurate specialist expertise (Weick et al., 2008)



Research Gap:

Sawyer and Harrison (2019) firmly established a research agenda for SCRes-HRT exploration. However, a theoretical tension between the SCRes and HRT literature strands has emerged, and this represents a research gap: HROs do not operationalise the formative SCRes elements in the same manner as described in the SCRes literature. Sheffi (2005) advises, for instance, that SCRes flexibility is developed through the standardisation of processes and procedures, and redundancy includes the positioning of duplicate capacity and inventory, whereas HROs are cognisant that such redundancies can fail simultaneously and increase complexity (Rijpma, 1997), and Weick et al. (2008) demonstrate that HROs are culturally reluctant to simplify interpretations, such as standardising procedures.

Research Design:

An exploratory, qualitative multiple-case study of Irish Defence Forces (DF) United Nations Peace Support Operations and Nordic Battle Group rotations has been selected. The DF operates under the extreme conditions and unique contexts that are increasingly considered as insightful sources that characterise phenomena under research, such as SCRes, despite its unconventionality (Scholten et al., 2014). The DF (as a HRO) can provide unique insights that traditional organisations are not able to, although there is no claim in this research that the DF is representative of all HROs (Siggelkow, 2007). The DF is 'unusually revelatory, an extreme exemplar', and an opportunity for innovative research access (Eisenhardt and Graebner, 2007). Critics of a single organisation may demand either a 'talking pig' or evidence from additional cases, but the presence of HROs in Ireland is limited (Siggelkow, 2007). Furthermore, HRT was founded on the study of three nuclear-powered aircraft carriers within a single organisation, the U.S. Navy. This research offers the greater robustness of comparative multiple cases that reduces the potential idiosyncrasy of a single case study, broadens the exploration of the questions, improves the quality and analytical power of the research, and increases its generalisability, albeit within one organisation that cannot provide polar types as a sampling approach (Eisenhardt and Graebner, 2007). Most people who write about HROs have never been in one (Bourrier, 2005). 'We depend on these invisible webs of teams, decisions, technology, infrastructures, and yet we know almost nothing about their daily operations. The investigation must go on' (Bourrier, 2011, p. 12).

Research Contributions:

An empirical, explorative, qualitative, multiple-case study of Supply Chain Disruption in a HRO-SCM context, which will lead to: an examination of the operationalisation of SCRes-HRT across HRO management scales; providing a greater understanding of how the enactment of SCRes can be enhanced from an HRT perspective; the development of an SCRes-HRT conceptual integrated framework; the potential enhancement of HRT through the study of actual military combat situations.

Preliminary Findings:

Data collected from semi-structured interviews of logistics personnel on both the Nordic Battle Group (NBG) 2015 rotation and UNIFIL 2018 mission enabled preliminary findings. In the emerging broader doctoral thesis, the processes of the HRT cognitive infrastructure of Collective Mindfulness and the elements of SCRes within a HRO-SCM context are described and juxtaposed against each SCRes phase found in the preliminary research findings within an emerging SCRes-HRT Integrated Framework:

- *Determine if SCM-HRO, as an interdependent organisational unit, enacts the HRT Cognitive Infrastructure of Collective Mindfulness, similar to its primary unit:* This research has found that the five processes of HRT Collective Mindfulness are evidenced and routinised within SCM. Integration across functions and management scales is a key consideration
- *Determine if SCM-HRO has a phased approach to Supply Chain Disruption:* A distinct mitigation phase, and a critical antecedent to the proceeding phases (Scholten et al., 2014) was found, but this is not repeated. This research categorises the mitigation phase as a Strategic Mode. In a Semi-Simulation Mode, there is both a preparation and response phase. The response time to disruptions during this mode is determined



by the duration of mission readiness exercises and this simultaneously incorporates capability development (growth). The Combat Operational Mode also has a preparation phase, and a response phase that incorporates simultaneous capability development (growth) before immediately proceeding again to a preparation phase. This demonstrates that reliability is an ongoing accomplishment (Weick, 1987; Weick et al., 2008). This is a continuous, cyclical process that removes complacency. The response time during this mode is determined by the duration of the combat mission because an interim containment response ensures continuous operations:

Strategic Mode	Semi-Simulation Mode		Operational Mode	
Mitigation Phase	Preparation Phase	Response Phase: Growth	Preparation Phase	Response Phase: Containment and Growth

- *Determine the collectively mindful enactment and inter-relation of SCRes formative elements in a SCM-HRO context:* Emerging data has enabled the mapping of the SCRes formative elements against the processes of HRT cognitive mindfulness that are evidenced within the strategic, semi-simulation and combat operational modes
- *Determine the SCM-HRO process of balancing the tension between efficiency and effectiveness, whilst maintaining performance reliability:* UNIFIL returned operations to an improved post-disruption state and simultaneously secured additional combat support capability at an absolute cost to the Irish tax-payer of less than 18% of market value. The NBG had a maximum return for the tax payer by co-coordinating procurement, engineering, and operations, whilst simultaneously improving Logistics and combat capabilities

Discussion:

Business supply chains are increasingly vulnerable to disruptions in an age of turbulence. This research aims to learn from a particular type of organisation that prevails in cannot-fail operating environments (High Reliability Organisations) to determine if the High Reliability Theory cognitive infrastructure of Collective Mindfulness enables Supply Chain Resilience. The literature strands of SCRes and HRT have been selected to address the research questions and objectives. SCRes is explored in depth in the main Ph.D. thesis document and HRT focuses more on the seminal theoretical foundations within United States Navy (U.S.N.) nuclear-powered aircraft carriers. This is linked to SCRes by Sheffi (2005) who suggested that the risk culture attributes found in the most prominent resilient business organisations, such as Dell and United Parcel Service, resemble those of U.S.N. aircraft carriers.

This research does not seek to replace SCRes, but rather to compliment it, and contribute to cementing the rich body of SCRes academic work that has been accomplished since 2000. The main premise is that HRT may provide an infrastructure grounded in TMT commitment for the enactment of SCRes. SCM practice, to which this research speaks to, can potentially learn from the subtle variances in the application of SCRes elements within HROs. SCRes-HRT similarities suggest that prosaic companies should not fear the perceived exotic nature of HROs. Preliminary findings from Irish Defence Forces case studies demonstrate SCRes-HRT integration and three distinct areas of exploration are emerging: SCRes as a social construction where people determine reliability (Rochlin, 1989); SCRes-TMT strategic alignment through collective mindfulness; balancing the effectiveness versus efficiency tension.

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A FRAMEWORK FOR THE SELECTION OF PERFORMANCE STRATEGIES FOR THE SUSTAINABLE SUPPLY CHAIN

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Introduction

The selection of performance strategies in a supply chain context is complex because some goals are contradictory, requiring prioritisation and/or trade-offs. This paper offers a means by which complementary strategies can be selected, aimed at achieving sustainability in a disruptive age. The literature review presented here establishes the need for supply chain sustainability to be approached in a way that is widely understood and can be discussed at the inter-firm level. Ambidexterity is discussed in the formation of a supply chain where vision and values are shared; practitioners were interviewed to discover the approaches employed in their companies, with the aim of identifying means to achieve convergence with selected partners.

Background and Literature Review

The supply chain has become a key management focus and source of competitive advantage, achieved through enhanced value creation and customer satisfaction, organisational effectiveness, efficiency, productivity and profitability (Mentzer et al., 2001; Katiyar et al. 2015). Developing on the theme of competition occurring not between companies, but supply chains (van Hoek, 1998), Thakkar (2012) found organisations increasingly focused on supply chain rather than corporate performance, indicating a need to discuss supply chain performance in particular.

The sustainable supply chain is viewed as an evolution of Supply Chain Management (SCM) (Pagell and Shevchenko, 2014; Beske and Seuring, 2014). This has become a popular domain in which to seek competitive advantage – and Katiyar et al. (2018) claim that sustainability is needed for competitive advantage and even long-term organisational survival. Due to its importance in driving superior performance, many organisations have adopted sustainable supply chain practices (Bhattacharya and Polman, 2017).

The literature on supply chain performance reveals an extensive theoretical understanding, but the impact on present day practice is limited (Halldórsson et al., 2015; Sweeney et al., 2015). While Beske and Seuring (2014) reported sustainable SCM to be a thriving field of research, many different terms were reported to be used interchangeably. Both Ahi and Searcy (2015) and Qorri et al. (2018) report concerns with regard to the measurement of sustainability performance. Katiyar et al. (2018) concurred, although recognising that the extant literature focused on economic and environmental performance (i.e. with less emphasis on the social dimension) – something also reported in Nakamba et al. (2017) and Sarkis et al. (2019), while Kühnen and Hahn (2017) found this to be fragmented, limited in empirical support and lacking standardised performance indicators.

Carter et al. (2020, p. 1858) cautioned that “firms must carefully oversee the sustainability of their supply chains” but Schaltegger and Burritt (2014) and Katiyar et al. (2018) reported that the impact of sustainability on supply chain performance was very limited – indicating a gap between theory and practice. In a world where competitiveness is derived from intra-firm capabilities, it is unfortunate to find that organisations participating in the same supply chain can have different and conflicting strategies (Hassini et al., 2012), necessitating trade-offs. Carter et al. (2020) reported clear conceptualisation to be lacking where trade-offs occur between social and environmental performance. This is consistent with Nakamba et al. (2017) calling for an understanding of how practitioners manage contradictory pressures with particular regard for the social dimension where we see factors such as human rights, poverty, diversity and inclusion, and safe working environments.

Managing the performance of entire supply chains is very difficult, if it is possible at all (Banomyong and Supatn, 2011; Anand and Grover, 2015). Formulating a general approach has proved to be onerous (Banomyong and Supatn, 2011). Sarkis et al. (2019) believe that performance in sustainability is dependent upon the members of the supply chain, though one might wonder if the result will be only local optimisation. Qorri et al. (2018) concurs: performance measurement typically involves a focal organisation rather than on inter-organisational metrics.

Firms tend not to know which indicators are truly critical to their performance because there is so little guidance on how best to utilise them (Neely et al., 1995; Anand and Grover, 2015). Thus, more research is required to understand the underlying nature of supply chain performance, with existing performance studies tending to be static, lagging behind in a changing business environment (Anand and Grover, 2015) and tending not to capture how the supply



chain as a whole has performed (Tsanos et al., 2014). In calling for the development of “defined metrics with relatively standardized terminology...to promote greater comparability in assessing the sustainability performance of different supply chains”, Ahi and Searcy (2015, p. 374) acknowledge the need for a unified approach that could facilitate the alignment of corporate goals, reducing the likelihood of conflicting aims and subsequent trade-offs. To pursue sustainability in this way casts supply chain participants as a team, with shared values (Muller et al., 2012) – just as SCM in general seeks to optimise the whole system rather than pursuing local optimisation (Linton et al., 2007).

While the optimisation of an integrated supply chain is a formidable quest (Briscoe and Dainty, 2005), alignment can be addressed at the triadic level (looking one step up- and downstream from the focal organisation, to immediate suppliers and customers). Here, the exchange of information is context-rich and less likely to be hindered by concerns about confidentiality since it is reasonable for a customer to have sustainability questions. Thus, it is possible to work toward sustainable SCM – if a suitable mechanism is understood and adopted by both parties. Such an understanding would be of value to both academics and practitioners, advancing the field by revealing how companies manage this aspect of their supply chain's performance, both within and between companies. Equally, benchmarking against other organisations should reveal how practitioners can improve company supply chain posture and positioning.

If businesses that trade within a supply chain relationship are to benefit from aligned goals, two things are required: that both parties have a common ontology (i.e. a shared understanding) and that they value the same outcomes. The literature revealed that a common understanding of performance measures in SCM is lacking, resulting in our research question: how do the practitioners manage their supply chain performance?

This research question is appropriate, since the “industry is always looking to see how [performance management systems] can become more efficient” (Bai et al., 2012, p. 79). Investigating the adoption of sustainability performance in a supply chain is crucial because poor sustainability performance within an organisation poses a reputational threat for other members in the extended supply chain (Sarkis et al., 2019). Meanwhile, society's expectations continue to develop: Pagell and Shevchenk (2014, p. 45) warn that “future SCM research will have to treat a supply chain's social and environmental performance as equally or more valid than economic performance” – so the question is timely.

Methodology

Exploratory research was conducted using a constructionist epistemological basis (per Easterby-Smith et al., 2015) and an inductive methodological approach. The study employed a case-study method (as advocated by Yin, 2014) with qualitative research techniques including semi-structured interviews, observations and the gathering of documents.

Twenty-four practitioners in three distinct supply chains were interviewed for the purposes of identifying their supply chain performance priorities and the strategies that they employed. The three companies studied operate in different industries:

- Bravo is a principal contractor in the construction industry.
- Charlie operates in the creative sector, providing services for events.
- Delta manufactures and distributes Fast-Moving-Consumer-Goods.

Relevant individuals were selected, including partners in immediate upstream and downstream relationships as well as within each focal company. The inclusion of such varied participants gave breadth and depth to the discussions, providing rich data for analysis. The triadic approach is consistent with Sarkis et al. (2019, p. 1) who assert that studies “beyond the typical dyadic, buyer-supplier relationship, are needed to further penetrate the supply chain and expand theoretical and practical study boundaries”. Site tours and non-participatory observations in meetings were also conducted, providing opportunities to triangulate data gathered during interviews. Secondary sources such as annual reports, internal policy documents, monthly newsletters, market research and news media also contributed in improving the validity and thus quality of the research – in accordance with and Ellram (1996).

Interview data were subjected to a three-stage coding process involving open, axial and selective coding, followed by analysis using the Grounded Theory approach outlined by Corbin and Strauss (2015). Themes emerging from the coding process were analysed using strategies and techniques commonly adopted in case study research, including examining rival explanations, comparing with conflicting theories, using multiple theories and perspectives to interpret findings, pattern matching and explanation building (Miles et al., 2014).



Results and Findings

While each case study company's performance management approach was found to differ, they shared some prominent similarities. All three companies used a bespoke performance measurement system and these had evolved over time, consistent with Wetsandornphong et al. (2019). Performance measures reported included cost, pricing, profit, service, delivery, schedule, quality, safety, environment, health, people, and social value. Comprehending and ultimately reconciling this mixture of competing measures is challenging for practitioners and researchers alike, though the complexity can be addressed to some degree by grouping measures into financial and non-financial; quantitative and qualitative; efficiency and effectiveness. The challenge inherent in categorising measures within specific sustainability performance dimensions was anticipated: Ahi and Searcy (2015) revealed that the sustainability measures are "cross-cutting" in nature such that they could be used to address more than one desired outcome. While this makes sustainability a complex thing to pursue, it also introduces the possibility that businesses within a supply chain can all contribute towards overall sustainability outcomes, despite having different strengths and different priorities.

According to Elkington's (1994) Triple Bottom Line (TBL), sustainability is found where financial, social and environmental outcomes are all aligned. Modern companies should, therefore, have measures that address each of these goals. It was notable that staff at all three case study organisations discussed sustainability in some depth when asked about the supply chain performance measures that their organisation employed. Each company had a different set of priorities, as befitting their industry and the nature of their processes. Bravo focused on creating social value, promoting urban regeneration and ensuring a safe workplace, while Charlie focused on economic sustainability, seeking to foster a healthy cluster of businesses in the creative industry with whom to operate. Delta focused on efficiency of plant operations. In each case there were measures pursued with sustainability in mind – along with requirements for on-time fulfilment and profitability. Figure 1 shows some of the measures identified in the context of the TBL, with size indicating their relative importance to participants. In the intersections between the three bottom line categories we can see their "cross-cutting" nature – as described by Ahi and Searcy (2015).

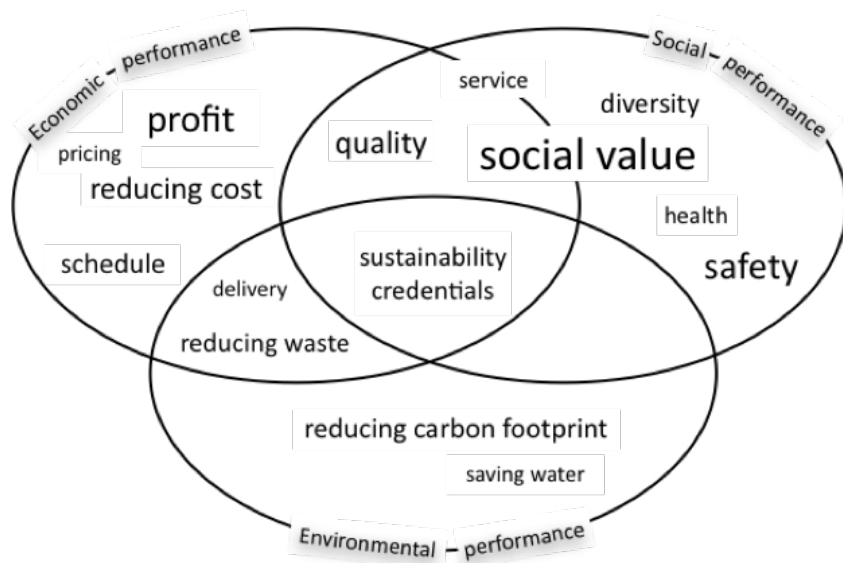


Figure 1: Performance Measures Reported at the Case Study Companies

Within the case study companies, social performance criteria took the form of employing local subcontractors, offering employment, training and apprenticeship opportunities, supporting communities and delivering corporate social responsibility outcomes. At Bravo, the creation of social value was said to be more important than the economic dimension. This was also one of Bravo's core performance areas, with clients acknowledging that while social value did not yield immediate financial returns, it fed into desired regional rejuvenation. This is consistent with Nakamba et al. (2017), reporting that social sustainability research is gaining traction – towards the "true sustainability" of Carter and Rogers (2008). However, Nakamba et al. (2017, p. 532) caution that "there is no unified approach for measuring social performance in supply chains, and not all aspects of social sustainability have been considered in developing measures".



Relevant measures were evident within the case study companies: Bravo had developed its own social value calculator to capture and quantify outcomes, recording the worth of every activity completed and converting these into a monetary value, feeding into the Social Return on Investment (SROI). Recognising this metric to be a critical indicator, Delta also quantified social impacts and presented them within their annual report. (For example, percentage of women in senior positions, percentage of minorities employed and other diversity targets – these informing KPIs for internal recruiters and recruitment agencies.) Overlaps with economic factors were apparent, e.g. where a tender must address certain social clauses in order to be shortlisted – an expectation discussed by employees of Bravo in particular. Schaltegger and Burritt (2014), Hassini et al. (2012) and Kühnen and Hahn (2017) all found social indicators to be difficult to quantify and prone to subjectivity.

Environmental performance was well-represented in the case study companies' annual reporting, but interviewees tended to discuss environmental measures and performance in terms of compliance. It was a "must have" criterion, rather than an area for aspirations or innovation beyond what was mandated by legislation. For example, Delta viewed environmental performance as necessary because a failure to comply with environmental requirements might result in monetary penalties or cause the company to lose a permit to operate. Delta was aware that a failure could also lead to lost sales, reduced profit and reputational damage – similar to the findings of Varsei et al. (2014) where penalties, protests, campaigns and sanctions were reported. This is consistent with Institutional Theory (DiMaggio and Powell, 1983; Kühnen and Hahn, 2017) as the regulator (the environment agency) has caused Delta to adopt environmental practices at both the firm and supply chain levels – matching the findings of Foerstl et al. (2015) who found stakeholder pressures to be the prime driver for sustainability. While Chen and Chen (2019) report that organisations determine the environmental performance of the supply chain through mechanisms such as supplier evaluation, auditing and monitoring, Delta chose to outsource these functions to a specialist third-party provider.

Two themes are apparent here: compliance and commitment. Compliance tends to be a short-term matter, closely associated with power exerted by a stakeholder, while commitment demands a more proactive approach that seeks long-term benefits. Carter et al. (2020) discussed balancing short- and long-term impacts in this context, while Foerstl et al. (2015) and Chen and Chen (2019) advocate moving beyond mere compliance toward voluntary commitments.

Measures to monitor economic performance were well-established in the case study companies – consistent with Friedman's (1970) statement that a business exists to make and increase profits, and Carroll's (1979) assertion that economic sustainability serves as the foundation of corporate performance. This may introduce a problem: describing trade-offs as "contesting capabilities", Hallgren et al. (2010, p. 514) found TBL outcomes hard to combine and thus "companies cannot perform well on more than one dimension simultaneously since an improvement along one dimension would have to be traded off for poorer performance along another".

Delta reduced the cost of operations via performance improvement initiatives led by the procurement function, e.g. renegotiation of payment terms and the consolidation of haulage and third-party warehousing. At the plant level, Delta focused on achieving optimum production throughput and productivity via a performance metric called overall equipment effectiveness (OEE) and from a distribution perspective they used case-fill metrics such as delivery against stock availability, customer order and rejection to evaluate customer fulfilment performance. At Bravo, economic performance was assessed early in the tendering process – attractive pricing often being critical to winning business. Bravo would normally collate the costings provided by various subcontractors, then conduct cost evaluation, valuing each work package to create a work scope that fed into a tender document. If Bravo won a bid, the agreed price was converted into a project contract document.

In many cases, participants were found to view the other parts of the TBL in terms of trade-offs. In some cases they saw positive social outcomes as a necessary feature for business to be won, but where outcomes had an adverse economic impact they were weighed carefully.

Analysis and Discussion

For the case study companies, our research revealed that social performance has joined the existing drivers of profitability, globalisation and customer focus. Among themes such as integration, cooptation, risk reduction and organisational structure, investigation revealed performance measures covering all three components of the TBL, with environmental goals largely limited to compliance with legislation (and emerging legislation) rather than shaping future voluntary commitments. This can be understood in terms of Hill's (1995) order winners (OW) and order qualifiers (OQ), drawing a distinction between features that are necessary to operate in an industry at all and those where excellence is directly related to increased sales. From a performance measurement perspective, social value was seen as an OW for Bravo, whereas safety was an OQ – a "must have" not expected



to contribute to additional growth. Responsiveness to clients' frequent, urgent and onerous change requests was an OW for Charlie with on-time completion as an OQ. For Delta, delivery fulfilment rate was an OW with product quality an OQ. For all, the environmental dimension of performance appears to satisfy the basic requirements of customers (OQ), whereas the social dimension was desired by customers (OW). The economic dimension of performance was thought of more as an output than a characteristic of the system itself.

Categorisation in terms of OQ and OW, however, depends on supply chain orientation. For example, Gligor et al. (2015) report that cost-efficiency is considered an OW in lean and an OQ in agile supply chains. There is also a "drift" whereby a characteristic previously considered OW can become OQ. For example, Bravo reported that on-time completion and quality were no longer OWs, but industry norms: measures evolving in accordance with what Hill (1995) recognised as the "time-specific" nature of OW and OQ – what Christopher and Towill (2000, p. 212) described thus: "periodically a new market winner emerges and downgrades the previous market winner to a market qualifier."

It is difficult to see how sustainability can drive the evolution of strategy if it is perceived as a necessary evil, e.g. a "cost of doing business" in order to win contracts or to retain a licence. Instead, a situation exists where there may be a temptation to offshore pollution or to push the costs of compliance onto a supply chain partner. Where performance targets demand actions that are not complementary, they remain the subject of trade-offs – but the literature suggests a way forward. In what appear, initially, to be contradictory goals, lean versus agile offers a good example of a duality where some practitioners have managed not to choose between them, but to achieve both – a phenomenon that is well reported. Gligor et al. (2015) found that agile (effective) supply chains could also be efficient, the states being not mutually exclusive but complementary. Naylor et al. (1999) named the approach as "leagility" – combining the essence of lean and agile for optimal SCM. Similarly, Hallgren et al. (2010) reveal that cost efficiency (lean) and flexibility (agile) can be developed in parallel without the need for trade-offs.

In our research, some participants reported dualities within the metrics that they used as a "this or that" choice, but in the literature companies have been reported to achieve both. Hallavo (2015) regarded agile as a natural progression from its precursor, lean; Gupta et al. (2006) described this as "punctuated equilibrium", advancing exploitation (lean) onto exploration (agile) sequentially – effectively ratcheting up the competitiveness of an enterprise, step by step. Instead of having to choose between mutually exclusive options, "leagility" shows how companies have pursued two apparently contradictory characteristics in a rejection of an "either-or" approach as reported in Selldin and Olhager (2007) who describe such situations as a "supply chain frontier"; also the complementarity theory of Halldórsson et al. (2015). Barney (1991) warns that resources are limited: a business cannot be all things to all potential supply chain partners, but some aspects of the business can be made to advance in both aspects of a duality. Pursuit of improvements beyond what is mandated poses difficulties (Constant et al., 2020) but may serve to "future-proof" the supply chain as legislation continues to evolve.

The simultaneous pursuit of both facets of a duality in order to achieve "the best of both worlds" – is recognised as ambidexterity by scholars such as March (1991) and Rojo-Gallego-Burin et al. (2020). Obviously, the development of such a capability requires considerable effort. Nonetheless, it is particularly valuable when configuring a supply chain to meet performance targets, since it avoids the need to pursue targets via trade-offs. Delta, in particular, was seen to pursue improvements via incremental continuous improvement (exploitation) and an accelerated improvement programme (exploration) – a strong example of a duality.

