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Discrete-event simulation in logistics and supply chain management: a scientometric perspective

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ABSTRACT

This paper has been designed in the form of a systematic literature review intended for evaluating the state-of-the-art of discrete-event simulation (DES) usage in the logistics and supply chain management fields under a scientometric perspective. With this primary aim in mind, 127 papers published between 2009 and 2022 are analysed, with the specific purposes of: 1) providing an overview of DES studies in logistics and supply chain management, map the main topics covered within this stream of literature and their evolution in time; 2) providing a robust ranking of the journals and authors in the field; 3) evaluating the rigor in the implementation of DES models in the logistics and supply chain management literature; and finally 4) correlating, through statistical elaborations, all the previous aspects to the success of these papers, measured as the citations received per year, taking inspiration from scientometric disciplines.

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1. Introduction

The increased level of complexity and competitiveness of all industrial sectors is pushing enterprises to strive for an optimization of their organizational processes and to seek new and improved methods to reduce uncertainty (Antonini, 2019; Terzi & Cavalieri, 2004). The complexity and dynamic behaviour of supply chains can make supply chain management (SCM) challenging. There are different approaches to supply chain design and analysis, including deterministic and analytical models, stochastic models, economic models and simulation (Mustafee et al., 2021).

Modelling and simulation are relevant techniques in the fields of industrial engineering, operations and logistics (de Paula Ferreira et al., 2020). Simulation, according to Shannon (1975), is ‘the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies for the operation of the system’ (Ingalls, 2011). In manufacturing and logistics systems, modelling and simulation denote a set of methods and technological tools that allows for the experimental analysis and validation of products or processes, for designing systems and predicting their performance (de

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Paula Ferreira et al., 2020). Depending on the type of problem – e.g. on the system simulated or the simulation goals – the most appropriate type of simulation must be chosen. Over the years, researchers and practitioners have developed and proposed numerous simulation techniques. Based on the randomness dimension, simulation models can be stochastic or deterministic. Deterministic means that the repetition of the same simulation will result in the same final output, while in stochastic simulation the repetition of the same simulation will not always result in the same output. As far as the time factor, simulation can be either static or dynamic. The static simulation is independent on time, whereas the dynamic simulation evolves with respect to time (Abid et al., 2019). Dynamic simulation can be further categorized into continuous and discrete. In discrete simulation, changes occur at discrete points in time, while in continuous simulation, time is a continuous variable (Mourtzis et al., 2014). The most widely studied simulation techniques are Monte Carlo (MC), discrete-event simulation (DES), agent-based simulation (ABS), continuous simulation and system dynamic (SD). Figure 1 presents a classification of all the simulation models.

By general understanding, a type of simulation that is quite easy to use in practical cases is DES and, as such, it is commonly used for optimizing business processes (Jadric et al., 2020; Tako & Robinson, 2012). ‘Discrete event’ systems are systems whose state changes discretely at some random time points, because of the occurrence of an event. The main purpose of DES models is therefore to analyse the statistical characteristics of the system’s events (Qiao & Wang, 2021). DES is well-known in the

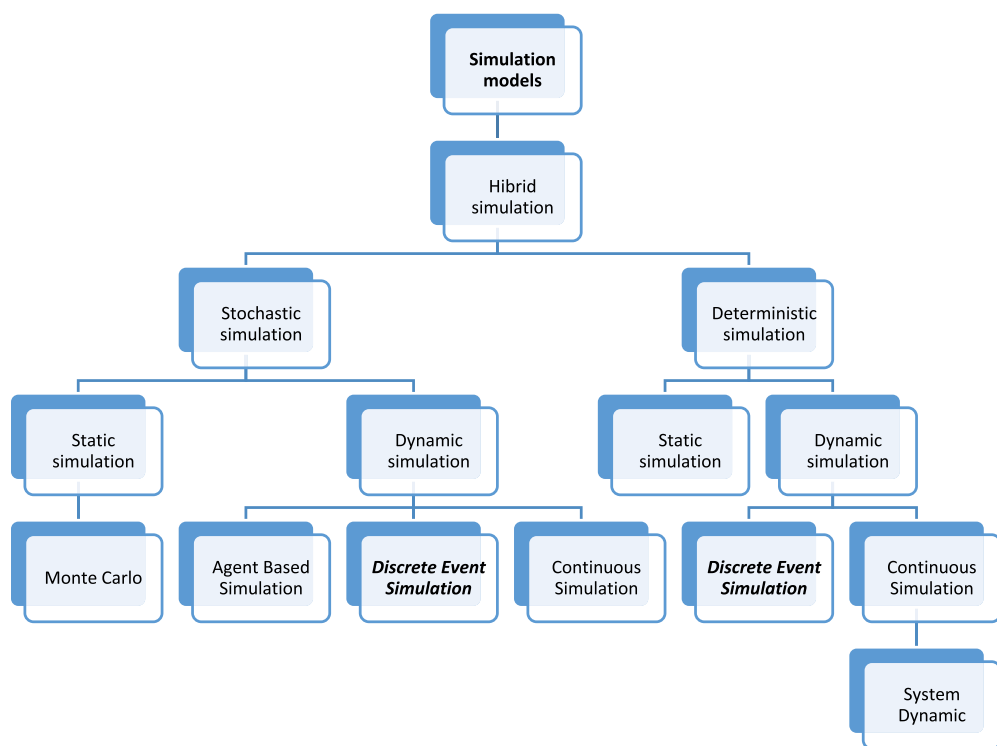


Figure 1. Classification of simulation models.