Based upon the information received from the case study companies, several places where ambidexterity could be found were identified. This was subsequently expanded, via the literature, into a detailed framework of potential dualities: due to space constraints in this paper, only those relevant to ambidexterity in the case study organisations ("maintaining an appropriate balance" per March, 1991 p. 71), are discussed here. The authors have adopted the supply chain operations reference (SCOR) model to provide structure: based on the findings, sustainability from the TBL perspective is mapped against the main areas of SCOR, the framework revealing that sustainability practices could be embedded in many areas of the supply chain. Using the concept of ambidexterity, performance strategies can be deployed to meet the needs of the society and ecology while maintaining profitability. It serves as a starting point for practitioners who seek to move beyond trade-offs between social, environmental and economic performance measures, striving instead to find "win-win-win" outcomes. The principal dualities where ambidexterity was implied by respondents are summarised in Table 1, offering a representative set of dualities:



Theme of Duality		Notes (and selected references)
Strategy (Plan) – Competitive strategy and Supply chain strategy		
Cost-leadership	Differentiation	Ability to differentiate service offering in the marketplace (e.g. offering innovative products and customer fulfilment) via robust sustainability practices (e.g. creating social value, using sustainable packaging materials, producing ecologically friendly products) while operating efficiently within the focal company and its extended supply chain partners. Consistent with Porter (1979).
Lean	Agile	“Leagility” – able to eliminate waste and respond swiftly to dynamic and volatile market environments through a customer focused supply chain. Consistent with Naylor et al. (1999); Christopher and Towill (2000).
Procurement (Source) – Purchasing approach and decision		
Purchasing	Supply	The ability to manage a broad range of suppliers by segmenting them into various categories, aimed at securing supply of products/services not only in a cost-efficient way but also responsive to the needs of the supply chain, taking into account sustainable sourcing issues (e.g. ethical sourcing, green buying, etc).
Make	Buy	The ability to combine make and buy decisions, leading towards supply chains that are able to be responsive while operating efficiently and in a sustainable way. This may involve buying standard parts directly from manufacturers for economies of scale or outsourcing to third parties (e.g. appointing local SMEs, hiring local apprentices and labour, etc.), while fully utilising in-house capabilities to produce products that match core competencies. Consistent with Williamson (2008).
Product attributes (Make) – Characteristics of the offering		
Standard High volume and variety; low complexity	Customised Low volume and variety; high complexity	Selection of appropriate product specifications and strategies, taking into account volume-variety decisions while incorporating associated services and customisation – plus closed-loop supply chains, where appropriate. This requires effective balancing (ambidexterity) between standardisation and localisation, while reflecting the most appropriate product life cycle. Consistent with Fisher (1997); Christopher and Towill (2000); Mason-Jones et al. (2000); Cox (2007); Selldin and Olhager (2007).
Demand characteristics (Deliver) – Market dynamism and demand pattern		
Stable market Predictable market	Dynamic market Unpredictable market	Ability to respond to customer requirements effectively (e.g. availability) in an efficient way (e.g. less transportation and consequent CO2 emissions). Determined by market dynamism, reported variously as instability, fragmentation, complexity, uncertainty, risk, volatility, unpredictability, seasonality, etc. Consistent with Fisher (1997); Mason-Jones et al. (2000); Cox (2007); Gligor et al (2015).
Sustainability (including but not limited to the SCOR category “Return”)		
Compliance	Commitment	The extent to which sustainability practices (e.g. reverse logistics, waste reduction, elimination of the use of plastic in packaging, etc.) and activities (recycling, reuse, reconditioning, etc.) could be deployed in supply chains and embedded into performance measurement systems, contributing to the circular economy not just for compliance purposes but also cultivating voluntary commitment. Consistent with Foerstl et al. (2015) and Chen and Chen (2019).

Table 1: Partial Set of Dualities Observed among those Participating in the Case Studies



Conclusions

The research outlined in this paper has revealed an evolving business landscape for three case study companies, where social value has become a basis for competition while environmental factors remain largely as an order qualifier.

Ambidexterity – initially seen to resolve the “lean vs. agile” question has been seen to have wider potential, offering an alternative to the trade-offs found when pursuing sustainability. Further, the necessary dualities offer a basis upon which to identify supply chain partners that share the same values and goals. In our own study, the balance between compliance and commitment in measures relating to the TBL exhibited ambidexterity, two distinct kinds of improvement in some cases being pursued simultaneously, either within one organisation or via partners to achieve positive outcomes in the supply network as a whole. Such occurrences deserve to be highlighted as they indicate areas of particular strength and focus that ought to be understood by any potential partner. These are best understood through a suitable framework, supporting strategy such that dualities can be identified and evaluated, to ensure that a shared vision exists.

The study revealed how participating practitioners in three distinct industries had managed their supply chains, achieving ambidexterity and driving performance improvements against social, environmental and economic targets.

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SUPPLY CHAIN RESILIENCE PERFORMANCE MEASUREMENT: AN INNOVATIVE FRAMEWORK

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Introduction

Supply chain resilience (SCRes) is gaining significance and increased attention by researchers and practitioners due to the importance of ensuring business continuity and competitiveness (Ali, Mahfouz, and Arisha, 2017). A resilient supply chain is expected to resist, react and recover better in case of disruptions (Christopher and Peck, 2004), allowing it not only to survive, but to adapt, grow and, in a nutshell, thrive (Pettit, Fiksel, and Croxton, 2010; Fiksel, 2006). However, this promise has been supported by relatively limited evidence. In particular, adequate frameworks to measure SCRes performance are still limited, despite being fundamental to assess achievements and benchmark performance (Negri et al., 2021). Most of the studies focus on a qualitative evaluation of SCRes, neglecting a more quantitative approach (Behzadi, O'Sullivan, and Olsen, 2020). Besides, there is a lack of holistic and operative frameworks of indicators for firms.

The aim of this study is to conduct a systematic literature review on metrics for SCRes, retrieving the most important contributions and building a framework of indicators. The latter will be linked to the practices of SCRes, to make it more operative and allow for a better assessment of impacts stemming from the implementation of the practices (Han, Chong, and Li, 2020). The topic of performance measurement in the field of SCRes is still relatively new. In particular, few contributions have tried to build a complete and operative framework of performance indicators. The novelty of this study lies in linking the performance measurement to the SCRes practices, through capabilities. In this way, it is possible to have a deeper understanding of how the implementation of SCRes works, and ultimately have better resilience in the supply chains.

Methodology

Sources selection and evaluation

This study is based on a systematic literature review, ensuring replicability and transparency (Denyer and Tranfield, 2009). The aim of the authors was to retrieve contributions on the topic of SCRes measurement and metrics. The international database Scopus was used, and the keywords for the query are presented in Table 1. No restrictions on the year of publication and research area were applied.

Keywords
TITLE-ABS-KEY ("framework" OR "model" OR "approach" OR "assessment") AND TITLE-ABS-KEY ("indicator" OR "KPI" OR "indicator" OR "metric") AND TITLE-ABS-KEY (resilien* OR risk) AND TITLE-ABS-KEY ("supply chain")

Table 1. Keywords used for the literature search

The keywords were carefully selected after a preliminary search of the literature, aiming at keeping them broad enough to include all relevant contributions (Thomé, Scavarda, and Scavarda, 2016). This also allowed to ensure external validity, as the search is not confined to any particular setting. The search was performed on February 17th 2021 and allowed retrieving 617 contributions. 29 papers were immediately discarded because relevant information was missing, such as the title or the authors. 5 were eliminated because of duplications. The remaining were screened with a title analysis, that brought to the exclusion of 513 papers. The remaining 70 were eligible for an abstract analysis, which allowed to exclude 31 papers. Finally, the full-text analysis brought to the exclusion of 6 papers. The final set of contributions consists of 33 papers. The so-called snowball method was applied to make sure all important papers on the topic were included in the analysis (Thomé, Scavarda, and Scavarda, 2016), and 6 additional papers were included. The exclusion criteria (Shea et al., 2007) involved papers not developing metrics or assessment methods were excluded from the list.

The selected papers were analysed, looking for metrics or frameworks for the measurement of SCRes.



Results

Most of the retrieved contributions have been published very recently, which mirrors the novelty of the topic. 60% of the papers included in this analysis have been published after 2017. Most consider resilience, but there are still contributions focused on risk management and assessment (e.g., Xu et al., 2019; Jung, Lim, and Oh, 2011). Most of the original papers develop a theoretical model or indicator, using principally literature reviews (Carvalho, Azevedo, and Cruz-Machado, 2013), simulation (Cardoso et al., 2015) and AHP methods (Min, Park, and Ahn, 2017). The indicators developed are usually not clustered in categories. When they are, they are some combination of resilience capabilities: the most common are flexibility (Rajesh, 2016), redundancy (Malek, Ebrahimnejad, and Tavakkoli-Moghaddam, 2017), collaboration (Sahu, Datta, and Mahapatra, 2017), availability (Wenjun Wang, Street, and DeMatta, 2015). Some of the contributions also provide an empirical analysis of the developed indicators, usually in the form of case studies. However, the case study presented is in the majority of the papers only one.

Among SCRes papers focusing on KPIs, there has been a proliferation of reviews in the last years, which attempt to standardize the topic and pave the way for future research (e.g., Karl et al., 2018; Ribeiro and Barbosa-Povoa, 2018). The importance of having well-established models for measuring performance is widespread, and there is still little research on SCRes measurement (Han, Chong, and Li, 2020). Models to assess SCRes are becoming more complex, following the development of theory, but a complete understanding of how to measure SCRes is still to be reached (Ribeiro and Barbosa-Povoa, 2018). In particular, more holistic models that are able to grasp the complexity of reality are missing (Ribeiro and Barbosa-Povoa, 2018). Among the relevant indicators, Karl et al. (2018) find that delivery lead time, order lead time and stock level are highly correlated with resilience capabilities, therefore being important in the evaluation of SCRes. The authors also divide the indicators among the focal firm, the customer and the supplier, to understand how much the indicators can synthesize the performance of the SC. Non-financial KPIs are particularly underrepresented in the models proposed in the literature. Common indicators suggested in previous papers are the time to recovery, the recovery level and the lost performance or profit due to the disruption (Behzadi, O'Sullivan, and Olsen, 2020). Many of the contributions in the literature develop an index to measure the overall performance of SCRes (e.g., Wang et al., 2019). This can have many benefits, including the easiness of communication and understanding, and it allows to benchmark performance (Cristóbal et al., 2018). However, indexes are highly dependent on the perspective used during their development, and might thus be subjective (Cagno, Neri, and Trianni, 2018).

Other authors propose a more complete set of indicators, up to 63 (Chowdhury and Quaddus, 2017). The indicators are commonly clustered in classes, based on their preparedness, responsiveness or recovery role (Han, Chong, and Li, 2020). Han et al. (2020) develop a framework of KPIs for SCRes, grouping them according to the capabilities of resilience they refer to. However, the model is still not operative as the metrics for the indicators are not reported. Further development is therefore needed to define a holistic set of performance indicators to assess SCRes.



Novel performance measurement framework

Basing on the extant literature, several gaps emerged. Firstly, there is a lack of a comprehensive framework of performance indicators for SCRes. Secondly, although recently some frameworks have been proposed in the literature, these are not operative and therefore not exploitable and useful for firms. Thirdly, there is no link between the indicators and the practices, which could be extremely useful to assess the impacts of the practices on performance (Han, Chong, and Li, 2020), and ensure an effective measurement competence.

For the aforementioned, this study proposes a novel framework of indicators to measure SCRes. The framework is presented in Table 2.

Phase	Capabilities	Indicator	KPI	Unit of measure	Reference
Readiness	Situation awareness	Quality of forecast	Forecast error MAE	%	(Shcherbakov et al., 2013)
		Supply chain alertness	Time needed to detect threats to supply chain network (Li et al. 2017)	Time unit	(Li et al., 2017)
		Disruption probability	$((\text{Disruption risk with disrupted supplier} - \text{Disruption risk baseline case}) / \text{Disruption risk baseline case}) * 100$	%	(Hosseini, Ivanov, and Dolgui, 2019)
	Visibility	Order accuracy	$(\text{Number of orders with no mistakes} / \text{Total number of orders}) * 100$	%	(Fisher, Lauria, and Matheus, 2009)
		Visibility	Time to know information of upstream and/or downstream inventory level	Time unit	
		Monitoring and maintenance	Unscheduled downtime	Boolean	(Lam and Bai, 2016)
		Reliability	Probability to satisfy the quantity required by its immediate buyer given its disruption risks (Chen et al. 2017) Demand fulfilled pre-mitigation actions/ total demand during disruption	%	(Chen, Xi, and Jing, 2017)
		Disaster preparation	Funding; Response time	€; Time unit	(Simpson and Katirai, 2006)
	Redundancy	Production changeover time and average production run length	Time to change production	Time measure	(Datta, Christopher, and Allen, 2007)
		Total average inventory across all distribution centres	Available stock	Pieces, time measure	(Datta, Christopher, and Allen, 2007)
		Stock-out rate	Number of nodes that experienced a stock out / total number of nodes	%	(Rajesh, 2016)
		Reserve capacity	Idle capacity / total capacity	%	(Wicher et al., 2016)
	Knowledge management and culture	Investment in knowledge sharing	Investment in knowledge sharing	Monetary unit	
		Preparation of contingency plans	Number of situation covered by contingency plans / total possible disruptions	#	



Response	Agility	Lead Time Ratio	Actual lead time / promised lead time	%	(Carvalho et al., 2012)
		Lead Time Reduction	Lead time (t-1) / Lead time (t)	%	(Cabral, Grilo, and Cruz-Machado, 2012)
		Speed of critical activities		Time measure	(Day, 2013)
	Flexibility	Responsiveness	Orders fulfilled on-time / total orders	%	(Rajesh, 2016)
		Internal Flexibility	(sales after design change - sales before design change)/(sales before design change) * 100	#	(Rajesh, 2016)
			(n° of items which stock record and physical count are equal)/(n° of items counted) * 100	%	(Rajesh, 2016)
			Small disruptions managed through flexibility / total small disruptions	%	(Rajesh, 2016)
		Alternative options to ensure production	Percentage of own capacities on total capacities	%	(Wicher et al., 2016)
		External flexibility	Percentage change of product delivery quantity	%	(Üstündağ and Urgan, 2020)
			Percentage change of order delivery time	%	(Üstündağ and Urgan, 2020)
	Collaboration	Collaboration, information sharing, trust and risk and revenue sharing	Decisions taken jointly	€	
		Strategic alliance, supply chain relationship	Investment	€	(Lam and Bai, 2016)
		Risk management infrastructure	Presence of a risk management infrastructure	Boolean	(Ambulkar, Blackhurst, and Grawe, 2015)
		Supply network resilience	Ratio of the total number of node/arc disruptions that do not lead to a disruption of the network over the total number of node/arc disruptions	%	(Kim, Chen, and Linderman, 2015)
			How often the nodes in a network lie on the shortest path between all combinations of pairs of nodes.	%	(Kim, Chen, and Linderman, 2015)
		Cooperation	Number of enterprises weighted by the size of material flow	#	(Wicher et al., 2016)
Recovery	Contingency planning	Resource reconfiguration scale	Time to reconfigure in response to dynamic environment	Time unit	
		Contingency plan	# of contingency plans and their coverage on the SC's operations	#, %	(Lam and Bai, 2016)
		Profile length	Time to return to 95% of performance	Time unit	(Han, Chong, and Li, 2020; Munoz and Dunbar, 2015)
		Performance loss	Performance loss	%	(Munoz and Dunbar, 2015)
		Recovery rate	Probability to return to normality after disruption	%	(Zeng and Yen, 2017)
	Market position	Customer service level		%	(Datta, Christopher, and Allen, 2007)
		Customer satisfaction	Satisfied customers / total customers	%	(Cabral, Grilo, and Cruz-Machado, 2012)
		Percentage of unfulfilled demand		%	(Dixit, Seshadrinath, and Tiwari, 2016)
		Post-disruption mitigation capabilities (Firm-buyer point of view)		%	(Chen, Xi, and Jing, 2017)
		Supply chain disruption scale	Number of nodes impacted after the first disruption	#	(Ambulkar, Blackhurst, and Grawe, 2015)
		Disruption impact	(Operation efficiency pre-disruption - op. eff. post-disruption)/(op. eff. post-disruption) * 100	%	(Ambulkar, Blackhurst, and Grawe, 2015)
		Ripple effect	Revenue after disruption / Planned revenue	#	(Kinra et al., 2020)
		Total cost	Production cost + material cost + holding inventory cost + transportation cost	Monetary unit	(Carvalho et al., 2012)
		Efficiency	(Planned contingency plans costs - Actual contingency plans costs)/(Planned contingency plans costs) * 100	%	(Han, Chong, and Li, 2020; Day, 2013)
		Financial perspective	(Profit after disruption - profit before disruption) / profit before disruption	%	(Han, Chong, and Li, 2020; Day, 2013)

Table 2. Novel framework of performance indicators for SCRes

The framework keeps the division of capabilities and indicators into the three phases of SCRes, i.e., readiness, response, recovery. The three phases are often highlighted in the extant literature as fundamental elements to build a complete SCRes (Chowdhury and Quaddus, 2017), and are therefore important for performance measurement. The classification in capabilities follows Han, Chong, and Li's (2020) contribution. The indicators have then been divided according to the SCRes capabilities they refer to. Although the division is not always unequivocal, as there might be more indicators that refer to the same capability, and indicators that refer to more than one capability, operating in this way provides extremely operative guidance to firms. We have used the capabilities as they are often used as an approximation of the desired performance in the supply chain (Kaviani et al., 2020).



The division according to the SCRes capabilities allows to connect the indicators to the practices. Given that the final objective is to improve the resilience inside the supply chain, many researchers have pointed out the benefits of linking performance indicators to the practices (Han, Chong, and Li, 2020; Behzadi, O'Sullivan, and Olsen, 2020).

Discussion and conclusions

This paper presented a systematic literature review with the aim of analysing the most important papers on SCRes performance measurement. The literature review allowed to highlight several gaps in the extant literature. This paper thus proposes an innovative framework of performance indicators. The framework allows to monitor the performance of SCRes in an operative way, by providing indicators and related formulas, which makes it usable by firms. Secondly, it connects the indicators with the practices of SCRes through the capabilities, which is highly important to track the impact stemming from the implementation of the practices. This research will have an impact in the academic sphere, as it contributes to the discussion concerning SCRes and to filling a research gap. In particular, future research could build on the tools developed in this study and reach an agreement on the measurement of performance for SCRes. The study will also contribute from a practical perspective, as it provides a useful tool to measure the SCRes performance, and an understanding of how to improve this performance. Indeed, through the capabilities firms will be able to understand which areas to focus on to improve their SCRes performance. This will be of fundamental importance for practitioners who strive to build a resilient supply chain.

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SIMULATION-BASED SCENARIO PLANNING MODEL TO INVESTIGATE POST-BREXIT IMPLICATIONS ON THE IRISH BEEF EXPORT SECTOR: A CASE STUDY

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Introduction

Geopolitical disruption is considered a regular risk that hits supply chains and results in a long-lasting impact on a local, national, and global scale (Hendry et al., 2019a). They can limit access to personnel and interrupt transportation and distribution networks, as happened in the Hong Kong protest in 2019 that brought the whole country to a halt. Trade disputes result from such disruptions, cause a dramatic increase in raw materials prices, and influence firms' competitiveness in the home market (Roscoe et al., 2020). Brexit, for instance, creates disruptions to every aspect of supply chains. It affects trade volumes, supply chain assets, material and information flow, human resource availability, and access to suppliers. Besides, Brexit imposes barriers, red tapes, and controls for the trade between the UK and EU (including Ireland). These barriers are divided into tariff and non-tariff barriers. While tariff barriers introduce duties on the EU products sold on the UK market, non-tariff barriers challenge the freedom of movement for goods and services. They reintroduce customs and border controls on the borders entry points and sanitary and phytosanitary (SPS) checks on animal origin products. The EU applied full non-tariff barriers on the imported goods from the UK directly after the end of the transition period – January 2021. On the other hand, the UK decided to postpone implementing the non-tariff barriers at the ports linking with the EU until October 2021 and January 2022 due to Covid-19 disruption to businesses, Figure 1.

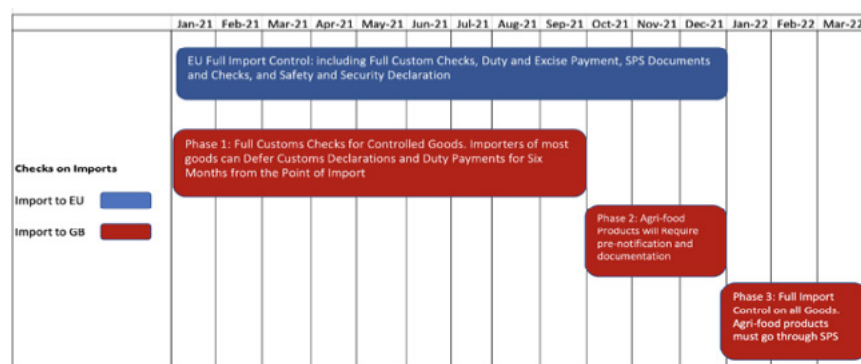


Figure 1 Phases of Non-Tariff barriers implementation at the GB and EU

The meat sector in Ireland is one of its most important indigenous industries as it generates total sales of around 4.5bn, with exports exceeding 4bn annually (Ibec, 2020). Irish beef exports to the UK are expected to be severely disrupted post-Brexit if a trade agreement cannot be concluded. It will face high tariffs, additional administrative burdens, increased veterinary checks and sampling, and a rise in transport and shipping costs. As a result, a decline in Irish beef imported into the UK is expected, which would be highly challenging since Irish beef traders cannot replace the UK market. Predicting Brexit scenarios and assessing the implications on the Irish Beef trade is necessary for Beef exporters to prepare actions to mitigate risks and understand how businesses could be affected. Scenario planning is an effective tool to understand these risks since uncertainties are high, and decision-makers have little control over them (Peterson et al., 2003). Using simulation to plan and assess scenarios quantitatively is introduced in various application domains in the last decade (Alcamo, 2008; Pizzitutti et al., 2017). Simulating future scenarios models complex relationships and system dynamics. It allows verification of internal consistency and testing of policies, strategies, or particular actions (Symstad et al., 2017). Hence, this paper introduces a simulation-based scenario planning framework to support decision-makers in the Irish beef export sector. Post-Brexit scenarios may come into effect following the second and third phases of border checks, on October and January 2021, Figure 1. The research aims to provide the stakeholders in the Beef industry with a clearer vision on how the Beef supply chain in Ireland and the UK may be affected.



Literature Review

Global supply chains involve complex and dynamic interrelationships that expose buyers and suppliers to unique challenges and transportation risks (Alvarado-Vargas and Kelley, 2020; Lei et al., 2021). They are particularly affected by significant uncertainty arising from geopolitical disruptions (Niknejad and Petrovic, 2016; Roscoe et al., 2020). Geopolitical disruption is one of the most urgent global risks at present (Selmi et al., 2020). They are sometimes referred to as constitutional changes (Hendry et al., 2019b), regulatory disruptions (Phadnis and Joglekar, 2020), or political risks (Charpin et al., 2020). Such disruptions lead to structural shifts in demand and require firms to adapt their supply chains to new market conditions to remain competitive (Phadnis and Joglekar, 2020). Tariff and non-tariff barriers are significant risks of geopolitical disruptions that generate additional uncertainties and turmoil in the cross-border transportation flow of materials and goods (Alvarado-Vargas and Kelley, 2020).

Food supply chains (FSC) are complex networks of interdependent firms and actors involved in growing, processing, distributing, and trading food across the globe (Mena and Stevens, 2010). Also, FSCs take strict measures to maintain the integrity and minimise food scares through contamination or deliberate food crimes, adding to the complexity of food systems (Whitworth et al., 2017). The unique characteristics of FSC make it sensitive to natural and political disruptions that could cause costly product recalls, market withdrawal, and hunger for people in particular regions (Dani and Deep, 2010). A broad literature exists that highlights disruptions impact on food systems and supply chains (Hendry et al., 2019a). In the context of supply chain uncertainty, Van der Vorst et al. (1998) highlighted the importance of managing FSC uncertainty and presented improvement principles to boost the service level. The influence of unethical business practices such as (e.g., collusion) on FSC uncertainty has also been highlighted by Simangunsong et al. (2016).

Problem Context

The UK primarily imports high-priced cuts of Irish beef, with more chilled than frozen produce. Beef exports to the UK increased by 4% in 2018. In the European market in general, Irish beef exporters enjoy a similar trade position. The sector has seen growth in exports to the Netherlands and Italy, rising by 4% and 6%. Beef is unlike other products as its trade is not based on selling a carcass as a whole. Each carcass is divided into a range of cuts, which are then exported to various markets according to consumer demand. Each cut has a different value, so exporters must plan their supply chain to maximise revenue. In beef supply chains, retailers are the most powerful link. They provide competitive prices to consumers and thus exercise substantial power over the prices paid to processors and producers.

A limited shelf-life characterises the beef supply chain, so concerns have been raised regarding the potential challenges arising from Brexit. The shelf-life of chilled beef is dependent on the type of product. For example, specific beef cuts can have up to six weeks of shelf-life, while ready-meal products with beef ingredients may have only one week. Brexit brings various complications to the Irish Beef supply chain that will negatively impact its performance like;

- **Veterinary health check and Custom controls:** EU officials have applied SPS checks and other veterinary inspections on the meat imports to the EU27 from the UK in all EU ports on January 2021 – based on the EU official control legislation (Veterinary Check Directive 97/78/EC). Similar inspections are also expected to be applied by the UK on animal products entering their market from the EU27 on October 2021 and January 2022, Figure 1. The introduction of these inspections will inevitably cause an increase in transactional and transportation costs, border check fees, processing times at customs posts, and further administrative burdens on exporters and their agents.
- **Accessibility to mainland Europe:** The majority of Irish beef exporters using the UK as a landbridge to access mainland Europe since it is the fastest route and the most effective in terms of cost. Shipments that use direct route services, from Ireland to Cherbourg or Rotterdam, can take up to twice the transit time of those shipments that go through the UK landbridge and are subject to interruptions because of uncertain weather conditions. However, the UK landbridge's efficiency may diminish when the UK leaves the EU single market and customs union. Beef products will be subject to two transit checks at UK borders. To date, it is unclear what types of checks will take place on trucks transiting through the landbridge. Such uncertainty undermines the current control that operators have over their transportation times and costs, which subsequently disrupts the reliability of beef delivery and quality standards.



Research Methodology

The model focuses on the Ro/Ro (Roll-on/Roll-off) traffic between Ireland, the UK, and Continental Europe through two transportation routes, Figure 2:

- East/West maritime corridor: This combines several maritime routes which link the eastern Irish ports (i.e., Dublin and Rosslare) with UK ports through the Dublin-Heysham, Dublin-Liverpool, Dublin-Holyhead, Rosslare-Fishguard, and Rosslare-Pembroke maritime routes.
- Land-bridge route: This model shows the transportation links between Ireland and the EU26 through 1) the East/West maritime corridor, 2) transit routes to and from Holyhead, Liverpool, Heysham, Fishguard, and Pembroke ports, on the western side of the UK, and Dover Port on the south-eastern side, and 3) the maritime route, Dover-Calais, to the rest of mainland Europe.



Figure 2: Transportation routes modelled in the simulation model

Before the simulation model, two conceptual models were developed to understand the processes of the transportation system between Ireland, the UK, and the EU. Mainly conceptual models include information related to the flow of inbound and outbound trucks, various check procedures (customs, SPS, and transit checks), and port operation systems. In the case of outbound flow (from Ireland to the UK or Continental Europe), the trucks started from an Irish-based supplier and moved toward the Irish ports. On arrival at Irish ports, the trucks roll on to the ferries, then based on ferries' frequencies and capacities, they sail to their destination ports. Upon arrival to their destined port, trucks roll off from the ferries and finish their journey either at a UK-based distributor or at an EU-based distribution, Figure 3.

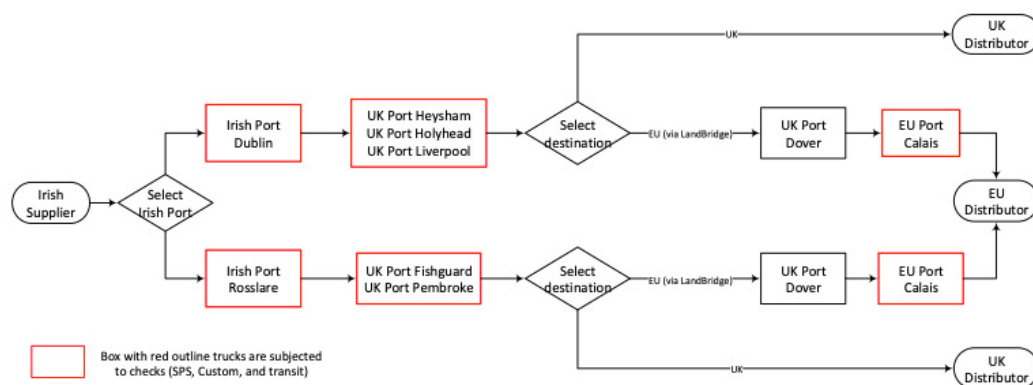


Figure 3 Outbound trucks flow from Ireland to UK or EU (via land bridge)

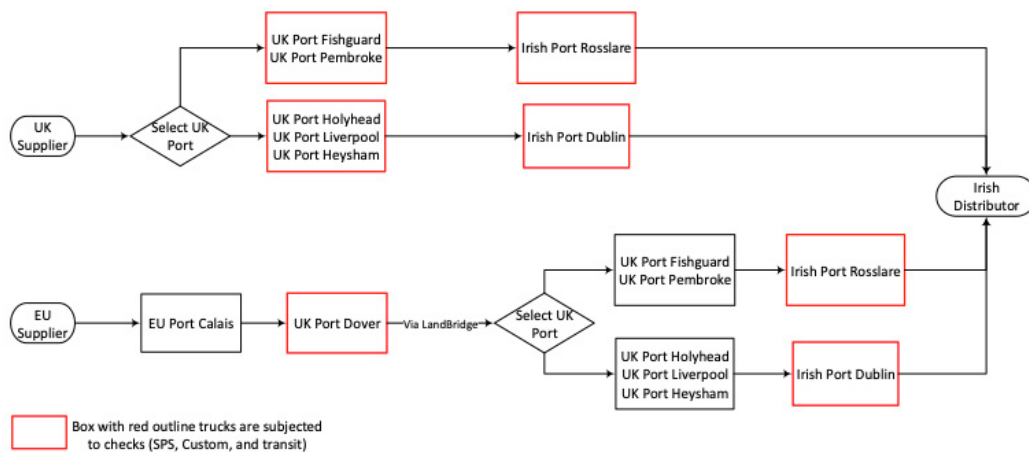


Figure 4 Inbound trucks flow from UK or EU (via land bridge) to Ireland

Similarly, in the inbound flow (from the EU or UK to Ireland), the trucks originating from either a UK-based or EU-based supplier. The trucks then pass through various ports depending on their routes and finish their journey at an Irish-based distributor, Figure 4.

Finally, a simulation-based scenario planning model developed using a hybrid approach (agent-based and discrete event simulation) based on a geographic information system (GIS) map in AnyLogic software. Specifically, agent-based modelling is used for interaction among 19 agents to mimic imports and exports between Ireland, the UK, and the EU. The agents include suppliers (the origin point generating the trucks), distributors (the destination point receiving the trucks), and port agents. Moreover, a leading agent was developed to manage the overall dynamics and interrelationships between the agents. On the other hand, discrete event modelling is applied for sequencing the processes inside the different agents. The simulation software can simulate road and maritime traffic routes and flexible enough to incorporate various trip times for other road and sea routes.

Scenario Analysis

The studied scenarios included introducing new border checks across the Irish Sea and applying transit checks on trucks using the landbridge. Three factors would influence the level of intervention and delay at UK ports: 1) the proportions of trucks selected for the border control checks; 2) the intensity and length of those checks, and 3) the accuracy of declarations and health documentation submitted. Two key performance indicators were used to quantify the impact of different interventions and delays:

- Transportation Time (total time taken by a truck from origin to destination)
- Remaining Shelf-life Time (i.e., transportation time subtract from total shelf-life)

Scenario 1- Level of border checks across the Irish Sea: This scenario applies non-tariff barriers to trade between Ireland, GB, and the EU, including documentary, identity, and physical checks. Three border checks scenarios at the UK ports were used: 1) Limited Check Delay, 2) Moderate Check Delay, and 3) High Check Delay. These three scenarios were tested and analysed with a baseline set as the pre-Brexit situation of trade named As-Is scenario (i.e., no border checks are applied). Table 1 shows the proportion of trucks checked, along with the check timing in each scenario.

The analysis shows how sensitive transportation times and the remaining shelf-life of products are to check delays at UK ports, Figure 5. A slight increase in truck transportation times is observed in the limited-check-delay and moderate-check-delay scenarios. However, the average truck transportation time increases by 234% in the high-check-delay scenario compared to the transportation time in the limited-check-delay scenario. The increase in transportation time disrupts the flow of beef exports for up to two days, which would have a devastating impact on Irish beef exports to the UK and affect the fresh beef supply chain in general. The average remaining beef shelf-life would be reduced by 9% in the high-check-delay scenario. The reduction in shelf-life would significantly lose the value of products, quality standards, and competitiveness (e.g., mince beef and fresh ready-meals).



Table 1: Levels of Borders Checks

Scenarios	Description
As-Is	No trucks are directed to any checks at the UK ports
Limited Check Delay	100% of consignments going for documentary and sealed identity checks (check timing is 20min/truck). 10% of the trucks carrying beef are directed to physical checks (check timing is 60min/truck).
Moderate Check Delay	100% of consignments going for checks, and check timing is 30min/truck. 20% of the trucks carrying beef are directed to physical checks (check timing is 90min/truck).
High Check Delay	100% of consignments going for checks, and check timing is 45min/truck. 30% of the trucks carrying beef are directed to physical checks (check timing is 135min/truck).

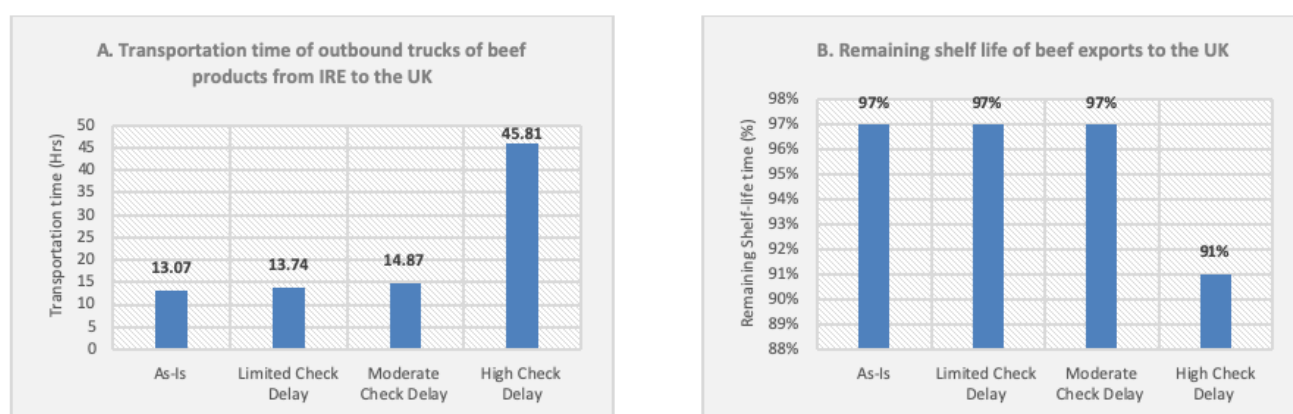


Figure 5 Level of Borders Checks Implications on the Transportation Flow

Scenario 2-Level of transit checks: The analysis in this section aimed to investigate various levels of transit checks and quantify their impact on fresh beef exports to Continental Europe, Table 2. Exports from Ireland to mainland Europe will be subject to transit checks at western UK ports. It is assumed that the number of offices of transit in each port will be two, and all will have paper-based transit procedures (i.e., all trucks must present their transit accompanied documents (TADs) and goods upon arrival at the ports). The model showed a slight interruption to Irish beef exports to mainland Europe via the UK landbridge in three transit check scenarios. The transportation time increased by around 1.5 hours and 5 hours in the moderate-transit-check-delay and high-transit-check-delay scenarios, respectively, Figure 6. The remaining shelf-life for beef was reduced by just 1% under the more extended transit check scenario.



Scenarios	Check timing (in min)	Description
As-Is	0	• No transit checks.
Limited Transit Check Delay	5	• Regular checks on transit accompanying documents.
Moderate Transit Check Delay	15	• More checks are required on the permissions for the operator to transit via UK territory.
High Transit Check Delay	25	• Further increase in transit checks timings

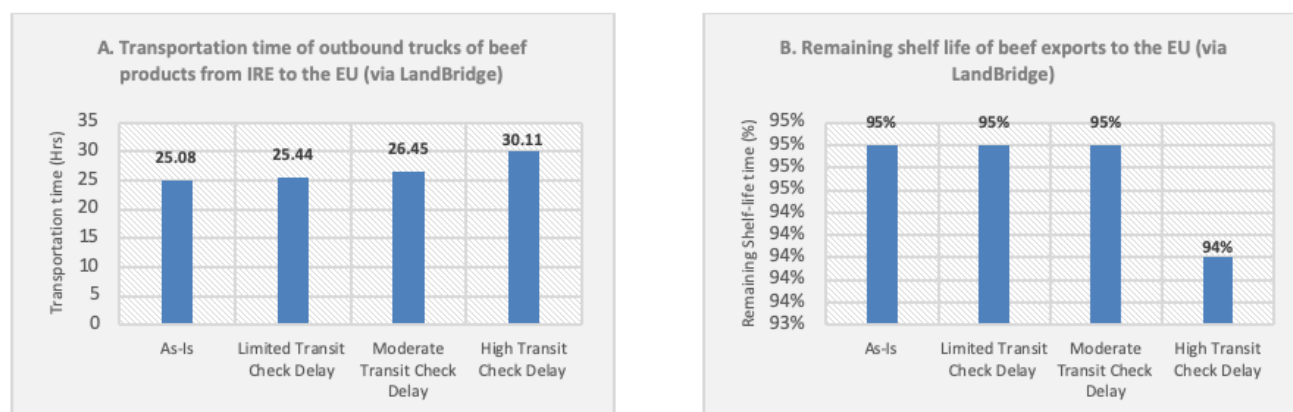


Figure 6 Levels of Transit Checks Implications

Discussion and Conclusion

Trade barriers, including tariff and non-tariff barriers, are expected to damage the beef trade partnership between Ireland and the UK. Beef exporters cannot see any opportunity to replace the UK market with other markets in Europe or beyond, considering that the beef supply chain with the UK is well established and has worked efficiently for many years. The strong ties between the two countries and the level of beef trade with the UK – 50% of Irish beef exports – mean that the UK cannot be replaced with any other countries or trade regions. The procedures of customs, veterinary, and immigration checks at UK ports post-Brexit, and the intensity of these checks (i.e., level of check intervention and check delay), is still unclear. The UK authorities have provided limited formal information. Companies anticipate longer waiting times for their freight at the UK's customs and veterinary checkpoints and transit offices. According to research estimations, truck delays could increase to two days if high check interventions with longer check delays are imposed. This delay could disrupt the whole supply-chain operation, particularly for limited shelf-life products. Changes in demand volumes and inventory strategies are foreseen to create a buffer against delays in product delivery. Retailers will plan their demand further to hold more stock and review the effectiveness of the just-in-time delivery strategy under the new border regimes. Demand for refrigerated trucks and containers will also grow since beef exporters will seek to maintain product freshness and avoid product spoilage.

Further, more than 90% of Irish meat exports to mainland Europe flow via the UK landbridge. It provides hauliers with more control over transit time and speed delivery to EU26 markets. Introducing new transit checks for trucks entering the UK will complicate freight transit via the UK landbridge and increase transit costs. Compared to the As-Is situation, transit checks could add to the freight transportation time based on check types and the intensity of checks. Recently, Covid-19 related procedures at European ports showed an example of what would happen at borders if more forms and checks are required. Filling in a simple form manually before crossing to Dover led to miles and miles of trucks queuing at Calais and considerable disruption to the supply chain. The level of uncertainty inherently associated with Brexit may arise unforeseen effects beyond the considered variables in the study. Beef exporters may respond to this uncertainty by reviewing their supply chain designs, opting for direct service to the continent, or shifting the trade to other markets. Further research is recommended to assess these potential scenarios and apply the utilised research methodology to support other economic sectors against Brexit risk.



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SUSTAINABILITY/CIRCULAR ECONOMY IN FOOD SUPPLY CHAINS



GOING CIRCULAR IN THE FOOD SUPPLY CHAIN: A LITERATURE REVIEW

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Introduction

The Food and Agriculture Organization of the United Nations estimated that around one-third of the food produced worldwide goes to waste, generating negative impacts at an environmental, social, and economic level (Gustavsson et al., 2011; Food and Agriculture Organization (FAO), 2019). The magnitude and relevance of this issue is reflected by the inclusion of the topic in the 2030 Agenda for Sustainable Development developed by the United Nations in 2015, namely in target 12.3 (United Nations, 2015; Food and Agriculture Organization (FAO), 2019). The importance of tackling the problem of food waste (FW) is clear when the sustainability impacts associated with the phenomenon are considered. At the environmental level, the food produced but not consumed represents a waste of resources. It is also associated with the emission of greenhouse gases that contribute to global warming and climate change. It has been estimated that food loss and waste accounts for 8% of the overall amount of global greenhouse gas emissions (Vilarinho et al., 2017). Considering the social implications, wasting food reduces food security (thus, a reduction in FW could contribute to reducing world hunger) and availability, inevitably associated with a price increase due to limited supply. This complex scenario requires a systemic and holistic approach. Scholars and practitioners widely recognized the potential of applying Circular Economy (CE) concepts to manage and reduce FW, even if the complexity is high since food products are automatically downgraded at each cascading loop (Ellen MacArthur Foundation, 2013, 2019; Halloran et al., 2014). The Ellen MacArthur foundation, with its report published in 2012, defines the concept of CE as “an industrial system that is restorative or regenerative by intention and design” and is opposed to the standard linear model “take-make-dispose” (Ellen MacArthur Foundation, 2012). The main concept underlying CE is the need to close the loop of materials by replacing the end-of-life with alternative solutions. CE principles support the development of this new vision of the economy where the reconceptualization of waste as a resource can be a trigger for disruptive innovation. The ability to see where the generated waste can become a resource can facilitate this vision-shift (Perey et al., 2018). The switch to a CE requires radical changes, and for companies, this translates into the need for strong commitment, strategic decisions, and overall cultural and organizational changes (Maranesi and De Giovanni, 2020). Tackling such significant changes can be challenging for a single company: a positive correlation has been shown between the level of integration and collaboration in the supply chain (SC) and the number of CE objectives collectively pursued (Elia et al., 2020). In fact, poor supply chain management (SCM) and poor logistics network design can be a cause of FW (Balaji and Arshinder, 2016; de Moraes et al., 2020; Magalhães et al., 2021), since it can lead to hold-ups in logistics and SC aging, where products spend most of their shelf lives in the SC instead of in retails or consumers’ pantries (Göbel et al., 2015; Akkas et al., 2019). This systematic literature review aims to understand how SCM and logistics can support the transition towards a CE of FW. This approach locates the field of study at the intersection of CE, SCM, and FW. Given the abundance of definitions related to FW, in this document the term FW is used to indicate any food flow that exits the value chain, at any step, for any reason (Chaboud and Daviron, 2017).

Methodology

The adopted research methodology is the Systematic Literature Review (SLR) (Denyer and Tranfield, 2009). First, to clearly embed the scope of the research into the literature review, a set of keywords has been identified for each of the investigated research area mentioned above. These are listed in Table 1.

Research Area	Keywords
Food Waste	“food waste” “food scrap” “food surplus” “food byproduct” “food loss”
Circular Economy	“circular economy”
SCM, Logistics	“supply chain” “supply network” “supply chain management” “logistic”

Table 1. Keywords for each research area

Regarding FW, the chosen words are often used as synonymous (Chaboud and Daviron, 2017) and this selection of keywords has been dictated by the exigence of including all the possible flows of materials leaving the food SC. The choice to use only the keyword “circular economy” for this field is based on the officially recognized definition of CE proposed by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2012).



This decision implied the exclusion from the keywords of similar concepts such as the 3Rs (reuse, reduce, recycle) or other similar frameworks (e.g., 6Rs, 9Rs). The keywords about SCM and logistics have been chosen to give a SC perspective to the research, so “supply chain” and its synonymous “supply network” have been included. The following three research strings using Boolean operators were generated:

1. ((“circular economy”) AND (“supply chain” OR “supply network” OR “logistic*” OR “supply chain management”))
2. ((“food waste” OR “food scrap” OR “food surplus” OR “food by-product” OR “food loss”) AND (“supply chain” OR “supply network” OR “logistic” OR “supply chain management”))
3. ((“food waste” OR “food scrap” OR “food surplus” OR “food by-product” OR “food loss”) AND (“circular economy”))

The combined analysis of the outcomes of the application of these three search strings allows investigating the intersection among the three research areas. The searches have been conducted using Scopus, adopting some inclusion criteria (Figure 1). The restriction about the publication year, i.e. the articles had to be published from 2012 onwards, was adopted because in that year the official recognized definition of CE had been given by Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2012). Before starting the screening of the articles, duplicates have been removed. Some exclusion criteria have been applied. Since the focus of this review is on companies operating in the food SC from an industrial perspective, those papers dealing only with consumer-related issues were excluded from the analysis. Once the sample has been defined with full-text reading, some other publications have been retrieved by means of forward and backward referencing. The selected papers include peer-reviewed articles and ones belonging to grey literature. The latter ones have been included since they are highly cited and bring important contributions to the research fields of FW (mainly FAO publications) and CE (e.g., reports developed by the Ellen MacArthur foundation). The above-described steps led us to have a final sample of 253 selected papers.

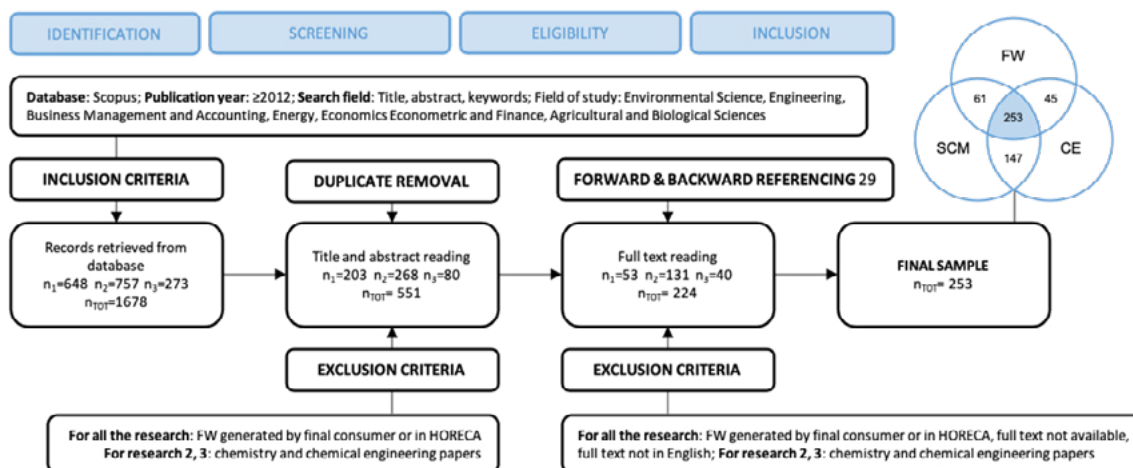


Figure 1 – Steps of the SLR

Results

Food waste and circular economy: concepts and practices

As a first emerging theme, to guide companies in adopting circular practices, the Ellen MacArthur Foundation developed the ReSOLVE framework, which has become pivotal in the development of value creation mechanisms in a CE context. ReSOLVE is the acronym of Regenerate, Share, Optimize, Loop, Virtualize, and Exchange, and these actions represent vital points to follow in the development of a circular system (Ellen MacArthur Foundation, 2015). In the 2012 report, the Ellen MacArthur Foundation states that CE can be developed both for technical and biological nutrients, that namely compose durable components that can't be returned to the biosphere, and consumables which can safely return in the biosphere. To demonstrate the possible looping of the nutrient flows, the report proposes the well-known butterfly graph (see Fig.2a), which shows that cascading flows is suitable for biological nutrients, which lose value at each loop, while for technological nutrients the inner loops are preferred, since most of the value is retained with respect to external ones (Ellen MacArthur Foundation, 2012). The butterfly graph has been adapted to represent the possible loops of food flows. The adaptation proposed by Teigiserova et al. (2020) better details the graph, by distinguishing between edible and inedible flows (see Fig. 2b) (Teigiserova et al., 2020).



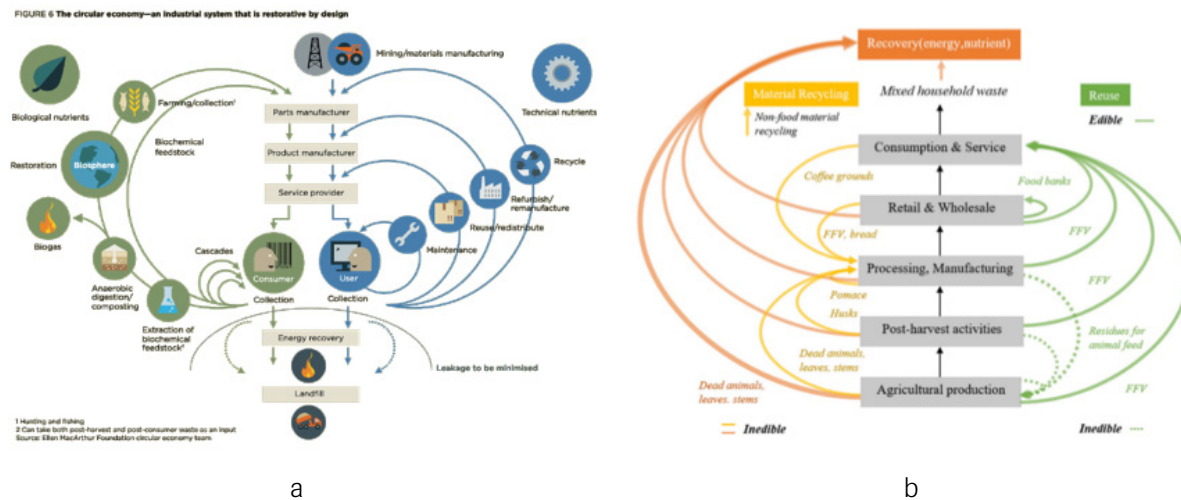


Fig 2. a) The butterfly graph (source:(Ellen MacArthur Foundation, 2012)) ;
b) The butterfly graph for food flows (source: (Teigiserova et al., 2020))

This concept of circularity for the food flows is connected to the food waste hierarchy (FWH), developed by Papargyropoulou et al. (2014). At the top of the FWH is the most favorable option, prevention, and going down the hierarchy, other least preferred alternatives are listed, which will retain less and less value in the products. The proposed options are prevention, reuse for human consumption through redistribution, recycling into animal feed, recycling via composting, energy recovery, and disposal into landfills (Papargyropoulou et al., 2014). Stemming from this key article, several takes on categorizing and prioritizing the alternatives for FW management have been proposed. One of the most recent takes on the FWH has been proposed by Teigiserova et al. (2020). In this paper the FWH is not only updated, but also connected to the butterfly graph, for a more holistic perspective on the potentialities of CE for FW management and reduction. This framework also better exemplifies that circular actions can be developed at each stage of the FSC, and that exchanges between actors can contribute to CE, with the establishment of reverse flows (Teigiserova et al., 2020). However, the plurality of CE practices available to valorize and prevent FW isn't yet reflected in the strategies currently adopted by companies; the study conducted by Ghisellini and Ulgiati (2020) on the transition towards CE in Italy, using a sample of 292 companies, has shown how most circular practices are still emerging, since a considerable portion only focuses on recycling (Ghisellini and Ulgiati, 2020). From a consumers' perspective, despite the increasing familiarity with the CE concept, the development of CE strongly relies on the acceptance of consumers of the products derived from circular practices. Different studies have assessed the attitude towards circular products, and they have shown the positive influence of providing information and knowledge (about "green" aspects, quality, risks...) on the purchasing intentions, which are also positively influenced by a cost advantage (Wang and Hazen, 2016; Wang et al., 2020). Understanding the consumer's opinion and acceptance level is particularly important for fostering companies' actions to reduce FW, especially when safety aspects are extremely relevant. Several studies confirm that in the specific case of food, giving more information to the consumers has benefits on the acceptance of the circular food products; in particular, knowing the environmental benefits, and why a circular ingredient is used, can help increase the familiarity with these products (Combest and Warren, 2019; McCarthy et al., 2019; Coderoni and Perito, 2020). Another aspect that influences the willingness to buy circular food products is the brand that proposes the product (a well-known brand is more likely to be accepted) (Aschemann-Witzel and Peschel, 2019). A potential source of FW is represented by products that don't meet aesthetic standards. In this case, the study conducted by de Hooge et al. (2017) proves that consumers are open to buy sub-optimal products, especially if a discount is offered, thus helping in the reduction of FW and towards the development of a circular food system (de Hooge et al., 2017).

Causes of food waste in the supply chain

Another theme emerging from the analysis regards the causes of FW related to the SC. These vary along the SC due to the different operations carried out at each step. Still, some of the ones identified in the literature specifically refer to the SC (Diaz-Ruiz et al., 2018). At the processing stage of a food SC, besides the technical problems that might occur during production, using raw materials of inadequate quality is a prominent cause of FW, enhanced if no assessment of the supplier is carried out and there are no quality specifications on the raw material (Gustavsson et al., 2011; Biliska et al., 2016; Biliska and Kołozyn-Krajewska, 2019). Overstocking is a consequence of overproduction, and for products with short shelf life, or if inadequate inventory management is in place, this can be a relevant source of FW (Mena et al., 2014;

Balaji and Arshinder, 2016; Chen et al., 2018; Magalhães et al., 2021). At the retail or wholesale level, one of the most cited causes of FW is the wide variety of products available on the shelves, in large quantities, throughout the whole day (Food and Agriculture Organization (FAO), 2014; Göbel et al., 2015; Canali et al., 2017; Diaz-Ruiz et al., 2018; Wunderlich and Martinez, 2018; Brancoli et al., 2019; Cicatiello et al., 2020; Magalhães et al., 2021). The number of displayed products that turn into waste increases if the environmental conditions are not proper, due to old or inadequate infrastructures (Gustavsson et al., 2011; Bilska et al., 2016; Cicatiello et al., 2020; de Moraes et al., 2020). Market power imbalances are often cited as a cause of FW in the SC, as usually the upstream tiers have much lower power than the downstream ones. This translates into practices that damage the growers and suppliers, and eventually lead to FW generation (Canali et al., 2017). Some examples: no agreements on volumes to be bought from the producers (Devin and Richards, 2018), agreements with significant quantity discounts (Wunderlich and Martinez, 2018), the 1/3 rule for which that amount of product's shelf life should be spent on the retailers' shelves (Diaz-Ruiz et al., 2018; Ishangulyyev et al., 2019), and free returns (also defined as take-back agreements-TBA) (Canali et al., 2017). TBA are agreements for which the supplier must collect the unsold products from the retailer and take care of their disposal. They are particularly common for bread, and several studies have highlighted their negative influence on FW, since this responsibility-shifting doesn't incentivize the supermarket to waste less. In some cases, the return rates, and thus the costs, were so high that the supplier eventually decided to stop supplying the retail (Eriksson et al., 2017; Brancoli et al., 2019; Ghosh and Eriksson, 2019). Furthermore, inventory policies and control, if not properly managed, can be a prominent cause of FW at the retail level, which also include the stock rotation and product rotation on shelves (Cicatiello et al., 2020; de Moraes et al., 2020). Akkas et al. (2019) determined that having a minimum order quantity leads to FW, due to increased inventory level (Akkas et al., 2019). Chabada et al. (2015) established a correlation between delivery frequency and FW: the higher the delivery frequency, the lower the FW, even if the reduction extent depends on the type of products (Chabada et al., 2015). The study by Wang et al. (2019) highlighted that the amount of safety stocks, and the way in which they are calculated, can be a driver for FW generation (Wang et al., 2019). Inaccurate forecasting is a relevant cause of FW also at retail level, where it's enhanced by the volatility of consumers' preferences that can cause unexpected demand drops (Diaz-Ruiz et al., 2018; Cicatiello et al., 2020; de Moraes et al., 2020; Dora et al., 2021). Promotions often offered in supermarkets have been indicated as a cause of FW, since consumers tend to buy more than they really need; this behavior is also exacerbated by products offered in bulks (Mena et al., 2014; Canali et al., 2017; Akkas et al., 2019; Ishangulyyev et al., 2019; Magalhães et al., 2021). Poor logistics network design can be a cause of FW (Balaji and Arshinder, 2016; de Moraes et al., 2020; Magalhães, Ferreira and Silva, 2021), since it can lead to hold-ups in logistics and SC aging, where products spend most of their shelf lives in the SC instead of in retailers or consumers' pantries (Göbel et al., 2015; Akkas, Gaur and Simchi-Levi, 2019). FW caused by logistics issues is enlarged by the lack of adequate infrastructures, such as refrigerated storage facilities and vehicles, or roads in a good state, eventually leading to cold chain inefficiencies or interruptions (Balaji and Arshinder, 2016; Bilska et al., 2016; Canali et al., 2017; Diaz-Ruiz et al., 2018; Ishangulyyev et al., 2019; de Moraes et al., 2020; Magalhães et al., 2021). During transportation, vehicle loading and unloading, and cross-docking activities, careless handling or mishandling of products frequently results in product damage or spillage, thus becoming waste (Arivazhagan et al., 2016; Balaji and Arshinder, 2016; Bilska et al., 2016; Canali et al., 2017; Parmar et al., 2017; Diaz-Ruiz et al., 2018; Ishangulyyev et al., 2019; Cicatiello et al., 2020; de Moraes et al., 2020; Magalhães et al., 2021). The influence of mishandled products on the generated FW is related to the type of packaging used, whose primary function is to protect the product. Using inadequate packaging or packaging material, which offers low mechanical protection, or is easily damaged, enhances the risk of food products turning into waste (Mena et al., 2014; Bilska et al., 2016; Canali et al., 2017; Kliaugait and Kruopien, 2017; Diaz-Ruiz et al., 2018; Ishangulyyev et al., 2019; Wohner et al., 2019; de Moraes et al., 2020). At each stage of the SC, the lack of knowledge, skills and training of personnel has been identified as one of the main causes of FW, which can amplify the structural problems that might be present in the chain (Arivazhagan et al., 2016; Bilska et al., 2016; Arias Bustos and Moors, 2018; Bilska and Kołozyn-Krajewska, 2019; Mithun Ali et al., 2019; Vats et al., 2019; de Moraes et al., 2020; Despoudi, 2021). The retrieved paper also include as causes of FW: poor leadership and managerial commitment (Bilska et al., 2016; de Moraes et al., 2020; El Bilali and Hassen, 2020), lack of awareness (Bilska et al., 2016; Diaz-Ruiz et al., 2018), limited capabilities of selling products about to expire (Diaz-Ruiz et al., 2018), and a strong focus on productivity (Messner et al., 2021). At a higher level, some papers mention the strict legal requirements about food safety as a driver for FW generation (Göbel et al., 2015; Canali et al., 2017; Diaz-Ruiz et al., 2018).



Solutions to manage FW in the circular supply chain

A significant portion of the retrieved literature is devoted to the proposal and analysis of solutions to tackle the problem of FW, either by reducing it or through its valorization. According to the objective of this research and following the classification proposed by Diaz-Ruiz et al. (2018), this section will be focused on those solutions that can be operationalized in the SC, so that require the collaboration between two or more SC actors, or are related with logistics and network design (meso level) (Diaz-Ruiz et al., 2018). At the boundaries between companies, collaboration mechanisms and logistics can influence the amount of FW generated in the SC and the development of CE practices, eventually resulting in circular supply chain management (CSCM) and with the introduction of sustainable practices in the SC (Priefer et al., 2016; Dora, 2020). CSCM has been defined as: "...the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users." (Farooque et al., 2019). This definition recalls, according to a CE approach, the need to involve all SC functions in the innovation towards circularity and circular SCs. Implementing circular practices in the SC has shown to positively correlate with the environmental performance, while being subordinated to the attitude of the individual company, which must fully understand the concept of CE and its implications (Hussain and Malik, 2020). Top management has the role of mediating between external pressures and supplier management to develop circular practices, so their commitment and motivations are crucial to transition the SC in becoming more circular and integrated (Dubey et al., 2019). The SC mechanisms and dimensions that allow the design of circular SCs (CSCs) have been identified by González-Sánchez et al. (2020) as being: greater intensity in the relationships established in the SC, by developing closer and more frequent interactions, that entail integrated and synergistic actions by all the parties involved; the adaptation of logistics and companies' organization, given the need of a reverse logistics network; introduction of disruptive and smart technologies that can allow for better communication and development of new functionalities; establishment of a functioning environment through agreements, financial commitments, and shared objectives (González-Sánchez et al., 2020). The collaboration between SC stakeholders can help address the core issues present in the chain that eventually lead to FW, such as infrastructures, packaging, and adopted standards (Bhattacharya and Fayezi, 2021). In the paper written by Despoudi et al. (2018) seven collaboration paradigms have been proposed and explored. The first one is 'goal congruence', so the presence and extent of shared goals, then there are 'communication' and 'information sharing', so how companies communicate and which type of data they share. 'Resource sharing' and 'incentive alignment' refer to the shared assets, costs, and risks between the actors. The joint decision-making process is defined as 'decision synchronization', while the ability to work together to respond to market changes has been defined as 'joint knowledge creation' (Despoudi et al., 2018). Similar collaboration aspects have been identified by Arias Bustos et al. (2018), which described information exchange, incentive alignment, effective partnership, and adequate use of technology as the building blocks of "innovative collaboration", which can be effective in reducing FW (Arias Bustos and Moors, 2018). In this sense, information sharing along the SC can be the first step towards coordination for FW reduction, since it can streamline the chain, thus reducing product handling and delays, and allows for efficient forecasting and material flow synchronization (Kaipia et al., 2013; de Moraes et al., 2020). The sharing of information with external stakeholder can create an "extended SC". For example, by increasing the collaboration between retail and food banks, donations of surplus food can become daily and part of the retail's routine, allowing to reduce FW, and therefore including food banks in the SC (Sert et al., 2016). When developing a collaboration or a partnership, achieving mutual benefits is a core aspect (Dora, 2020). Aligning goals between the leading company and the suppliers is crucial, and more favorable conditions can be created if the economic benefits are clear to all parties involved. If the collaboration project doesn't include the core business of some of the actors, the perceived risks can undermine the success of the project (Ramkumar, 2020). Trust and active cooperation are important in the development of CSCs, but governance instruments can influence it. Most of the agreements, relationships, and negotiations are defined with contracts, facilitating the arrangement between companies and setting the basis for long-term project and goals. Chain-coordination mechanisms can also be facilitated by an external actor, for instance, the technology provider (Fischer and Pascucci, 2017; de Oliveira et al., 2019). Besides, geographical proximity facilitates collaboration and can result in the establishment of industrial symbiosis (IS) relationships (Dora, 2020). The companies involved don't usually belong to the same SC. They exchange material and energy flows to reduce the consumption of resources and exploit the products' value at best, thus developing a closed-loop SC (CLSC) (Rosado and Kalmykova, 2019). When engaging in IS, companies can both maximize their profit and minimize their environmental impact, by finding a trade-off between the two objectives (Vimal, Rajak and Kandasamy, 2019). The project developed in the city of Göthenburg, reported by Rosado and Kalmykova. (2019), involved four distinct value chains (lamb, fruit and vegetables, beef, chicken) in the development of an IS network. The project required coordination by the



developer companies, to identify value chains, stakeholders, infrastructures, and flows. The involvement of stakeholders, and the understanding of their activities, have allowed the development of the IS network, associated with the adoption of circular practices, which contribute to sustainable development (Rosado and Kalmykova, 2019). Examples of IS can be found at the agricultural level as well: agroparks can be developed, which rely exclusively on the exchange of bio-based flows between different stakeholders present in the area. (Donner et al., 2020) Logistics solutions can reduce FW, and these require collaboration between SC actors (Liljestrand, 2017). When transporting food products, packaging protects them from damages. Thus adopting new and more performing packaging solutions can reduce the amount of FW (Liljestrand, 2017). Intelligent packaging can provide information about quality decay, which can be used to allocate products between producer and retailer, to minimize waste (Heising et al., 2017). Temperature monitoring during transportation allows keeping the products at the optimal storage temperature, thus minimizing the FW caused by interruptions in the cold chain. This technology can also be implemented in refrigerated containers, for example, for long-route transportation (Porat et al., 2018). Intelligent containers able to calculate the remaining shelf life, start controlled ripening, and eventually communicate products' spoilage represent a great opportunity to tackle FW, since they have shown to reduce it by 22% (Haass et al., 2015). Routing models that include the quality decay of products, and the costs associated with waste, have been developed. One of the objectives is reducing FW, which is coupled with the increased quality of the products delivered to the customer (Rijpkema et al., 2014; Soysal et al., 2015; Fikar, 2018). Warehouse management can be improved through information sharing between SC actors. The shared data can be used for collaborative forecasting, to revise the product groups (if some show particularly high levels of FW), to define the level of safety stocks, and better manage the lead time (Liljestrand, 2017). Replenishment policies can also be optimized thanks to information sharing. This can be achieved with automatic replenishment policies, where highly granular data about each SKU are shared with the supplier; an order proposal is generated according to these data, which can be accepted or denied. The introduction of automatic replenishment policies has shown to be particularly effective in reducing the FW of products with long shelf life (around 20%) (Kiil et al., 2018). The development of a CSC requires establishing new relationships and likely a reverse logistics network. The changes needed for the SC structure and how to optimize the new network have been explored in several papers. Some use mixed-integer linear programming, setting as objectives the minimization of the costs and the maximization of the environmental benefits. Applying these models in the design of CLSCs shows the feasibility of developing an optimized reverse logistics network (Accorsi et al., 2015; Bottani et al., 2018; Atabaki et al., 2020; Liao et al., 2020; Santander et al., 2020). Other studies have focused their attention on the dynamics that arise in the CSCs. Flow uncertainties affect the inventory performance of the SC, while they don't have a relevant effect of the bullwhip effect, which is generally reduced in CLSC, even with long and variable lead times. On the contrary, circular chains seem to benefit from long lead times, this dynamic is defined "lead time paradox" (Dominguez et al., 2020). The centralization of the remanufacturing processes can reduce the flow uncertainties, thus allowing smoother production and more efficient logistics (Dominguez et al., 2021). The transition towards CSCs can be facilitated with the use of innovative and disruptive technologies, which enable coordination and collaboration among SC members, digitization of SC activities, and the integration of digital and physical systems, to overall improve the CE performance of the SC (Del Giudice et al., 2020; González-Sánchez et al., 2020; Yadav et al., 2020). Blockchain, which can provide trustable, transparent, and secure data, can help strengthen the relationships across the SC. This technology allows localizing the materials in the SC, thus increasing visibility and traceability, and eventually improving the sustainability and resilience of the whole chain, with the development of secure systems and smart contracts (Nandi et al., 2021). In the context of FW, blockchain technology has potentialities to track waste and losses, understand the causes, and track the redistribution flows (Kayikci et al., 2020). Brokerage platforms represent a technology particularly suited to close the loop of FW. They can be either B2B, B2C, or C2C. They don't only allow to match supply and demand, but can also inform about the problem of FW, mobilize stakeholders, integrate the users, and measure the avoided impacts (Ciulli et al., 2020). SIVEQ is an IoT-based platform that connects retailers with food banks. It can be accessed with a mobile app, where the donors upload the available products, enabling the receiver to navigate the food up for donation, and being notified when the food can be retrieved (Scazzoli et al., 2019).

Discussions and conclusion

The integration of CE in the SC appears as a promising approach for the reduction of FW, but despite the frameworks proposed in the literature, an effective approach seems to be lacking. The implementation in SCs of general guidelines about CE and FW, such as the FWH or the butterfly graph, is still scarce and not well documented in scientific literature. The difficulties in translating these paradigms into practice are enhanced by the underlying lack of knowledge and culture about these topics.



Overcoming such barriers can be crucial to develop effective collaborations in SCs, built on CE principles. Partnerships and coordination between SC actors can prevent FW's generation, thanks to reduced market imbalances that lead to more beneficial and balanced agreements between companies (i.e., avoiding take-back agreements that damage the supplier). When companies decide to collaborate, sharing skills and knowledge can facilitate the development of new and innovative solutions to tackle FW. The novel solutions might entail a partial reconfiguration of the supply network, as in the case of IS, and the presence of a third party can facilitate the shift towards a more circular SC. The establishment of new practices devoted to FW reduction might also require the introduction of new technologies; hence the presence of a third actor, in this case the technology provider, can boost and simplify the implementation process. Technology and innovation are key enablers for a CSC, both in terms of IT solutions and improvement of existing assets and practices (for example, better performing packaging, improved warehouse management, optimized transportation...). From a SC perspective, technology is no longer a tool that the stand-alone company can employ, but that is tailored to the SC, to optimize and improve its dynamics and processes. The exploitation of the potential offered by new technologies would allow the creation of CSC, where the exchanges at the interfaces between companies are facilitated and the benefits of CE are shared among SC players.

Consumers appear to have a role in defining how SCs and companies deal with FW and shape FW. Despite the consumption stage being out of this SLR scope, the relevance of the consumers' perspective is testified by the studies devoted to exploring the acceptance of circular or suboptimal food products or the effect of promotions on customers' purchases.

This SLR delineates some possible research topics, which can deepen knowledge about circularity in food SCs. Investigating empirically, through case study research for example, how SCs deal with CE can provide insights on best practices and collaboration mechanisms. Exploring different value chains can highlight the most common approaches, the peculiarities of each food product, and thus each FW. Studying these mechanisms might also contribute to define the facilitating role of a third-party actor. At last, evaluating the consumers' perspective and role in the SC, in terms of generated FW, and acceptance of circular food products, can provide insights and guidance of the solutions to be implemented in the SC.

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A THEORETICAL SUSTAINABILITY MODEL ON USING IOT SENSORS AND CLOUD SYSTEMS FOR REDUCING FOOD WASTE AND EMISSIONS IN THE FRESH FOOD SECTOR

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Introduction

In 2015, the United Nations sustainable development goals pledged to halve the per capita food losses in the retail and consumer levels by 2030. In order to achieve this, the post-harvest supply chain will have to regain a greater level of integration between the actors at different stages of the supply chain. Digital technology such as IoT sensors, cloud based continuous monitoring and artificial intelligence provide a competitive edge for fresh food companies in their efforts to replace traditional thumb rule based quality monitoring with real-time monitoring systems to overcome challenges and achieve a transparent, quality focussed and sustainable supply chain system in the food sector. The present work is being conducted in the context of REAMIT project (www.reamit.eu), supported and funded by the Interreg North West Europe programme which focusses on improving resource efficiency of agri-business supply chains through big data and IoT sensors. Islam and Cullen (2021) reported that using IoT systems helps to improve food traceability across the food supply chain. Similarly, the opportunities or perceived benefits of using IoT systems are not only limited to having traceability, but can also be visualised in terms of its contribution to inculcating sustainable practice, food waste reduction, generating market opportunities and building a green image. Despite the huge benefits, one can argue, IoT sensor technology implementation does not come easy and is connected with significant costs to the company, it's employees and the environment. Therefore, this paper aims to build a conceptual model to evaluate the degree to which the use of IoT sensors and related technology fits (underfit, overfit or ideal fit) to track food quality and reduce food waste while considering various opportunities, enablers and barriers to its implementation across the food sector.

Literature review

The literature review is categorised in to three broad categories for the purpose of this paper: Studies that capture opportunities, enablers and barriers for IoT systems implementation. The literature points out several challenges or barriers for implementation of IoT sensors in the fresh food sector to reduce food wastage and associated emissions. Aamer et. al. (2021) pointed out that there are a total of 15 challenges associated with implementation of IoT in the food sector including social, operational, technical, governmental and financial challenges. Manavalan and Jaykrishna (2019) reiterated the importance of Industry 4.0 and Internet of Things for building sustainable supply chains while highlighting on the complexity of data and data handling methodologies available for analysing them based on empirical evidence. An IoT system enabled data-driven management system was investigated by Wen et al. (2018) for the case of restaurant food waste at Suzhou, China and found that operational cost for constant replacement of sensors, selection of the right type of sensors and disagreements between stakeholders while interpreting the data, are some of the challenges. The difficulty in choosing the right kind of sensor for a particular environment also affects the capability of the system to measure energy dissipation from a sensor or an embedded IoT device to estimate the overall emissions from the IoT system. Furthermore, some of the other technical challenges reported in literature include failure of GPS signals, lack of communication between devices, user friendly technology, dealing with inefficient road paths and vibration environments (Paciarotti & Torregiani, 2021; Muñoz-Villamizar et al., 2021) In addition to aforementioned issues, regulatory concerns, location and weather related issues, and organisational barriers (Alfian et al., 2020; Balaji & Arshinder, 2016; Haji et al., 2020) are some of the important barriers noted in literature.

Having discussed barriers, it is important to understand the enablers that promote the use of IoT systems in the food sector. Montanari, 2008 emphasise on the importance of using cost effective IoT sensors and intention to promote IoT infrastructure. Aamer et al. 2021 mentioned the need for providing financial support along with formulation of policies and regulation to reduce food waste. Few authors have also discussed how non-financial support can help industries to operationalise IoT systems in the food sector (Aamer et al., 2021; Aytaç & Korçak, 2021; Grimm et al., 2014). From literature study, the type of enablers that support implementation of IoT in food sector can be summarised into four broad categories which are technology and infrastructure enablers, policy and economic enablers, social and behavioural enablers.



Finally, the literature study encapsulates studies that highlight the benefits and opportunities for using IoT systems in food sector under three broad categories which are food safety, market opportunities and environmental benefits. Pal and Kant, 2020 emphasised on the importance of smart sensing and control mechanisms available in order to ensure food safety in the perishable food supply chains. Onwude et al. 2020 stressed upon the usage of IoT technology for coping with food losses and the need for simultaneously considering environmentally friendly solutions.

Based on the aforementioned literature review the authors identify that the database of knowledge pertaining to barriers, enablers and opportunities to implementation of IoT systems for reducing food waste and associated emissions is heavily scattered and lacks a common platform. Furthermore, the literature ignores social and environmental dimensions while discussing them and therefore this paper contributes to the existing literature in the following three ways. Firstly it aims to capture in one place the barrier, enabler and opportunity constructs for implementation of IoT systems in the fresh food sector for reducing food waste and associated emissions. Secondly it uniquely emphasis on additional environmental and social aspects under each of the aforementioned constructs. Thirdly, it proposes a requirements technology fit model to investigate the influence of tracing and tracking, data reliability and impacts of external environment on the supply chain performance measured by amount of food waste and emissions reduced.

Methodology

The research methodology for this study comprises of two stages. The first stage would involve reviewing the existing literature and analysing studies published in renowned journals. The search for papers would be conducted using databases such as Web of Science, Scopus and google scholar categories. We aim to review approximately a total of 150 articles to understand the barriers, enablers and opportunities for food sector. The second stage would involve linking the aforementioned constructs to measure food waste reduction with help of a theoretical model. Putting together the aforementioned barrier-enabler-opportunity constructs provides a strong base to investigate the relationships between each of these elements that maximise or minimise the benefits that can be reaped out of the opportunities available. However, given the fact that it is not feasible to consider and investigate all factors in a single model, the present study aims to develop a theoretical model using a sample selection of constructs from the set of barriers, enablers and opportunities. It is important to note that testing the model is out of scope of this study and will be dealt with in the extension of this work. Thus, less emphasis is provided towards data collection and methodology to solve the proposed model.

Findings

A list of barriers, enablers, and opportunities for implementation of IoT in food sector is formulated by referring to literature as shown in Tables 1, 2 and 3. Each of them are divided into broad category and specific category variables. Table 1 shows the list of various barriers to adoption of IoT in fresh food supply chains such as technical challenges, challenges due to regulatory environments/requirements, organisational, social and economic barriers. Table 2 shows the list of probable enablers that could accelerate the implementation of IoT sensor in food supply chains. Finally, Table 3 showcases the probable set of opportunities for stakeholders to consider implementation of IoT sensor technology.



Broader category	Specific issues	References
Technical challenges	- Monitoring and controlling of large volume of data - Failure of GPS signals - Inefficient road paths - Lack of accuracy in detecting the location of the truck - Lack of communication - User-friendly features	Aamer et al., 2021; Alfian et al., 2017; Haddud et al., n.d.; Lee & Lee, 2015; Manavalan & Jayakrishna, 2019; Onwude et al., 2020; Rejeb et al., 2019; Tian, 2017; Hajghasem & shojaie, 2016; Muñoz-Villamizar et al., 2021; Paciarotti & Torregiani, 2021; Snoeck et al., 2020; Pal & Kant 2020; Pang et al., 2015; Rejeb et al., 2019; Zhang et al., 2017
Regulatory environment	- Vibration - Health issues - Privacy issues - Certification for the fresh food - Food safety and quality issues	Alfian et al., 2017, 2020; Balaji & Arshinder, 2016; Haji et al., 2020; Onwude et al., 2020; Bouzembrak et al., 2019; Chen et al., 2013; Gu et al., 2012;
Location-related issues	- Accidents - Obstacles in transportation of food	Hobbs, 2020; Singh et al., 2020; Tang, 2006; Haji et al., 2020; Tsang et al., 2018
Weather	IoT sensors is sensitive to external weather	García et al., 2020; Kousiouris et al., 2019; Nukala et al., 2016
Organisational barriers/inertia	- Lack of <u>organisation</u> capabilities to adopt IoT sensors - Management support - Technical incompetency of the employees - Lack of motivation - Lack of awareness and knowledge of the benefits of IoT sensors	Arunachalam et al., 2017; de Vass et al., 2018; Kaloxylas et al., 2013; Kamble et al., 2019; Bravi et al., 2020; Graham-Rowe et al., 2014; Visschers et al., 2016; Onwude et al., 2020; Paciarotti & Torregiani, 2021
Social barriers	Lack of willingness and coordination	Govindan et al., 2014; Grimm et al., 2014
Economic barriers	- High cost of the IoT sensors - High operational and maintenance cost	Gupta et al., 2019; Kuo & Chen, 2010; Montanari, 2008; Pal & Kant, 2020;

Table 1 Barriers to adoption of IoT Sensors in fresh food supply chain



Broader category	Specific issues	References
Technology and infrastructure enablers	• Providing cost effective IoT sensors • Promote the strong infrastructure support • Increasing awareness of the usage of IoT sensors for food wastage reduction • Promoting sustainable food supply chain	Montanari, 2008; Grimm et al., 2014, 2014; Manavalan & Jayakrishna, 2019; Moktadir et al., 2018; Aytaç & Korçak, 2021; Do Nascimento Nunes et al., 2014
Policy and economic enablers	• Introduce policies and regulations for food wastage reduction • Provide financial support such as incentives to increase use of IoT sensors • Provide non-financial supports such as training and skill development programs to enhance the adoption of IoT sensors	Aamer et al., 2021; Aytaç & Korçak, 2021; Grimm et al., 2014
Social enablers	• Information transparency and trust development • Develop network and cooperation	Caro et al., 2018; Badia-Melis et al., 2018
<u>Behavioural enablers</u>	• Increasing awareness of the benefits of the IoT sensors • Emphasis on the consumers' concern on food safety	Wang & Yue, 2017
Economic enablers	• Develop affordable IoT sensors for SMEs • Cost optimization of IoT sensors	García et al., 2020; Pal & Kant, 2020; Tsang et al., 2018

Table 2 Enablers to adoption of IoT Sensors in fresh food supply chain

Broader category	Specific issues	References
Food safety	• Real time temperature tracking • Effective cold chain management of fresh food • Better quality assurance	(Do Nascimento Nunes et al., 2014; Ellis et al., 2015; Pal & Kant, 2020b; Montanari, 2008; Oliva & Revetria, 2008; Tsang et al., 2018; Chen et al., 2013; Onwude et al., 2020
Market opportunities	• Improve brand reputation • Capture quality concerned customer • Enhance accessibility of new market • Create opportunities for partnership with new suppliers or producer	Autry et al., 2010; Mejuto et al., 2018; Alfian et al., 2017; Chen et al., 2013; Tsang et al., 2018; Govindan et al., 201

Table 3 Opportunities to adoption of IoT Sensors in fresh food supply chain



A Requirements Technology Fit based theoretical model for analysing IoT system performance

The list presented in Tables 1-3 will serve as a handy tool to pick and investigate the individual or combined role of various first and second category variables, in improving the performance of a food company or a specific food sector when trying to implement IoT sensors across the supply chains. This paper derives one such combination of constructs as shown in Fig. 1 to see how best the IoT sensor technology fits the purpose of reducing food waste. To achieve this, the literature on various theoretical models was revisited and it was found that Requirements Technology Fit (RTF) model proposed by Sinha et al. 2019 suits best with the purpose of this study. As different from the traditional technology acceptance model, this approach provides a way to analyse the technology with respect to specific set of performance factors. Therefore the present study, as shown in Fig. 1., hypothesises that “Task requirement and IoT sensor characteristics independently influence the food supply chain performance. The amount of food waste reduced and total emissions reduced will be taken as the food supply chain performance indicators. Requirements Technology fit construct mediates the relationship that connects “Task requirement”, and “IoT sensor characteristics” with “Impact on supply chain performance”. In general, the task requirements are derived from the list of barriers (Table1), enablers would be seen analogous with variables of Requirement Technology Fit construct, whereas opportunities from Table 1 would form the basis of considering the performance indicators.

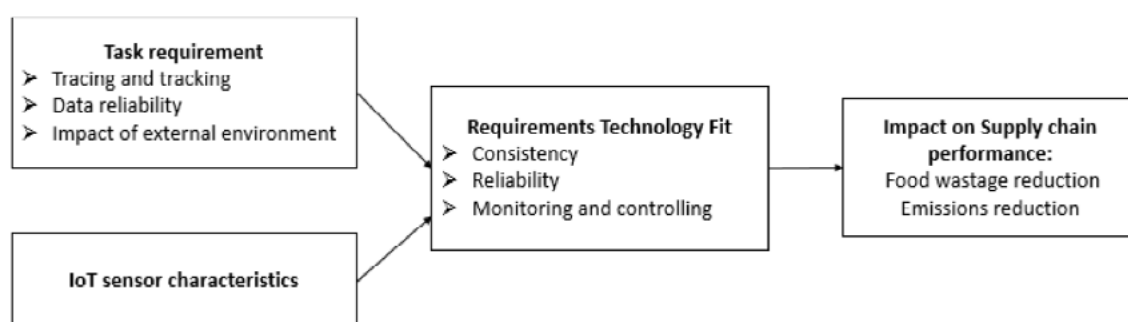


Figure 1 Requirements Technology fit model for food waste and emissions reduction using IoT sensors

Conclusion and future work

This work proposes a list of barriers, enablers and opportunities of using IoT sensor technology for food waste reduction. Furthermore, it links the barrier-enabler-opportunity framework with the constructs of requirements technology fit based theoretical model to investigate the roles of tracing and tracking, data reliability and impact of external environments on reduction of food waste and emissions. The study provides huge potential for future research by opening avenues for investigating the roles of different barriers, enablers and opportunities in augmenting IoT implementation across the food sector.

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SUSTAINABLE DESIGN AND MANUFACTURING



SUSTAINABILITY AND ECONOMIC SECTORS IN NORTH YORKSHIRE: A CLUSTER ANALYSIS

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Introduction

The objective of this study is to uncover the links between sectoral clusters in the local economy in North Yorkshire in the UK and to examine the interdependence among sectors in 2018, with the final aim to inform policy to enhance climate action. Rather than studying individual sectors, it is suggested to observe a set of variables that cuts across different sectors and classify them based on both economic (value added, number of employee jobs, number of private sector businesses) and environmental (levels of CO₂ emissions) factors. A sample of 20 industrial sectors in North Yorkshire and a hierarchical cluster analysis were used. It is expected that this analysis can provide a useful input for policy makers when setting targets and defining priority sectors for addressing the climate change challenge.

Scientists across the world have almost unanimously agreed that human activities, such as manufacturing, the burning of fossil fuels, cement production, and deforestation, have rapidly increased the concentration of greenhouse gases in the atmosphere (Trenberth, 2018). Particularly, carbon dioxide (CO₂) emissions have gone up drastically in a relatively short period of time (Song et al., 2018; Cavicchioli et al., 2019) threatening human life and natural environment of our planet (IPCC, 2018).

This year, the UK has pledged to reduce CO₂ emissions by 78% by 2035 compared to 1990 levels. However, there is no simple solution to tackle climate change and UK local authorities have already started thinking of different ways to achieve this goal. For instance, North Yorkshire is supporting new investments in low-carbon technologies and clean sources of energy to reach carbon neutrality by 2034 and become carbon negative by 2040.

The remainder of this paper is structured as follows. The next section presents a description of the challenge. Then a brief literature review of previous studies in relation to environmental and economic factors is presented. This is then followed by the methodology section on hierarchical cluster analysis. Next, the results section presents the findings. The discussion shows the key points in the context of recent literature. Finally, the conclusions section summarises the paper, states some limitations and provides some avenues for future research.

Description of the challenge

According to official data from the UK Department for Business, Energy and Industrial Strategy, the UK emitted roughly 357 million metric tonnes (Mt) of carbon dioxide (CO₂) in 2018, 1.16% lower than in the previous year. Although reductions have occurred in the level of CO₂, industrial sectors still release considerable amounts of CO₂ into the atmosphere.

North Yorkshire is one of the largest CO₂ emitters in the Yorkshire and the Humber Region, after North Lincolnshire, thus having an important role to play in tackling climate change. Historically, North Yorkshire has been at the heart of the industrial revolution in the country. In fact, throughout the years, North Yorkshire's economic performance has been tied to fishing, agriculture, coal, steel, wool, and shipping industries (Hahn, 2020; Sykes, 1964). However, during the past decades, the North Yorkshire's economy has undergone fundamental changes. Most notably, economic growth has relied heavily on the retail sector, which has become the dominant industry of the North Yorkshire economy. Mining and quarrying, construction, electricity, and gas, have significantly decreased their share over time, while human health and social work activities have increased their share in the total value added.

Between 2005 and 2018, North Yorkshire's contributions to the region's total CO₂ emissions increased from 11.9 percent to 13.1 percent, which represented the highest increase in the region. In 2018, the transport sector was the largest CO₂ emitter, accounting for 45.3% of total CO₂ emissions in North Yorkshire. The industry and commercial sector was the second biggest contributor of CO₂ emissions followed by domestic sector. Croplands and settlements released the lowest amount of CO₂, accounting for 4.7% and 2.9% of the CO₂ emissions, respectively, while forests and grasslands acted as sinks of CO₂, absorbing approximately 4% of total CO₂ from the atmosphere. Large Industrial Installations (mainly located in the district of Selby) accounted for about 1% of total CO₂ emissions.

Figure 1 shows the contributions of CO₂ emissions by sector to the total CO₂ emissions for 2005, 2010, 2015 and 2018. It is observed that domestic gas and road transport have significantly increased their share of CO₂ emissions over time, whereas diesel railways have decreased their share in the total CO₂ emissions



over time. Cropland and settlements have remained stable during this period. The rapid increase in the road transport CO₂ emissions suggests that there has been an increase in urbanisation levels.

Thus, the challenge is how to achieve decarbonisation targets whilst continuing to enjoy economic prosperity, which translates into quality of life and at the same time in a healthy planet for future generations to enjoy. This is done in this paper by providing input to inform policy.

Literature review

Previous studies of economic sectoral analysis have highlighted the importance of infrastructure-related sectors for the economic development of regions and countries (Hall et al., 2014). Whereas, other studies have focused on the environmental factors, such as air pollution, that are generated by the activities carried out in different sectors of the economy (Fujii and Managi, 2016). In the same vein, Jorquera and Villalobos (2020) combined cluster analysis of short-term receptor models with CO₂ emissions and meteorological data to create a longer-term plan on how to tackle air pollutants in Chilean cities.

Linking environmental and economic factors, Koelbl et al. (2016) examined the use of Carbon Capture Storage (CCS) in order to mitigate the effects of greenhouse gas emissions, focusing mainly on the power generation sectors. They concluded that a CCS-inclusive strategy is less favourable for the power sector in the Netherlands (in terms of GVA, employment and energy security) than a portfolio that is dominated by renewables. On the topic of carbon capture, Naims (2020) presents a review of carbon capture and utilization (CCU) publications in order to provide some guidance on the aspirational economic effects of CCU, their analysis reveals how CCU innovations are anticipated to impact different industries. The paper suggests that equipment manufacturers could contribute to economic growth, while high-emitting producers, could use CCU as an option for “surviving” sustainability transitions, finally, material and fuel producers need to act as “problem solvers” by offering competitive ways of utilising CO₂.

² See <https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy>

More recently, Cheng et al. (2021) show the effect of local public expenditure on CO₂ emissions, they found differences in emissions within Chinese cities with similar socio-economic conditions. Their study provides some recommendations for policy formulation. Similarly, Chang et al. (2021) generated a new regional classification framework which resulted from combining factor analysis with Ward clustering method for regions in China, by including both environmental and economic factors, such as: population size, GDP per capita, energy structure, energy intensity, urbanization level and industrialization level on CO₂ emissions.

Our research provides a preliminary application of sectoral analysis of the local economy in North Yorkshire and provides some guidance to policy makers.

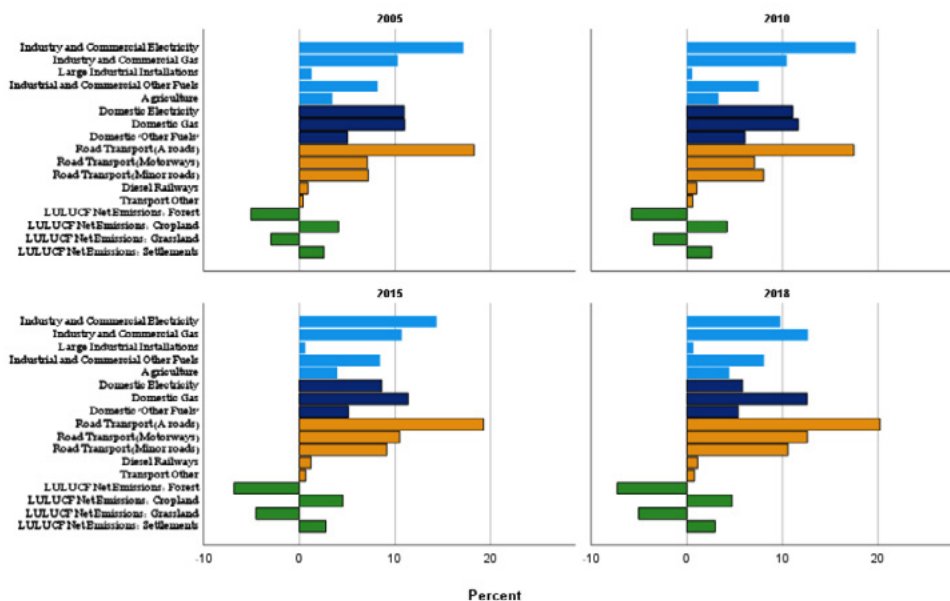


Figure 1. Carbon Dioxide (CO₂) Emissions in North Yorkshire by Sector (%)



Methodology

A hierarchical cluster procedure was used to determine the appropriate number of clusters and identify groups of similar industry sectors. A cluster analysis is a statistical procedure used to classify objects that are very similar to others based on a set of selected characteristics (Hoen, 2002) – in the case of this paper, based on economic and sustainability indicators. The resulting cluster of objects should exhibit high internal (within-cluster) homogeneity and high external (between-clusters) heterogeneity.

The hierarchical clustering procedure used here is an agglomerative one (Ward's method). It starts by considering every industry sector independently and then gradually puts them together. So, it begins with as many clusters as there are industry sectors and then clusters them naturally by similarity, according to a multidimensional analysis, until it ends up with just one cluster containing all sectors. The software used was IBM SPSS Statistics 27.

The sectors were classified based on their value added, number of employee jobs, number of private sector businesses, and levels of CO2 emissions. Because these variables are measured in different scales (e.g., value added is measured in £millions, employee jobs are measured in units, and CO2 emissions in thousand tonnes), the standard deviation of each variable was normalised to the range of 0 to 1, with 0 expressing the lowest standard deviation and 1 the highest. As a consequence of normalization, the variations of all dimensions are equally weighted.

Data

The data used in this paper were obtained from the Office for National Statistics (ONS) (for CO2 emissions and gross value added), The National Offender Management Information System (NOMIS) and Data North Yorkshire (for population and employment), and the Department for Business, Energy and Industrial Strategy (for number of businesses). The variables used in the analysis were employment, economic growth, business, and CO2 emissions. The gross value added and number of business measure the relative size of the industry sector, CO2 emissions measure the contribution to climate change impact, and employment measure contribution to social wellbeing.

Following the UK standard industrial classification of economic activities (SIC 2007), 20 industry sectors in North Yorkshire were considered and a database of sustainability and economic indicators at sectoral level was built. The industry sectors included in the analysis are: 1- agriculture, forestry and fishing; 2 -mining and quarrying; 3- manufacturing; 4- electricity, gas, steam, air conditioning supply; 5- water supply, sewerage, waste management and remediation activities; 6- construction; 7- wholesale and retail trade, repair of motor vehicles and motorcycles; 8- transportation and storage; 9- accommodation and food service activities; 10- information and communication; 11- financial and insurance activities; 12- real estate activities; 13- professional, scientific and technical activities; 14- administrative and support service activities; 15- public administration and defence, compulsory social security; 16- education; 17- human health and social work activities; 18- arts, entertainment and recreation; 19- other service activities; and 20- activities of People employed by households. Once all our variables were collected, they were linked at industry level for North Yorkshire.

Our analysis is based on two fundamental assumptions. First, it is assumed that the distribution of emissions across industry sectors in the United Kingdom is approximately equal to the distribution of CO2 emissions in North Yorkshire. Second, it is assumed that the structure of workforce jobs in North Yorkshire and the Yorkshire and Humber region are nearly identical. Despite these assumptions, our data are likely to be highly representative of the underlying interregional flows of goods and services.

Results

Figure 2 reports the dendrogram for the cluster analysis performed. The dendrogram provides a visual representation of how individual industries are successively grouped into larger groups of clusters. The ordinate on the dendrogram indicates the industry sector and the abscissa at the top of the dendrogram shows the merging distance with value 0 in the origin. By cutting the dendrogram at distance 20, three clusters that differ significantly from one another were obtained. Cluster A is subdivided into two sub-clusters, cluster A1 and cluster A2. Likewise, cluster C is subdivided into two sub-clusters, cluster C1 and cluster C2.

³ See <https://www.ons.gov.uk/>



Three clusters were differentiated clearly from one another. In the first cluster, arts and entertainment were related to financial and insurance activities, water supply and activities of households. In the second cluster, electricity was related to transportation and manufacturing. In the third cluster, accommodation and food service activities were related to real estate activities and wholesale and retail trade.

Sectors in the second cluster had significantly more CO2 emissions than those in either the first or the third clusters, whereas sectors classified into the third cluster had significantly more private sector businesses than those in either the first or the second clusters. The first cluster showed low CO2 emissions, low value added, low level of employee jobs, and low in number of private businesses. The second cluster revealed high CO2 emissions, high value added, high level of employee jobs, and low number of private businesses. The third cluster reflected low CO2 emissions, high value added, high level of employee jobs, and high number of private businesses.

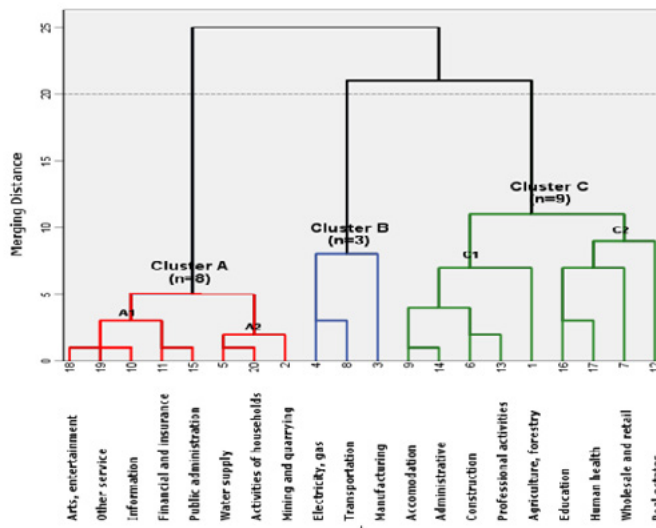


Figure 2. Hierarchical Cluster Dendrogram, North Yorkshire 2018

Figure 3 displays the industrial sectors and the number sectors aggregated in each cluster, as follows:

- Cluster A includes sectors such as arts, entertainment and recreation; other service activities, information and communication; financial and insurance activities; public administration and defence, compulsory social security, water supply, sewerage, waste management and remediation activities; and activities of households as employers.
- Cluster B, the smallest cluster, comprises sectors such as electricity, gas, steam, air conditioning supply; transportation and storage; and manufacturing.
- Cluster C, the largest cluster, includes sectors such as construction, accommodation and food service activities, administrative and support service activities, agriculture, forestry and fishing; mining and quarrying, professional, scientific and technical activities, education, real estate activities; wholesale and retail trade; repair of motor vehicles and motorcycles, and human health and social work activities.

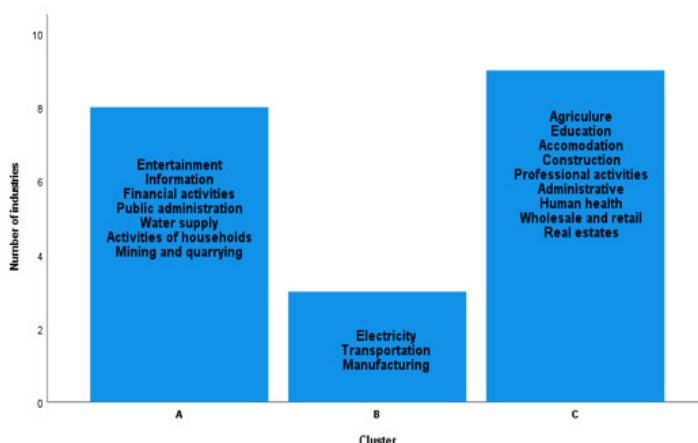


Figure 3. Cluster Composition, North Yorkshire 2018



Descriptive statistics on all variables for each cluster are presented in Table 1. Cluster A includes industrial sectors that are low in CO2 emissions, low in value added, low in level of employee jobs, and low in number of private businesses. Cluster B includes sectors that are high in CO2 emissions, high in value added, high in level of employee jobs, and low in number of private businesses. Finally, Cluster C includes sectors that are high in level of employee jobs, high in number of private businesses, and low in CO2 emissions. Analysis of Variance (ANOVA) was performed to test the statistical significance of the differences between the clusters. The results support the distinctive clusters, as our four criteria (private sector businesses, value added, CO2 emissions, and employee jobs) differ significantly across the identified clusters. Within each group of clusters, sector variation is likely to be greater in Cluster A than in Cluster B.

Table 1. Descriptive Statistics, North Yorkshire 2018

Clusters	Descriptive Statistics	Private Sector Businesses	Gross Value Added	Employee Jobs	CO ₂ Emissions
		units	£million	units	thousand tons
Cluster A	N	8	8	8	8
	Mean	1127	405	46094	4035
	Std. Deviation	1021	359	37258	6707
	Minimum	0	34	1516	48
	Maximum	2615	990	104257	19955
	Sum	9015	3241	368753	32279
Cluster B	N	3	3	3	3
	Mean	1958	1250	139504	84643
	Std. Deviation	1662	1044	134906	5143
	Minimum	135	493	8198	80768
	Maximum	3390	2441	277742	90478
	Sum	5875	3750	418513	253928
Cluster C	N	9	9	9	9
	Mean	6111	1454	177387	5793
	Std. Deviation	3965	850	120038	4806
	Minimum	1235	453	11773	954
	Maximum	13090	3242	365447	13435
	Sum	55000	13089	1596480	52135
Total	N	20	20	20	20
	Mean	3495	1004	119187	16917
	Std. Deviation	3643	850	111415	29695
	Minimum	0	34	1516	48
	Maximum	13090	3242	365447	90478
	Sum	69890	20080	2383746	338342



Discussion

The linkages among industrial sectors in North Yorkshire for 2018 were studied. Our analysis highlights otherwise hidden similarities between sectors that could be leveraged from a policy perspective. The North Yorkshire County Council (NYCC) could consider the clusters of sectors to adapt their strategies in the long term, considering the political, environmental, social, technological, legal and ethical challenges affecting the UK. These results compare favourably with previous research where interconnections were found between infrastructure sectors as reported by Hall et al. (2014) and providing evidence-based analysis for policy decision making (Chang et al., 2021).

Our cross-sectoral cluster analysis suggests that individual sectors have particular characteristics, some of the industrial sectors share more common features than others. Our analysis also suggest that sustainable strategies need to be developed across sectors. For example, even if the electricity sector needs to be decarbonised, the transportation sector would also need to follow. Our recommendations for the NYCC are three-fold. First, to evaluate whether the low emitters of CO₂ and that bring low value added to the Economy could look for new ways of operating which would be valuable and important. Second, to propose how to better manage the high emitters of CO₂ which also bring high value added to the Economy, however, it would be good to ask whether focusing on financial value is too short-sighted? for example, water supply is among the low value added sectors, not showing its real value. Third, to assess whether low emitters of CO₂ and that bring high value added to the Economy should be further encouraged and promoted? These recommendations are aligned with those provided by Naims (2020).

Conclusions

This study has used a hierarchical cluster analysis for examining linkages between sectors in North Yorkshire in 2018, with the aim of contributing to tackling climate change policy. Following the UK standard industrial classification, 20 industrial sectors were considered. These sectors were identified based on their value added, number of employee jobs, number of private sector businesses, and levels of CO₂ emissions.

The limitations of the research include the fact that only one year of data was used, and that the data was pre Covid-19 pandemic. It would be interesting to see how the Covid-19 pandemic has affected the clustering of sectors, in terms of economic and environmental factors in North Yorkshire.

Further research could investigate clusters in two different years. Such an analysis could clarify the changes in the connections among economy sectors and the dynamics of these connections over time. The comparative analysis can foster improved environmental policies needed to achieve sustainable development, with a focus on tackling climate change. Our analysis also opens up the possibility of future policies based on scenarios to be modelled considering the cluster analysis presented here.

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MOBILE ROBOT SYSTEMS IN WAREHOUSES: AN EVALUATION FRAMEWORK AND A DEMONSTRATION

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Introduction

Warehouses face the challenge of meeting customers' orders swiftly and efficiently whilst managing the increasing complexity and variability of order fulfilment. Driven by e-commerce, customer orders in retail such as electronics, groceries, clothing, pharmaceuticals, and footwear have become complex with large assortments of small products. Tens of thousands of daily orders for thousands of different products make the warehouse environment chaotic and complicate operations, especially the picking. Moreover, an order fulfilment system should be capable of handling fluctuating customer demand. On retail days such as Cyber Monday, the daily revenue of even a small-sized retailer could increase by up to threefold ('Adobe Holiday Shopping Trends', 2019) which puts pressure on all warehouse operations. Further, many customers expect their orders to be fulfilled on the same day or the next day, making scalability and flexibility vital aspects of warehouse operations.

Order picking, which is the process of removing items from storage to shipping to meet a specific demand, is generally the most expensive operation which may account for 50-55% of the total operating costs in manually operated warehouses (Bartholdi & Hackman, 2017). This high percentage is primarily due to the amount of time lost by pickers travelling that takes around 55% of the picker's total time spent (Boysen et al., 2019). Amazon automated fulfilling e-commerce orders in their warehouses with autonomous mobile robots (AMRs) by acquiring Kiva Systems. Alibaba, Ocado, and JD.com are among the first companies that followed the warehouse automation move. With this technology adoption in order picking operations, Amazon has cut its operational warehouse costs by 20% and saved \$22 million per annum in picking costs for each of its fulfilment centres (Bogue 2016). They achieved this saving through AMRs in a goods-to-picker (G2P) setting (Wurman et al., 2008).

Automated Guided Vehicles (AGVs) were the only type of unmanned mobile robots in warehouses until the early 2000s. AGVs are defined as unmanned transport systems used for the horizontal movement of materials. These robots move materials by moving pallets, shelves, totes, boxes, or the material itself. They have little or no onboard intelligence and rely on orders coming from a centralised mechanism. They follow fixed and pre-programmed routes and stop when their sensors face an obstacle (Kattepur et al. 2018; Hor áková et al. 2019). In the 2000s, AMRs were introduced to warehouses. These robots have high onboard intelligence which helps them to make decisions on their own (Kattepur et al. 2018). They can map the environment, plan their paths, dynamically respond to their surroundings, and bypass an obstacle by themselves i.e., without being remotely controlled (Kattepur et al. 2018; Hor áková et al. 2019). These characteristics make AMRs more flexible and suitable to chaotic and complicated warehouse environments such as an e-commerce environment.

G2P is an order picking method where goods are brought to the human picker by an automated system. Pickers stay stationary to do the picking and other related tasks while retrieved products are restored to their positions automatically (Azadeh et al., 2019). The second type of order picking method is the picker-to-goods (P2G) method, where human pickers travel to the goods generally with a material handling unit (De Koster 2018). Human collaborative robot (co-bot) solutions are examples of this method. Recently there is a third type of order picking method named the robots-to-goods (R2G) method. In this more automated method, mobile picking robots travel to the shelves alone and do the picking on their own (Huang et al., 2015).

Yet, considering these settings and mobile robot types, mobile robot systems should be identified and evaluated for the picking operation to aid warehouse managers to choose a suitable mobile robot system. This paper aims to contribute to knowledge by clearly explaining the typology of mobile robots and systems stemming from them that are adopted in picking operations. Further, it evaluates mobile robot systems being used with multiple criteria and discusses how the multiple-criteria decision making could be applied in practice, through a realistic scenario.



Methodology

This paper delivers key insights of a larger systematic literature review including 107 peer-reviewed papers from 2000 to 2020. The SLR protocol was adopted from Denyer and Tranfield (2009) and Tranfield et al. (2003), and four databases (Scopus, Web of Science, ABI Inform, EBSCO) were selected to search for a combination of two strings as: 'String 1 AND String 2'. Strings are as follows:

String 1 (warehouse): warehous* OR "distribut* cent*" OR (fulfil* W/2 (good* OR part* OR tote* OR stock*)) OR (order* W/2 (pack* OR ship* OR pick*)) OR ((operat* OR goods OR activit* OR automat*) W/2 (pick* OR packing OR receiving OR shipping OR sort* OR put* OR stor*)) OR d?spatch OR replenishment OR marshal*

String 2 (mobile robots): (robot* W/2 (multi* OR warehous* OR mobile OR intelligent OR autonomy* OR logistic*)) OR agv* OR "automated guided vehicle*" OR amr*

Based on the results of the SLR, a realistic scenario is created to demonstrate the execution of mobile robot system selection through multiple evaluation criteria. There are two research questions and a sub-research question specified for this paper:

RQ1. What are the mobile robot systems being adopted in warehouses?

RQ2. How can those systems be evaluated by warehouse decision-makers before adoption?

RQ2.1. How can evaluation be performed on a realistic mobile robot system application scenario?

Analysis of Mobile Robot Systems

Systems involving these mobile robots can be categorised in three according to their types of navigation: rail using, guided, and freeway (Wior et al., 2018). This paper adopts that categorisation strategy and introduces a fourth category: linear route robots, guided robots, freeway robots, and hybrid systems. Linear route robots cover rail using robots and add wire using robots. Since these systems might be used together with Automated Storage and Retrieval Systems (AS/RS) or other systems, hybrid systems are included as the fourth category.

Cost, service-level, flexibility, and scalability are the four main criteria to evaluate mobile robot systems (Schmidt and Schulze, 2009). Except for service-level criterion, the other three criteria are mentioned in many other studies (Azadeh et al., 2019; Bauters et al. 2016; Huang et al., 2015; Roy et al. 2019; Zou et al. 2018; Hanson et al., 2018). In these studies, flexibility is explained in two different contexts: 'Flexibility of the Infrastructure' and 'Flexibility in Material Handling'. Further, to be able to estimate the cost criterion, this paper considers cost as the fixed 'Mobile Robot Cost'. Many warehouses are still manually operated and once these warehouses recognise the need to transform their operational model into an automated system, they should consider the required installation and implementation time of the mobile robot systems. Hence, 'Time to Implement' is considered as a decision criterion in this paper to give the managers an idea of the time these systems require to implementation. These criteria are rated on a 3-point scale where the higher the score, the better the performance in the given criterion. Explanations of these criteria in terms of ratings are presented in Table 1. Considering these factors, an overview of mobile robot systems is made and their use cases in picking operations are explained in the following sub-sections. After the analysis, a synthesis table displays the ratings of mobile robot systems from each criterion.

RATING	MOBILE ROBOT COST	FLEXIBILITY OF THE INFRASTRUCTURE	FLEXIBILITY IN MATERIAL HANDLING	SCALABILITY	TIME TO IMPLEMENT
3	Has neither the onboard intelligence nor the gripping function	Infrastructure is not fixed; it is easy to adapt to process/layout changes	Capable of handling bulky products (palletised) or small products (bins/boxes)	Responds to dynamic demand changes within days with extra robots only	Needs weeks for the setup (software installation and training)
2	Has either onboard intelligence or gripping function	Infrastructure is not completely fixed; a new setup is necessary to adapt	Capable of handling a variety of products, but might require adjustments	Besides extra robots, needs low-level construction or human workforce	Needs few months for the setup (rail ways, barcodes, laser systems)
1	Has both the gripping function and the onboard intelligence	Infrastructure is fixed, it is hard to adapt to process/layout changes	Can only handle either bulky products or small products	Besides extra robots, has high-level construction requirements	Needs several months for the setup (high level of construction)

Table 1 Mobile Robot Evaluation Criteria and Ratings, Source: Authors



Linear Route Robots follow a linear route made of rails or wires and have been used in logistics to transport products within the warehouse since the 1950s (Wurman et al., 2008). The main difference between them is the structure they travel on (rail or wire). Recent P2G examples that are also adaptable to chaotic warehouse contexts are the trolley line picking system (Füßler et al., 2019) and the AGV Weasel system (“AGV Weasel”, 2021). Since both types of linear route robots have similar outcomes in decision criteria evaluation, we deem one evaluation for both systems sufficient.

Linear route robots can only move linearly in the environment and cannot bypass an obstacle. Thus, instead of AMRs, AGVs are preferred for such systems that do not require extensive onboard intelligence (Wior et al., 2018). The infrastructure (railways or wires) is fixed and not adaptable to process or layout changes. They are flexible from the material handling perspective as they can transport heavy products on pallets and small products in bins. They are not easily scalable because they require new routes and a low-medium level of construction which may last for several weeks to either start operating or increase the throughput of the existing solution. (“AGV Weasel”, 2021).

Guided Robots are more recent systems and, due to their ability to move non-linearly, they have more flexibility in terms of navigation when compared to linear route robots. There are two types of guided robots being used in the picking operations: barcode guided robots, laser guided robots.

Barcode Guided Robots became popular with Amazon’s acquisition of Kiva Systems, which resulted in an increase of Amazon’s worker productivity up to threefold (Enright and Wurman 2011). Mobile robots travel on grid-based and restricted layouts in a G2P method. Due to their ability to sense and bypass dynamic obstacles, AMRs are preferred over AGVs. With the requirement of special shelf and barcode floor construction and AMRs, these systems are costlier than linear route robots in terms of mobile robot costs and require a few months for complete installation (“Geek+” 2021). Layout changes require extra time since they have a dedicated navigation area (Wurman et al., 2008). They can carry shelves that have boxes or small products to pickers even though they cannot carry pallets (Liu et al. 2019; Enright and Wurman 2011). These systems could easily increase or decrease their capacity by adding or removing robots when the workload varies (Boysen et al., 2019).

Laser Guided Robots navigate on predefined paths and can only carry pallets in the warehouse environment with the R2G setting. Hence, AGVs are generally preferred for laser-guided operations as they are the cheaper alternative. This system takes advantage of mirrors placed in an area and they are only able to adapt to a new process/layout with a new setup (Ferrara et al., 2014). They are adaptable to varying workloads just like barcode guided robots for similar reasons. However, they are big vehicles and adding too many of them could decrease the warehouse space available for navigation. Installation of mirrors and the integration of the system could take several months even though it is a low-medium level construction (Banker 2018).

Freeway Robots do not generally require construction and they move in the warehouse autonomously, without limitations. Owing to their ability to map the warehouse with its onboard intelligence, AMRs are the only choice in these systems (Wior et al., 2018). There are three types of freeway robot systems: autonomous forklifts, human collaborated robots, and mobile picking robots.

Autonomous Forklifts carry pallets and require extra tools to carry smaller products in an R2G setting. Even though it is not as expensive as a gripping function, these robots have forks that lift pallets autonomously. They do not need any fixed infrastructure which makes them extremely flexible to adapt to layout and process alterations. Even though they are big vehicles like laser guided robots, they are somewhat suitable for a chaotic warehouse setting since they can scale with more mobile robots. They have a rather short installation time as they require no construction, and they are ready to operate as soon as they are in the warehouse (“Forklift” 2021).

Human Collaborated Robots operate with human pickers in a P2G method. Human pickers stand in the aisles of the warehouse and mobile robots travel in the warehouse according to their picking list. Once they request a product, they travel to the correct aisle and wait for the picker to load the product. When they reach their capacity, they return to the packing station and unload the products (Boysen et al., 2019). Although closely following a human worker necessitates AMRs, fetching products is done by human pickers. These robots do not have any fixed infrastructure, so they are adaptable to layout or process adjustments. They can collect small products or boxes, but they cannot carry palletised products. They are suitable for a chaotic warehouse setting since they can coordinate and scale easily with more mobile robots. This solution is highly adaptive which does not require a re-layout while transforming manually operated order picking in conventional warehouses which also significantly decreases the time required to implement (De Koster 2018; Wang et al., 2019).



Mobile Picking Robots are relatively new and popular because they can do the picking on their own in the R2G setting. This feature removes human errors and human cost in the order picking operation.

Mobile picking robots have compartments or tote bins on them, and they put the products they pick into these spaces. Once they reach their capacity, they return to the packing area to unload (Bogue 2016; Huang et al., 2015). This system requires the robot to have a gripping functionality together with the high-level onboard intelligence which increases the costs of robots. Like human collaborated robots, these robots do not have any fixed infrastructure, so they are adaptable to layout or process adjustments. They have limited flexibility in terms of materials they can transport because of materials' weight (few kg) and shape (boxes or products that have edges) requirements (Kimura et al. 2015). Moreover, the picking areas of the robots should be structured for correct and efficient picking (Huang et al., 2015). Otherwise, the robots may fail the picking process, or it might take too long for them to locate the product. They are suitable for a chaotic warehouse setting since they can coordinate and scale easily with more mobile robots without any additional needs.

Hybrid Systems are the combination of at least one mobile robot system with other solutions. These solutions might be preferable to remove the disadvantage of a specific system or to take advantage of a higher level of automation. The literature reveals three types of hybrid systems all of which operate in the R2G method: 1) AS/RS, conveyors, and linear route robots; 2) picker and transport robots; 3) laser guided robots and pallet shuttles.

AS/RS, Conveyors, and Linear Mobile Robots systems are generally useful if the warehouse traffic consists mainly of pallets or similar handling units according to the capability of the AS/RS. In this system, when the required pallet is retrieved by the AS/RS, they are taken by mobile robots and put on a conveyor (Liu 2018). AGVs suffice to carry the products or pallets that are taken from the AS/RS. The system is fixed, and it is not adaptive to any process or layout changes due to its infrastructure. Together with having the capability of carrying different sizes of products, an AS/RS can only carry one type of handling unit due to its physical build (Bauters et al. 2016). The system is not scalable as it would need new construction to increase the system capacity (Wurman et al., 2008; Roy et al. 2019). It takes between six months and a year to construct the system to become operable (Cribley 2014).

Picker & Transport Robot systems are akin to the human-collaborated system. Picker robots with gripping functionality, to fetch and lift small products, replaces human pickers and transport robots carry products placed into tote bins or pallets on them (Bogue 2016; Lee and Murray 2019). This system completely automates the picking operation (Kimura et al. 2015) and requires both an AMR with the gripping functionality and an AMR as a transporter. For this reason, mobile robot costs are rather high. Like mobile picking robots, these robots do not have any fixed infrastructure, so they are adaptable to layout or process adjustments. This system is not flexible in terms of product types or product handling units that can be carried. For instance, the picking robot of Fetch Robotics could lift products that weigh up to 6 kg and its arm has a reach of 2 m (Bogue 2016). These systems are scalable with more mobile robots which also ensures their robustness against malfunctions (Huang et al., 2015). The system requires weeks to implement as robots could operate as soon as they are placed in the warehouse with a structured picking area and require no construction.

Laser Guided Robots & Pallet Shuttles differ from a laser-guided mobile robot system in the automation of pallet movements from the face to the interior with pallet shuttles. Pallets are stored on rails, narrow aisles are removed, and pallet storing is optimised with the help of these pallet shuttles (Ferrara et al., 2014). AGVs are generally preferred for these systems similar to the case with laser guided robot solutions. Shelving units are fixed infrastructures that are hardly adaptable to process or layout alterations. This system only works with pallets or similar handling units which decreases the level of flexibility in material handling. There is high-level construction work for the shelves that hold pallet shuttles and light construction work due to laser-guided robot system structure which increases the time to implement such systems. According to the evaluation made above, Table 2 presents the ratings of mobile robot systems concerning each criterion.

Mobile Robot Systems (System Method)	Mobile Robot Cost	Flexibility of Infrastructure	Flexibility in Handling	Scalability	Time to Implement
Rail Using Robots (P2G)	3	1	3	2	2
Wire Using Robots (P2G)	3	1	3	2	2
Barcode Guided Robots (G2P)	2	2	2	2	2
Laser Guided Robots (R2G)	3	2	1	2	2
Autonomous Forklifts (R2G)	1	3	1	2	3
Human Collaborated Robots (P2G)	2	3	2	2	3
Mobile Picking Robots (R2G)	1	3	1	3	3
AS/RS, Conveyors, Linear Route Robots (R2G)	3	1	1	1	1
Picker & Transport Robots (R2G)	1	3	1	3	3
Laser Guided Robots & Pallet Shuttles (R2G)	3	1	1	1	1

Table 2 Rating Table, Source: Authors



This paper defines five criteria that are built on Schmidt and Schulze (2009) to evaluate and choose from ten mobile robot systems categorised by their type of navigation (Wior et al., 2018). The rationale for this multi-criteria selection support for mobile robot systems is further explained with a realistic scenario with a decision tree to provide a guided example of the approach. The approach towards the scenario is not limited to mobile robot systems mentioned in this paper but can include any others as it is based on the evaluation criteria rather than being system-specific (Figure 1).

Mobile Robot Selection Scenario: a Logistics Service Provider in the E-commerce Fulfilment Market

The company is a logistics service provider in the e-commerce fulfilment market and serves several large e-commerce retailers. The upper management of the company is confident that e-commerce will continue to grow due to customers' tendency to buy online which is further increased due to Covid-19. Hence, they want to increase the throughput of their warehouse and are seeking a scalable automation solution. The current portfolio includes small- to medium- sized products handled through manual case picking and broken-case picking. The company is not looking to expand their product portfolio through bulky products such as TVs. The company might expand its operational area by purchasing the adjacent warehousing space in the logistics park if they see the targeted throughput growth. Thus, the upper management would like the system to be adaptable to potential layout alterations. Even though the upper management is motivated to implement a mobile robot system, considering the financial instability of the company, they prefer an affordable solution. Finally, they want to implement the solution as soon as possible to recruit new customers.

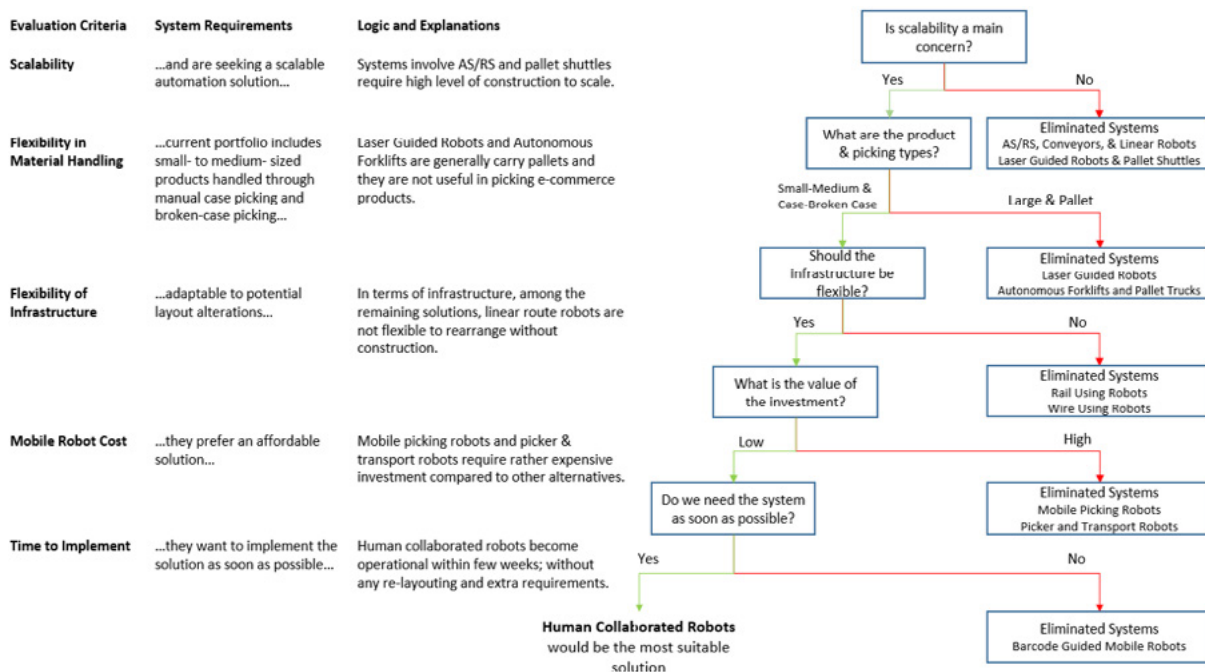


Figure 1 Decision Tree of the Scenario with Explanations, Source: Authors

Discussion and Conclusion

This study contributes to knowledge with a clear typology of mobile robots in warehouse operations and evaluates the characteristics of ten mobile robot systems in this regard. Moreover, it rates these systems according to a list of criteria and a rating system and supports the practicality of the criteria through a realistic scenario. In combination, these outcomes form the key contribution of this paper which could also aid warehouse decision-makers when they need to automate their warehouse. As with any study, there are limitations in this review and analysis. The research is formed using academic databases only and focused on studies from the year 2000 onwards. Thus, its outcomes might not be a complete reflection of available mobile robot systems in the picking operation.

Mobile robots seem promising for improving warehouse efficiency and coping with the increasingly challenging demand from customers by being flexible, scalable, and sometimes adaptable to existing solutions. However, implementing mobile robots in warehouses involves a plethora of complex decisions, and failures such as the implementation of unsuitable mobile robot systems or overlooking key decision factors could lead to costly mistakes. Hence, warehouse managers require guidance, a tailored managerial decision framework that would aid them in the implementation of mobile robots.



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INDUSTRIAL PACKAGING SELECTION PRINCIPLES IN THE AUTOMOTIVE INDUSTRY: ENVIRONMENTAL AND COST IMPACTS

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Purpose

The selection of industrial packaging for material supply in the automotive industry can be guided by different principles. The purpose of this paper is to explain how different material supply strategies affect industrial packaging selection, which, in turn, affect costs and CO₂ factors in the supply chain.

Research Approach

A case study of the material supply in returnable packaging to a truck manufacturer's plant captured detailed data related to all material from all suppliers for 12 months. The data were analysed using a tool for supply chain effects.

Findings

Material supply strategies affect packaging size, which, in turn, affects five cost and CO₂ factors including packaging material, transport efficiency, material handling efficiency, waste handling efficiency, and inventory costs. The study analyses the total costs and CO₂ for four material supply strategies. The results show the cost and CO₂ efficiency of these four strategies. They explain the reasons for and supply chain and packaging characteristics of each strategy. They show what characterises the packaging solutions related to the greenest material supply strategy.

Research Impact

This is the first study that clearly quantifies the extent to which common guiding principles for industrial packaging affect supply chain costs and CO₂. It explains how material supply strategies affect the packaging type, and, in turn, how it affect supply chain costs and CO₂. The insights have implications for the body of knowledge on packaging logistics and on green supply chain management.

Practical Impact

Companies are advised to make informed decisions for industrial packaging selection, as it affects supply chain costs and CO₂ to great extent. This paper presents recommendations for doing so.

Keywords

Automotive, Environment, Material supply, Packaging, Returnable

Introduction

The public debate as well as research about packaging and its environmental impact focus largely on consumer packaging, whereas industrial packaging is less emphasised despite its great impact on eco-efficient supply chains (Mahmoudi and Parvizioman, 2020). Industrial packaging affects costs and CO₂ of all logistics activities from the point of filling at a supplier to the end use. The importance can be exemplified by that logistics costs, which are greatly influenced by packaging, represent, on average, about 10–12% of the turnover of manufacturing and retail companies (Jensen, 2007; Lönnblad, 2012).

This paper focuses on returnable industrial packaging in the automotive industry where companies have their own fleet of returnable packaging of variable sizes. They use the returnable packages in their material supply from suppliers to the plants. The principles for packaging selection have generally not been developed from a holistic approach to minimise costs and CO₂. They have rather been developed based on experience with a focus on fulfilling production requirements regarding packaging size and ergonomics, as well as on obtaining supplier needs. In particular, the selection of packaging solutions is highly influenced by requirements from production, which has a strong position in automotive companies (Hanson and Finnsgård 2014, Coronado Mondragon and Lyons 2008, Cousins and Menguc 2006). The production line generally prefers small packages, which can be beneficial for the production line (Hanson and Finnsgård 2014). It is also in line with the dominating production philosophies of just-in-time and lean. However, small packages may cause inefficiencies in transportation, storage and picking. It is thus necessary to determine the combined impacts of a packaging solution in order to have eco-efficient supply chains. Otherwise, there is an apparent risk for sub-optimisation.

Selecting eco-efficient packaging solutions requires a systems approach where all costs and environmental impacts are considered. Previous research has identified factors, which together cover the cost and CO₂ for supplying material from the point of filling to the point of use, and then forwarded to disposal and waste handling (Pålsson, Finnsgård and



Wänström, 2013). This is a complex matter, but research and practice clearly show that insightful management of such an approach can reduce costs and CO2 significantly (Early et al., 2009). The cost and CO2 factors are (Pålsson, 2018):

- Packaging material: Purchasing cost and CO2 from packaging production
- Transport efficiency: Packaging affects how many components that can be loaded onto a truck, which affects both costs and CO2
- Internal material flow: Packaging affects how many packages (and components) that are handled simultaneously
- Packaging supply and disposal: Costs and CO2 from supplying empty packaging to the point of filling, and from handling packaging waste (e.g. transport, washing, recycling, etc.). This factor includes administration costs for managing returnable packaging flows
- Capital cost (not CO2): The size of packaging affects the average storage time, which affects the capital cost for inventory

The packaging selection principles are, as noted, often guided by material supply strategies heavily influenced by production requirements and interpretations of just-in-time and lean philosophies. This leads to certain packaging solutions, which affect each of the cost and CO2 factors and thus the total cost and total CO2. However, the selection principles may instead be guided by minimising the total cost of the five cost factors, minimising the total CO2 of the four CO2 factors, or minimising transport costs. These policies can still fulfil a production requirement of packaging size through repacking if needed. Applying any of these policies result in changed total costs and CO2, as the cost and CO2 factors change.

An interesting perspective on eco-efficient packaging solutions is that the most cost-efficient packaging solution may differ from the most environmentally efficient one. However, the body of knowledge on eco-efficient industrial packaging lacks insights into how the cost factors are affected by minimising CO2, and vice versa. In other words, how much extra would it cost to minimise CO2 instead of minimising costs, or how much more CO2 will be emitted if costs are minimised instead of CO2? This paper addresses these questions and the general questions about the impact of selection principles for industrial packaging on eco-efficient supply chains. The purpose is to explain how different material supply strategies affect industrial packaging selection, which, in turn, affect costs and CO2 factors in the supply chain. The study focuses on a case study in the automotive industry. The research is guided by four research questions:

1. What is the cost differences between different material supply strategies?
2. What is the CO2 differences between different material supply strategies?
3. How are the cost and CO2 factors affected by the different material supply strategies?
4. What characterises the packaging solutions related to the greenest material supply strategy?

To meet the requirements for eco-efficient supply chains with limited space on an assembly line, vehicle manufacturers can choose different principles for packaging selection. This paper increases the knowledge base about industrial packaging and their cost and environmental impact in supply chains. It specifically contributes with new knowledge about the cost and environmental impact of packaging based on four packaging selection principles in a case study in the automotive industry. This increases knowledge about how the size of returnable packaging affects eco-efficiency in supply chains. In addition, the study presents quantitative figures for trade-offs between cost and environmental efficiency in supply chains with different selection principles. The analyses require detailed data and complex calculations, which was possible due to full access to the company data and an advanced analysis tool that was developed in a previous collaborate research project between the automotive company and the researchers. The tool enables unique opportunities to combine and analyse a vast amount of packaging, product, and supply chain data in novel ways.

Research Approach

A case study of the material supply in returnable packaging to a truck manufacturer's plant captured detailed data related to all material from all suppliers for 12 months. The data were analysed using a tool for supply chain effects, which was developed during 4 years by the researchers in collaboration with industry. The tool is based on an analytical strategy-structure-performance framework, which was deduced from literature. The framework links the selection principles of industrial packaging to supply chain characteristics and supply chain performance in terms of costs and CO2. In this study, we analysed all articles supplied in three types of packaging on two types of pallets to a truck manufacturer's plant in Sweden. The articles are supplied from suppliers all over Europe using both road and sea transport. Table 1 shows article and supply chain characteristics.



Table 1. Article and supply chain characteristics

Articles		Supplier		Transport			Repacking procedure	
No.	No.	Countries	Direct deliveries	Road	Sea		No. of articles repacked one at a time	No. of articles repacked by pouring
418	>100	23	192	All	216		327	83

Table 2 describes the packaging and pallets types. Packaging 1 is most common with 258 articles supplied in this type, followed by packaging 2 used by 153 articles. Packaging 3 is only used by 7 articles in the plant. The pallets are used with 1-4 collars to obtain flexible heights.

Table 2. Packaging data

	Packaging 1	Packaging 2	Packaging 3	Pallet 1	Pallet 2	Collar 1	Collar 2
Dimension (mm)	400x300x200	600x400x200	300x200x150	1225x820xCollar 1 height	820x615xCollar 2 height	Height: 160+195*no. of collars	Height: 135+195*no. of collars
Weight (kg)	1.25	2.05	0.45	31	14	10	7.5
Load capacity (kg)	40	40	15	1 000	700	N/A	N/A
Load volume (l)	15.7	36.6	5	Depends on no. of collars	Depends on no. of collars	N/A	N/A

The system studied includes a closed loop of reusable packaging, which is illustrated in Figure 1. Different types of packaging and pallets are stored in packaging pools. Empty packaging are delivered at least weekly to suppliers of components for the truck manufacturer. The suppliers have a small packaging buffer not to run empty. After packaging filling at the suppliers, pallets and packaging with components are transported to the manufacturer. These transports always include LTL truck deliveries, but it can also include sea and rail transport. This depends on the location of the supplier. The analysis tool uses the exact transport route for each article.

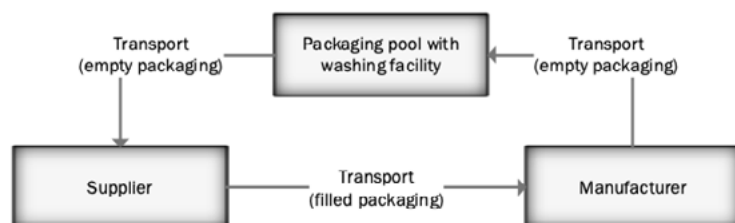


Figure 1. Packaging flow

Analyses

The baseline material supply strategy for the analysis of CO₂ and costs for material supply is based on the current principles used by the automotive company. These principles imply that the smallest possible package should be used to minimise the need for repacking into a predetermined line packaging in production. The package should contain enough articles for the replenishment time in production to be more than 2h.

Three alternative material supply strategies were analysed to get insights into the effects of packaging on CO₂ and costs in the material supply. These alternatives are minimising total CO₂, minimising total supply chain costs, and deliver articles on pallets without packaging and then repack into predetermined line packaging in production. The logic of the latter is that it increases the volume utilisation in transportation, but it increases the need for repacking.

In order to calculate these strategies in the analysis tool, we used three alternatives:

1. Baseline – CO₂ and costs in the current setup
2. Upsize – all packages were supplied in the next bigger size, and then repacked into the baseline one (improves transport efficiency but add repacking)
3. Pallet delivery – articles are transported on a pallet with collars, and then repacked into the baseline one (improves transport efficiency even more than alternative 2, but it adds repacking)

Alternatives 2 and 3 also differ in the way that the CO₂ and cost factors (see introduction) are affected are affected differently for different articles. This is because of different packaging and pallet weight and different packaging materials in alternatives 2 and 3 as well as because of different order quantity for different articles. By combining the three alternatives



in different ways as shown in Table 3, we calculated the CO₂ and costs for the four material supply strategies.

Table 3. The baseline and the three alternative material supply strategies

Material supply strategy	Description
1. Baseline	Smallest possible package with minimal need for repacking and replenishment time in production over 2h
2. Minimising total CO ₂	Select alternative 1, 2 or 3 with minimal CO ₂ for each article
3. Minimising total supply chain costs	Select alternative 1, 2 or 3 with minimal costs for each article
4. Pallet deliveries	Deliver in pallets and repack to line packaging

Findings

This section first presents overall outcomes of each material supply strategy. Then, it analyses how different CO₂ and cost factors contribute in each strategy. The final part focuses on the greening strategy as it scrutinizes the characteristics for minimising total CO₂ (material supply strategy 2).

Total CO₂ and costs for each strategy

Each of the four material supply strategies results in different costs and CO₂. This is because each strategy leads to different size and type of packaging, which, in turn, affect each of the CO₂ and cost factors. For instance, changing packaging size at the supplier may principally affect:

- Transport efficiency as the amount of empty space to be transported is affected.
- Repacking, which affects labour costs and may add an additional package (which both increases handling and transport CO₂ and costs from the package and transport).
- Cost and CO₂ from the package used.
- Cost and CO₂ from the pallet used.
- Internal flow efficiency, as a bigger package typically handles more articles in the same amount of time and uses less inventory space for the same amount of articles than a smaller package does.

By analysing CO₂ and costs for each of the 418 articles, we assessed the efficiency of each material supply strategy. Figure 2 shows the results, whereas Figure 3 highlights differences between material supply strategies 2-4 and the baseline strategy. From these graphs, it is clear that applying a pallet delivery strategy (strategy 4) with repacking for all articles is inefficient both from CO₂ and cost perspectives. Applying material supply strategy 3 to minimise costs would reduce CO₂ by 10% and costs by 13%, whereas material supply strategy 4 (minimise CO₂) would reduce CO₂ by 12% and costs by 7%. This means that a company that prioritise to green the supply chain reduces CO₂ by 2% more than if the company focuses on minimising costs. This comes at the expense of 6% less reduced costs.

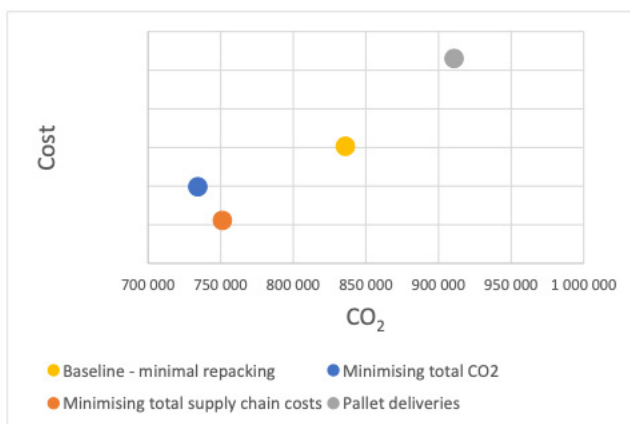


Figure 2. CO₂ and costs from four material supply strategies

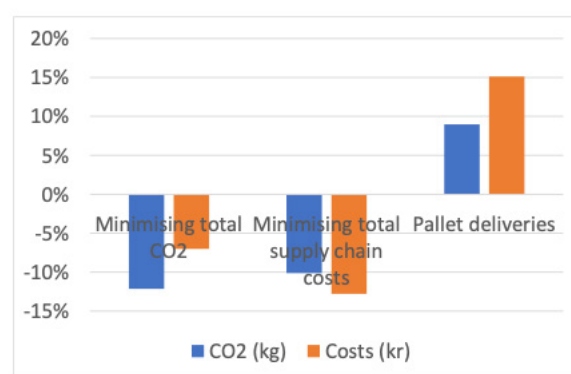


Figure 3. CO₂ and cost differences in three material supply strategies compared to the baseline



Contributions from CO2 and cost factors in each strategy

To analyse the reasons for the outcomes, Figures 4 and 5 show the effect on each CO2 and cost factor the three alternative strategies compared to the baseline strategy. Figure 4 shows that both strategy 2 (minimising total CO2) and strategy 3 (minimising total supply chain costs) reduce the transport factor the most. They also reduce pallet configuration and packaging inbound. The added CO2 from repacking and internal flow is lower than these reductions. Strategy 4 (pallet deliveries) reduce pallet configuration and packaging inbound, but it increases transport and repacking more. The CO2 from transport increases because collars and middle layers needed on pallet deliveries weigh more than boxes.

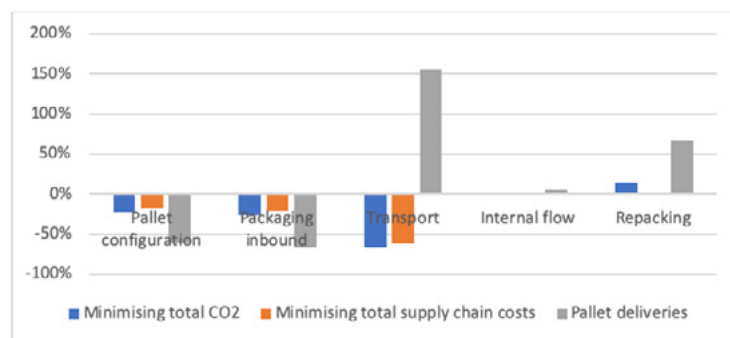


Figure 4. CO2 factors share of total CO2 difference as a result from three strategies compared to the baseline

Figure 5 shows that the most cost-effective strategy (strategy 3) reduces pallet configuration, packaging inbound, transport and internal flow factors almost equally much, and it only slightly increases costs from capital and repacking. Strategy 2, on the other hand, which focuses on minimising CO2, reduces pallet configuration, packaging inbound and transport factors more than twice as much as strategy 2. However, this leads to much higher costs in repacking as well as greater costs from capital and internal flow. Strategy 4 has a similar pattern as strategy 3, but it increases costs in the internal flow much more. This is because more boxes must be handled in the plant, as all pallets must be repacked.

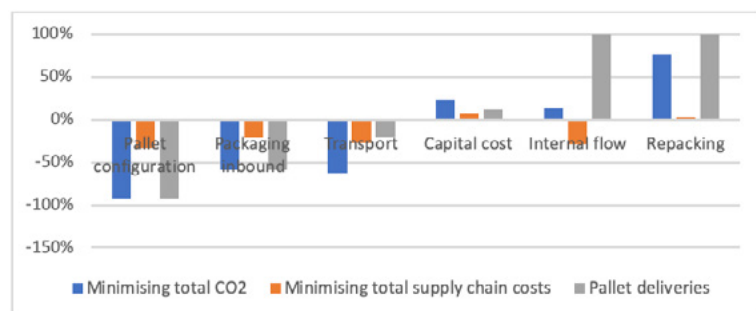


Figure 5. Cost factors share of total cost difference as a result from three strategies compared to the baseline

Characteristics for the material supply strategy to minimise CO2

The previous sections showed how the different material supply strategies affect total CO2 and total costs as well as the detailed CO2 and cost factors. Here, we analyse material supply strategy 3 (minimise total CO2) further to gain insights into greening characteristics. As described in the research approach section, each strategy combines three alternatives: baseline, upsized and pallet delivery. When minimising CO2 in strategy 3, the most CO2 efficient alternative was chosen. Table 4 shows how many articles use each alternative in strategy 3. It also shows how much CO2 comes from each alternative, both in total and from different CO2 factors. It is noticeable that minimising total CO2 requires a combination of the three alternatives where 97 articles use the baseline setup, 135 articles are upsized to the next bigger package and 186 articles use the pallet delivery with repacking alternative. The single greatest CO2 factor is transport in the upsized alternative. This is related to the annual volume and transport distances for these articles.

Table 4. CO2 from different alternatives and different CO2 factors in material supply strategy 3

Alternative	No.	CO ₂ total	Pallet configuration	Packaging inbound	Transport	Internal flow	Repacking
Baseline	97	100 261	8 405	20 635	70 320	220	633
Upsized	135	545 695	23 712	81 416	430 763	481	9 258
Pallet	186	88 257	1 905	11 396	66 951	1 007	6 903
Sum	418	734 213	34 022	113 447	568 035	1 708	16 793



To analyse the characteristics for the articles in strategy 3 further, Table 5 compares average CO₂ factors in this strategy first to average CO₂ factors if the same articles use the baseline strategy. This enables us to explain why, for example, the upsized alternative minimises CO₂ for some articles compared to the baseline. Second, in the right part of Table 5, the average CO₂ factors for articles in strategy 3 are compared to average CO₂ factors when the other articles use the baseline strategy. This part should particularly compare (i) to (ii), which helps us to identify differences in CO₂ factors in the baseline strategy for those articles which are CO₂ efficient to upsize or deliver on pallets compared to those that are not. For instance, articles with high pallet configuration and packaging inbound and transport factors in the baseline strategy should be upsized to minimise CO₂, whereas articles with low values for these factors should not.

Table 5. Average CO₂ factors in material supply strategy 3 compared to (i) average CO₂ factors if the same articles use the baseline strategy and (ii) average CO₂ factors for the other articles in the baseline strategy

Alternative	Average CO ₂ in strategy 3					(i) Average CO ₂ in baseline strategy (for the articles in strategy 3)					(ii) Average CO ₂ in baseline strategy (for the articles not in strategy 3)				
	Pallet conf.	Packaging inb.	Transport	Internal flow	Repacking	Pallet conf.	Packaging inb.	Transport	Internal flow	Repacking	Pallet conf.	Packaging inb.	Transport	Internal flow	Repacking
Baseline	87	213	725	2	7	87	213	725	2	7	152	371	1 760	4	4
Upsized/ Baseline in (i) and (ii)	176	603	3 191	4	69	269	680	3 406	7	1	74	169	620	2	6
Pallet/ Baseline in (i) and (ii)	10	61	360	5	37	67	146	566	2	5	193	485	2 285	5	4

The insights from Tables 4 and 5 are:

- CO₂ in pallet configuration, packaging and transport determine CO₂ efficiency
- Articles with high CO₂ in pallet configuration, packaging and transport in the baseline strategy should be upsized
- Articles with low CO₂ in pallet configuration, packaging inbound and transport in the baseline strategy should be delivered on pallets
- Articles with average CO₂ values on pallet configuration, packaging and transport should use the baseline strategy with minimal repacking
- Pallet delivery (strategy 4) is more frequently CO₂ efficient for large order quantities, for pallet type 1, and for few number of collars (it is almost never CO₂ efficient with four collars)

Conclusions and future research

This paper posed four research questions. The first refers to cost differences and the second to CO₂ differences between material supply strategies. The defined a baseline and three alternative material supply strategies. Each strategy results in different packaging types, which, in turn affects supply chain total costs and CO₂. If the company in this case focuses on CO₂ minimisation, it reduces CO₂ by 12% and costs by 7%. If the company instead focuses on cost minimisation, it reduces CO₂ by 10% and costs by 13%. The third material supply strategy where all articles are delivered on pallets without packaging would increase both CO₂ and costs. The most CO₂ efficient material supply strategy thus reduces CO₂ by 2% more than the most cost efficient strategy. The cost of this can be estimated to 6% less cost reduction (difference between cost reduction in CO₂ minimisation and cost minimisation strategies).

The third research question refers to the differences in cost and CO₂ factors when applying different material supply strategies. Both CO₂ minimisation and cost minimisation strategies reduce the transport factor the most. They also reduce pallet configuration and packaging inbound. The added CO₂ from repacking and internal flow is lower than these reductions. The pallet delivery strategy increases transport and repacking more than it reduces pallet configuration and packaging inbound.

The fourth research question covers the characteristics of the packaging solutions related to the greenest material supply strategy. The findings show that minimising total CO₂ requires a combination of three alternatives of material supply where 97 articles use the baseline alternative, 135 articles are upsized to the next bigger package and 186 articles use the pallet delivery with repacking alternative. The findings section presents details about the characteristics.



The theoretical implications of this paper can be viewed from two perspectives, i.e., how the findings affect the body of knowledge on packaging logistics and on green supply chain management. The body of knowledge on packaging logistics highlights the influence of packaging on costs and CO₂ in supply chains, as a result of packaging influences on all logistics activities. The current knowledge describes general effects on different activities. It also problematises the complex matter of finding cost and CO₂ efficient packaging solutions. There is, however, a lack of studies on the combined, total costs and CO₂ of these influences, which is a complex matter. There is also a lack of empirical studies which quantifies the influences, and only a limited number of studies on industrial packaging. This study contributes to all three perspectives as it analyses in-depth empirical data from a truck manufacturer. After defining a baseline and three alternative material supply strategies, it explains how these strategies affect the packaging type, and, in turn, how they affect supply chain costs and CO₂. The study captures and explains the complex matter of packaging influences throughout supply chains by linking the material supply strategies to industrial packaging and supply chain performance.

From a broader perspective, the findings contribute to green supply chain management. The exploration and quantification of the CO₂ minimisation strategy for material supply in the automotive industry adds new insights to literature on greening supply chains where the perspective of practices related to industrial packaging is limited. The current literature on green industrial packaging covers mainly packaging material challenges, such as packaging production, recycling or reusable packaging. This paper complements with insights on the indirect effects of industrial packaging practices in the logistics activities.

The findings should be valuable for managers in the automotive industry and in other manufacturing industries where standardised packaging are used, either reusable or disposable packaging. Overall, the findings should inspire companies to carefully analyse their material supply strategies and their principles for selecting industrial packaging. This paper shows that such an approach can save both costs and CO₂. Companies are thus advised to make informed decisions for industrial packaging selection. This paper can also help companies conduct analyses in the way that they can apply the methodology used in this paper to adopt the most cost or CO₂ efficient material supply strategy. Since the effects of packaging arise in various parts of a supply chain, the companies should collaborate internally to find the best possible selection principles for the company.

Future research should test the findings in this study in other contexts. In this case the trade-off between minimising CO₂ and minimising cost were quite small. It would be particularly interesting to see the difference in other cases and try to explain reasons for similarities and differences. It is also possible to propose and test a material supply strategy model with links to packaging types which describes supply chain and article characteristics for different strategies. From a practical perspective, it would be interesting to formulate the output in practitioner guidelines.

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AN EXPLORATION OF RELATIONSHIP BETWEEN CIRCULAR ECONOMY AND SERVITISATION: A SYSTEMATIC LITERATURE REVIEW

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Introduction

Since the industrial revolution, businesses have been pursued better strategies comprised of efficient supply chain activities competing for priority and scrutinising fast-changing technical processes (Atif et al., 2021). The increasing cycle of waste production and extreme shortages of resources has led the world to adopt Circular Economy (CE) paradigm within their business models (BM) (Ghisetti & Montresor, 2019). Evidence suggests that value capture has been considered as the primary challenge of CE (Oghazi & Mostaghel, 2018) that can be overcome by shaping servitisation strategies (Martín et al., 2021) and stakeholder's collaboration (Martín et al., 2021). However, despite a general agreement that the CE paradigm plays a vital role in enabling servitisation. To date, little is known about the relationship between CE and servitisation in general (Machado et al., 2020). It is not clear how a circular product captures value while generating revenues by designing a feasible servitisation package and how companies should be managing this interface (Kohtamäki et al., 2019). And finally, what would be an appropriate strategy to implement this combination (CE and servitisation) in their BM (Kühl et al., 2019).

This research study adopts a systematic literature review (SLR) methodology to identify and review 81 articles from the CE and servitisation literature to fill the aforementioned research gaps. This paper is organised as follow: Section 2 will present a summary of the methodology used to conduct this SLR; followed by Section 3 that displays the analysis of the critical review of CE and servitisation literature; while the fourth section will shed some light on the relationship between CE and servitisation and section 5 is the final section that presents the conclusion of the analysis along with future research directions for researchers.

Methodology

This study adopts the SLR method presented by Denyer and Tranfield (Denyer & Tranfield, 2009). SLR is an evidence-based approach that identifies the current state of knowledge using secondary data from a relevant field of interest (Ahmed et al., 2021; Kitchenham et al., 2009). Thus, it is viable to know how the relationship among key constructs (CE and servitisation) occurs, especially the related circumstances, to conclude their overlaps. The authors have adopted the SLR approach to provide a deeper understanding of the key variables in a structured way to reveal research gaps and identify the future research agenda in an organised manner.

In the first phase of question formation for the SLR, the authors used Denyer and Tranfield's (Denyer & Tranfield, 2009) CIMO criteria (Context, Intervention, Mechanisms, and Outcome) to understand the link between CE and servitisation such as:

- *Context*: According to CIMO logic, the main emergent themes from CE and servitisation literature perceives CE principle as an enabler for servitisation through increased product longevity (Kühl et al., 2019), closed-loop supply chain (Lieder et al., 2018) and resource/functional efficiency (Heyes et al., 2018; Kühl et al., 2018).
- *Intervention*: This element of CIMO determines or infers the event's effect through comparing and contrasting interventions in different contexts. Therefore, the spreading of operations via multi-stakeholders (Kristensen & Remmen, 2019), value creation and capturing (Liu et al., 2019), competitive advantage (Jensen & Remmen, 2017) and reconfiguration of BM (Adel & Wiesner, 2015; Geissdoerfer et al., 2017) while redefining the supply chain management (Bal & Badurdeen, 2020; Kumar et al., 2020) has been studied to engender a reliable outcome.
- *Mechanisms*: The mechanism explains the collection between different interventions that bring a particular type of outcome and their settings, such as supply chain management (Bal & Badurdeen, 2020; Kumar et al., 2020), cost management (Kalsoom et al., 2020) and change management (Werning & Spinler, 2020).
- *Outcomes*: all research/studies are conducted to document the pre-decided interventions' impact and monitor their intended and unintended effect. Applying CIMO logic, the effect of this combination (CE and servitisation) on firm performance (Ayala et al., 2021), the contextual factors that impact the supply chain (Kumar et al., 2020), and the economic viability of this transition (Copani & Behnam, 2020).



The second phase involved classifying the relevant keywords according to the study's objectives to position the research work to the applicable subject area appropriately. After extensive discussions among the authors, nine keywords were chosen, which were then refined using Boolean logic. Four keywords related to the research domain were finalised that met the screening criteria, i.e. Servitisation, Product-Service System (PSS), CE and BM. Later these keywords were refined by different combinations, for instance, "CE and/or Servitisation", "CE and/or PSS", "PSS and/or Sustainability", "Sustainability and/or Servitisation", "business model and/or Servitisation", "CE and/or business model" and "business model and/or PSS". Eighty-one articles were extracted and analysed to identify the patterns, directions, comparisons and variances in articles related to the key variables of this study (CE and servitisation).

This study aims to investigate the relationship among the key variables (CE and servitisation). Thus, the third phase involves downloading the finalised articles published in a pre-decided time span (2015-2021) from the databases. The three databases that were used are Web of Science, ScienceDirect and Emerald Insight. These databases are seen as the most influential and credible data storage systems as they store high-quality and peer-reviewed papers.

The fourth step was concerned with validating the quality and reliability of the data following the research protocol. Thus, the author followed Newbert's (2007) inclusive and exclusive criteria to shortlist the scientific papers:

- Empirical papers from the business and management subject area.
- CE and servitisation literature from Multidisciplinary disciplines such as supply chain management, accountancy, marketing, etc.
- Papers are written using the English language only.
- Scientific papers from peer-reviewed journals only.
- Papers with at least one keyword (CE, servitisation, PSS, and BM) were selected in the title or abstract.
- Non-academic documents/papers were excluded.
- Duplicate papers were excluded.
- Papers that were out of the pre-selected time span (2015-2021) were excluded.

This rigorous process aided the author to finalise 81 relevant papers to conduct the critical analysis review for this study. Hence, figure 1 and 2 shows the yearly number of publications related to CE and servitisation:

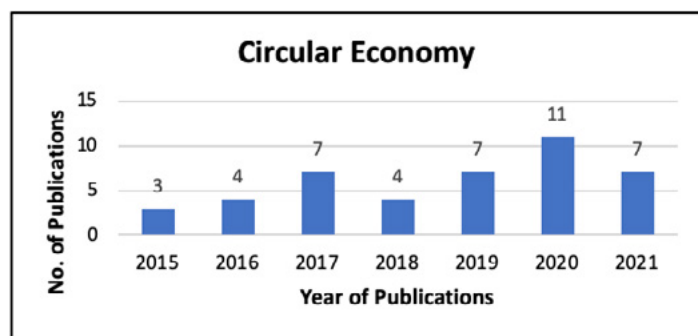


Figure 1: Yearly number of published papers on Circular Economy

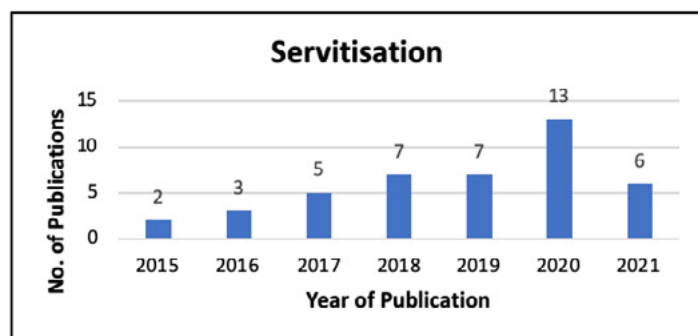


Figure 2: Yearly number of published papers on Servitisation



Results/ Analysis: Circular Economy

The increasing economic uncertainty and negative environmental effect of the traditional linear take-make-dispose model have driven a transition towards an innovative sustainable arrangement in the BM. Linear economics presents an open loop where a product's lifecycle starts by extracting resources and then disposing of the used product into the environment after the first cycle. Thus, specific characteristics are integral to the CE. This model can be used to explain how the CE can be applied to each constituent of the BM, but firms can also decide to apply hybrids (Senzi et al., 2016) these are:

- Closed-Loop Supply Chain (CLSC)
- Resources recovery/Reverse Logistics
- Product Life Extension
- Shared Platform/ Indirect Reverse Logistics

Scarcity of resources (Han et al., 2020), depletion of ecological risks (Schröder, Lemille, & Desmond, 2020), human wellbeing, and social equality challenges raised the question for sustainability trends in society (Atif et al., 2021). Therefore, the idea of the Circular Economy (CE) can be considered as an anthology of various holistic views aiming to achieve a sustainable and waste-free society created in the 1990s (Turner, 1990). This novel model progressively developed from multiple schools of thought such as cradle-to-cradle (Schröder et al., 2020), green economy (Beier et al., 2018), biomimicry and industrial ecology (Kirchherr et al., 2018). Lately, CE has been prevalent in the market as a business concept among practitioners and policy-makers (EMF, 2015).

Servitisation

Servitisation is often labelled as a shift from product-oriented manufacturers to a system offering a mix of products and related services to create a differentiation strategy. Manufacturers are gradually incorporating service-based strategies to renew business practices that enhance the perceived value across the product lifecycle and sustaining competitive advantage in the market (Adel & Wiesner, 2015). The earliest concept of servitisation is linked to Vandermerwe and Rada (1988), who coined the term “servitisation” in the late 1980s (Kühl et al., 2019) and described it by saying: “corporations are increasingly offering fuller market packages or bundles of customer focussed combinations of goods, services, support, self service, and knowledge” (Vandermerwe and Rada, 1988). The above definition shows that servitisation aims to promote transformational processes that replace a product-centric BM with a product-service model.

Linking Circular Economy principle and Servitisation approach

The CE paradigm used by servitisation has been increasing over the last decade (Bressanelli et al., 2018; Kühl et al., 2018). Despite this, there are still numerous research gaps in the literature. such as: when servitisation is profitable? (Baines et al., 2017); what are the associated risks (Bustinza et al., 2019); whether the transformation to a CE principle is achievable and measurable (Yang et al., 2018) and whether the manufacturing firms should convert to this transition (Bustinza et al., 2019). Despite this, considerable research has covered a wide range of themes in a different context and using various research tools has been taking place. This SLR is developed to construct a framework that presents an accumulated constructive knowledge on the key variables between CE and servitisation.

CE has been defined by most of the authors as an economic system that avoids landfill at the end-of-life by recirculating the material/resources in a supply chain to achieve sustainable development by creating environmental, social and economic benefits for current and future generations (Elliott, 2005; Hartley et al., 2020; Kirchherr et al., 2018). While most of the servitisation literature conceptualised value domain at the system (Kühl et al., 2019) or network levels (Isaksson et al., 2018), highlighting the role of organisational integration (Mishra et al., 2020) and change management (Zighan et al., 2021) to achieve optimal performance (Liu et al., 2019). Kohtamäki et al., (2020) suggested that firms' adopt servitisation strategies to minimise the associated costs and enhance customer services (Zighan et al., 2021). Reim et al. (2019) also identified major capabilities and market-related challenges. They presented a contingency model to accommodate four servitisation strategies: service extension, service benchmarking, digitalisation, and customer co-creation. Thus, most servitisation literature combined process view with inter-organisational perspective discussing the manufacturing firm's efforts in implementing CE principles co-create and deliver the value-propositions (Hedvall et al., 2019).



It is evident from the analysis that manufacturing firms are adopting the CE paradigm within their BM to support the functionality and efficiency of the product (Bressanelli et al., 2018; Kühl et al., 2018) and delivering maximum value to their customer. Thus, understanding the implication of value co-creation and identifying a firm's dynamic capabilities provides greater insight for firms to decide the level of innovation needed in their strategy. In this context, CE literature gives a great emphasis on extending the lifetime-in-use of products (Bressanelli et al., 2019; Senzi et al., 2016) with enhanced durability (Lieder et al., 2017) with the aim of closed-loop-supply-chain through 10 R (such as Reusing the discarded product or deploying its component as a by-product; Rethinking the Strategy; Reducing or limiting the resource usage; Reusing through outsourcing; Repairing and maintenance; Refurbishing and Restoring by upgrading; Remanufacturing; Repurposing a rejected product with different functionality and recycling of products or material. However, while the majority of servitisation related papers took a theoretical perspective to bridge the gaps in strategy and innovation development literature by investigating the conflicting interests among stakeholders (Adel & Wiesner, 2015; Zighan et al., 2021), misalignment of strategy (Kühl et al., 2019; Zighan et al., 2021), and ineffective knowledge management across the value chain (Ayala et al., 2021; Kühl et al., 2019).

Conclusion and Future Research Directions

This paper is a contribution to CE and servitisation literature. The SLR helped us identify how the servitisation approach provides support to the CE paradigm in relation to BM, value proposition, and supply chain network. Findings show that CE is seen as a relatively novel phenomenon, so firms must consider a system perspective when designing their BM. Furthermore, due to the volatile and unpredictable market state, firms need to shift from product orientation to service orientation to achieve better potential added value in the CE (Kristensen & Remmen, 2019; Werning & Spinler, 2020). Finally, our results also show that servitisation will further support CE by connecting end-of-life product design with the business strategy (Lieder et al., 2017; Tukker, 2015; Zighan et al., 2021). Firms are required to achieve a differentiated advantage in the competitive market through adaption, integration and reconfiguration of their resources, skills and functional competencies in a digital environment by involving customers in the value co-creation process (Lee et al., 2020). Ideally, there should be more empirical researches to determine a data-driven discussion supporting informed decisions towards realising CE principle from a servitisation perspective.

To conclude, there have been some papers that discuss the transition from linear BM to CE (Ghisetti & Montresor, 2019; Kristensen & Remmen, 2019; Werning & Spinler, 2020) and how it facilitates value creation and value delivery through servitisation (Bressanelli et al., 2018; Kühl et al., 2018). When it is, the alignment of the supply chain network supports the sustainable design of a product and the efficacy of processes. Still, current research shows a lack of a method-based framework of supply chain management and how it incorporates the efficiency, sufficiency, and consistency strategies (Kalsoom et al., 2020; Rafi-UI-Shan et al., 2018). So, future research should try to close this gap by investigating an answer for the question: will this transition lead to a market shift? It depends on how well servitisation can support CE that leads to a sustainable reverse-logistic-based supply chain (Chiappetta et al., 2020).

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THE OPERATIONAL AND SUPPLY CHAIN IMPLICATIONS OF ERRORS IN OTIF CALCULATIONS

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Introduction

Within the context of operations and supply chain management key performance indicators such as On Time In Full (OTIF) or Delivery In Full On Time (DIFOT) are measurements of logistics or delivery performance within a supply chain. Typically, it would be expressed as a percentage, measuring whether the supply chain was able to deliver: the ordered product; in the quantity requested; to a location specified by the customer; within the time period requested by the customer.

Even though OTIF is primarily a measure of logistics performance it can also be used as a measure of the effectiveness of the operations of a company. This is because in order to achieve a high OTIF performance there is an inherent need for the entire operation to work well. Ranging from procurement and suppliers to manufacturing operations to sales. This study examines the ways in which OTIF for suppliers and for the company can be incorrectly calculated, the causes and the operational and reputational ramifications. Focusing on a fast-growing manufacturing company that had been experiencing stock shortages of component parts which had led to lead-times increasing and increasing inventory levels to try and mitigate the impact of shortages.

Background

Literature review

Improving the performance of a manufacturing supply chain is a continuous process. This process requires both an analytical performance measurement system, together with a mechanism to initiate steps for realising the key performance indicator (KPI) goals (Cai et al., 2009).

OTIF or DIFOT are a form of supply chain KPI which are numbers or percentages that can be compared against targets set either internally for company performance, or externally for “benchmarking” evaluation of performance. In general KPIs can relate to data collected or calculated from any process or activity.

As product delivery performance (OTIF) can be used to evaluate incoming and outgoing products it can be broken down into OTIF to customers and from suppliers to provide greater clarity (Ahmad and Dhafr, 2002). In a study of European companies the OTIF goal for a world-class operation was considered to be 99% (Restivo, 2004).

The purpose of customer OTIF is to measure the delivery of the product in question to the customers of a on time and in full. Therefore OTIF measures the ability of a company to adhere to the agreed due date for each order. It has been noted that there need to be rigorous process and systems in place for recording this information either by the company itself or by the logistics provider if this aspect is out-sourced (Ahmad and Benson, 1999).

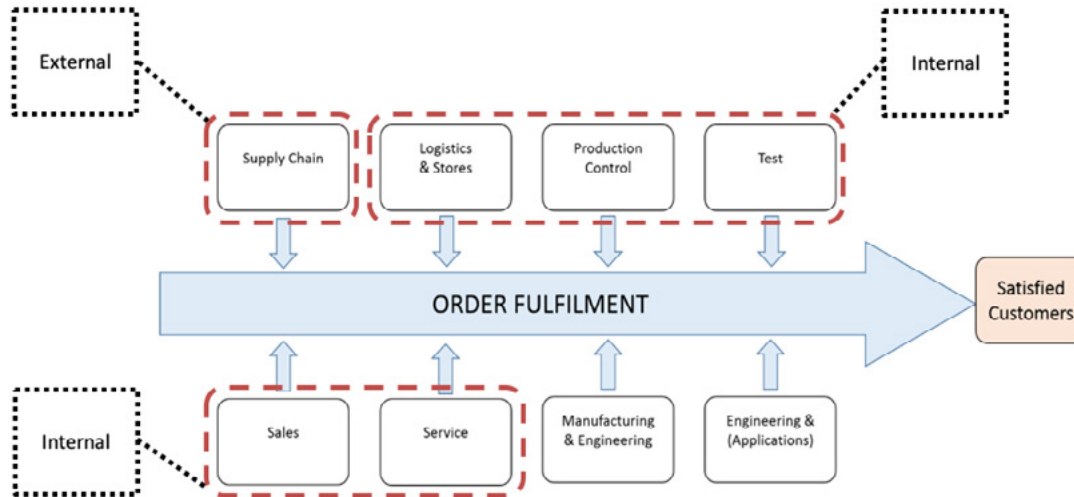
The purpose of supplier OTIF is to measure the receipt (by a company) of materials and parts on time and in full. Once again the measure could potentially be expanded to include factors such as product being in working condition and undamaged in transit. The supplier OTIF could have a big impact on the operations of the customers, whether they are component parts or just packaging. OTIFs therefore measure the ability of the suppliers to adhere to the due date for each order as such it is a commonly used metric for evaluating the service level of a company (Otto and Kotzab, 2003).

Whilst OTIF is a useful tool research has shown that there does need to be some care taken when calculating OTIF as there can be nuances within the measure. For example, there are instances where OTIF targets are met when measured against a target of the promised due date provided by the manufacturer to the customer. However, these same manufacturers would often fail to meet the OTIF metric when the requested due date from the customer was used as the target (Godsell and van Hoek, 2009).



Company processes

The process of the company at the time the work was undertaken are illustrated in Figure 1 illustrating how internal and external factors influence the various business processes. Supply chain management and production control are separate functions controlled by different people, with one person at senior management level having oversight of both. The supply chain team looked after the purchasing, supplier management and new supplier engagement functions of the company. Whilst production control managed production and testing.



Research method

Primary data for the period in question was extracted from the company's ERP system that maintains detailed records of sales orders as well as goods receipts. A quantitative analytical approach was then taken to analyse the data based on the OTIF measure and potential interpretations of the measure.

The method used to generate the OTIF figure was reversed engineered for one problem supplier in order to determine how OTIF is being calculated. Through this process it should be possible to determine which variant of OTIF was used (if any). Furthermore it could highlight the conceptual errors in how OTIF is calculated.

Case study on OTIF

This study first of all examines whether OTIF has been calculated incorrectly and the ways in which this OTIF miscalculation may have occurred and the causes and implications. The method used to generate the OTIF figure was reversed engineered for one particular problem supplier in order to determine how OTIF was being calculated at the company. Over the period of the study the OTIF value used by the company for this supplier was 77% (73% if one special order line is included).

As a starting point several variations of OTIF that could be used were examined (as shown below). Eq.1 provides an On Time and In Full figure per order line; eq.2 provides a On Time (but not in full) figure per order line; eq. 3 provides an OTIF figure for the quantities ordered; eq.4 provides a On Time (but not in full) figure for the quantities ordered; eq. 6 provides an OTIF figure for the number of orders; eq.4 provides a On Time (but not in full) figure for the orders.

$$OTIF_{by\ line}\% = \left(\frac{Number\ Order\ Lines\ On\ Time\ in\ Full}{Total\ Number\ Order\ Lines} \right) \times 100 \quad eq. 1$$

$$OT_{by\ line}\% = \left(\frac{Number\ Order\ Lines\ On\ Time\ in\ Full}{Total\ Number\ Order\ Lines} \right) \times 100 \quad eq. 2$$

$$OTIF_{quantity}\% = \left(\frac{Number\ Items\ On\ Time\ in\ Full}{Total\ Number\ Items} \right) \times 100 \quad eq. 3$$

$$OT_{quantity}\% = \left(\frac{Number\ Items\ On\ Time\ in\ Full}{Total\ Number\ Items} \right) \times 100 \quad eq. 4$$

$$OTIF_{order}\% = \left(\frac{Number\ Orders\ On\ Time\ in\ Full}{Total\ Number\ Orders} \right) \times 100 \quad eq. 5$$

$$OT_{order}\% = \left(\frac{Number\ Orders\ On\ Time}{Total\ Number\ Orders} \right) \times 100 \quad eq. 6$$



OTIF variant	OTIF value
Excluding special order line	
OTIF by line	43%
OT by line	77%
OTIF by quantity	11%
OT by quantity	25%
OTIF by orders	27%
OT by orders	54%
Including special order line	
OTIF by line	41%
OT by line	73%
OTIF by quantity	11%
OT by quantity	25%
OTIF by orders	26%
OT by orders	52%

Table 1 OTIF calculations

The major implication of incorrect calculation is that the scale of the problem with the supplier will not fully realised and therefore addressed. Operationally it had been determined that the supplier in question is a problem yet the figures from the incorrectly calculated OTIF showed that whilst the supplier was far from perfect it couldn't be shown to be the sole cause (original OTIF was 77% / 73%). Taking the different interpretations of OTIF the figure could be as low as 11% (exacerbated by data entry issues and very high order quantities for consumables that are detailed in the section below) or with a very relaxed interpretation 77% or 73% calculated by the company. Using the standard by OTIF (by order line) calculation with allowance given for deliveries not processed until the next day 43% OTIF was achieved.

The method used is best described as On Time By Line. However, as the calculations have shown if On Time In Full By Line was used the supplier would have an OTIF figure of 43% which is reflected in by the challenges that manufacturing face. Even OTIF by order is

Examination of order data

Once the calculation spreadsheet became available it could be confirmed that indeed the method used was not a conventional OTIF measure listed above but rather a form of On Time was used. An example of this is the product item that we will call AAA002 for the purposes of this paper. There were two separate purchase orders, for one for 100 and one for 200. The order of 200 was received in-full and on-time, but of the 100 order only 51 had been received. Within the spreadsheet (pivot table) the two orders were combined and classified as being not being late. Within the strict implementation of OTIF this would be 50% OTIF (one line OTIF, one line on time but not in full).

With regards to the 25% On Time (but not in full) and 11% OTIF by unit quality this performance is particularly poor. It was discovered that this is primarily because of an issue with the entry of consumables orders into the ERP. Orders that should have been spread across multiple lines were in fact entered as one line with one due date. An example of this is that over 30,000 units of one consumable were placed on one order line with a single delivery due date. Although after discussions with the company it transpires that the order should have been split into multiple lines with differing due dates. This does highlight the need to ensure that data is correctly entered otherwise a supplier that has a very good OTIF figure could be incorrectly identified as underperforming in certain circumstances.

Key findings

An important finding of this case study was that the company benefited great deal from a flexible workforce and resources. Having a multi-skilled assembly team allowed the company work around shortages in component parts. So that sub-assemblies could be produced ready for integration into the finished product when the missing parts arrive. Not all companies have this luxury and production could easily grind to a halt because of shortages.

The main finding of this case study was that there were three ways incorrect OTIF calculations and order data entry errors could negatively impact a company and its supply chain.



Firstly, OTIF can misidentify problem suppliers, potentially hiding or even protecting them. In this study the problem supplier in reality had an OTIF of 43%, whilst the reported OTIF was 77% (73%). This can lead to problematic suppliers inadvertently being shielded, so that whilst their supposed OTIF is not as high as a company would like it appears to be better than it is. There is a risk that this could be utilised for more nefarious purposes in that a problematic suppliers real performance could be deliberately concealed, either to mask their own failures or those of a supplier they have favourable relationship with. Furthermore, errors in order entry can result in companies being mis-identified as having problems.

Secondly, it can create divisions and friction between parts of a company, this is especially true if one party believes the figure to be indicating something it is. For example, a production manager might complain that shortages of parts from a particular supplier cause production issues. A purchasing manager can produce when they might believe are OTIF figures that indicate that whilst the supplier was far from perfect it isn't the sole cause. It could take the intervention of a third person to overcome this problem.

Finally, these can result in time and resources into fixing the wrong things. This could involve increasing inventory levels, potentially placing more pressure on suppliers who are struggling. Attention could be focused on resolving problems with the wrong suppliers, although improving supplier performance is beneficial for the company if it's not the correct company then performance will not improve.

Conclusions and Outcomes

The work highlights some potential causes of errors that can creep into OTIF calculations including the incorrect application of the OTIF and data entry issues within an ERP system. Showing just how large the discrepancy can be between implementations of what is termed OTIF. It needs to be clear for everyone what measure is being used, in this case OT was being applied instead of OTIF, and what the limitations are of this measure.

Furthermore, it highlights that when operations indicate that there might be a problem with a supplier then it is good practice to ensure metrics are being correctly applied as errors can hide the magnitude of the problem. This is especially true when analysis produced by the purchasing department contradicts this.

As a result of this study highlighting the problems associated with the OTIF measure that was being used the company, together with further work conducted within the company there have been several changes made to strategy. Supplier issues have been addressed in two ways. Firstly, through bringing new suppliers on board. Secondly, through dual sourcing where necessary / beneficial.

The changes made in procurement and suppliers have enabled the company to reduce its lead-times, which has allowed the company to grow and expand.

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