manufacturing world, wherein Tocher developed the first simulation language in the late 1950s for constructing a model to reproduce a steel plant in the UK (Vázquez-Serrano et al., 2021). Literature includes some reviews about simulation in general (and DES in particular); however, most of these studies have not focused on the area of logistics, rather treating specific supply systems (e.g. (Kim et al., 2023; Kogler & Rauch, 2018; Opacic & Sowlati, 2017)) or software tools used for simulation purposes (e.g. (Dagkakis & Heavey, 2016; García-García et al., 2020)). Looking expressively at the logistics and SCM context, Semini et al. (2006) have made a survey of 52 papers from a main conference on simulation, by investigating the kind of decision supported by simulation tools, the characteristics of the (possible) case study, the methodological issues and the software tool used. Manuj et al. (2009) have made an extensive review of the literature about logistics and supply chain studies in which DES modelling is adopted; from an analysis of those studies, the authors have delineated a framework for the development of DES models in the context of logistics and SCM. Tako et al. (2012) have analysed 127 peer-reviewed journal papers published between 1996 and 2006, that use DES or SD as decision support systems for logistics and supply chain modelling. Mustafee et al. (2021) have reviewed 130 studies about distributed supply chain simulation, as a tool that enables the coordinated execution of simulation models using specialist software packages; the role of technologies like Internet-of-Things and cloud computing for providing data useful to simulation studies are also explored.

Compared to the available reviews, this paper contributes to the literature in several ways. First, from a general point of view, review studies focusing on DES models in logistics and SCM are somehow outdated and would benefit from an update of the relating contents. Second, from a more specific perspective, after the work by Manuj et al. (2009) no studies have further attempted to evaluate the rigor of implementation of DES models applied to logistics and SCM by assessing their compliance with the framework proposed by these authors. As that study dates back to more than a decade ago, it would be interesting to investigate whether the approach proposed by Manuj et al. (2009) has somehow been taken as a reference in subsequent studies. Third, as opposed to the previous reviews, this paper takes a scientometric perspective, for evaluating whether some characteristics of the paper (for instance, the specific topic investigated, but also the rigor of implementation of the DES model) can affect the success of the manuscript among the scientific community.

To capture all the points listed above, this paper has been conceived as a literature review of DES studies in the logistics and SCM area, targeting papers published from 2009 to 2022, for a total of 127 manuscripts. The specific aims of this study are:

- (1) to provide an overview of the published literature on DES in the logistics and SCM areas, map the main topics covered within this stream of literature and their evolution in time. Descriptive statistics and keyword analyses supported this goal (Fadlalla & Amani, 2015);
- (2) to classify and rank the studies retrieved based on a structured approach. The procedure by Bottani et al. (2022), consisting in a revisited Pareto ranking of journals and authors, was selected for categorization and ranking purposes;

- (3) to evaluate the rigor in the implementation of DES models available in literature, on the basis of their compliance with the guidelines proposed by Manuj et al. (2009), taken as reference;
- (4) and finally, taking inspiration from scientometrics, to identify correlations between the outcomes resulting from the previous analyses and the success of a paper, measured as the citations/year received.

The remainder of the paper is organised as follows. The methodological part of the study is presented in [Section 2](#), which details the sample creation and the full framework of the analysis. The key findings of the analyses made are presented in [Sections 3-6](#). In particular, [Section 3](#) provides an overview of the sample of studies and maps the topics covered in the literature; [Section 4](#) shows the outcomes of the classification and ranking of the literature, looking at authors and journals; [Section 5](#) details the evaluation of the papers' contents, in terms of their consistency with the reference framework by Manuj et al. (2009); correlations between the previous outcomes, as well as with the citations received by the papers, are presented in [section 6](#). A discussion of the overall outcomes, with implications for researchers and managers, is finally proposed in [Section 7](#), together with limitations and suggestions for possible future research directions.

2. Materials and methods

2.1. Sample creation

A systematic review is based on a well-defined methodology which makes it less likely that the literature results will be biased, although it does not protect against publication bias in primary studies (Ben Rabia & Bellabdaoui, 2022). This kind of review identifies, selects and critically appraises research, for answering a clearly formulated scope, which in this study, consists in achieving the set of goals previously delineated. The pertinent literature, relating to DES usage in logistics and SCM, was retrieved from the online database Scopus (www.scopus.com) in November 2022.

A crucial point when carrying out systematic literature reviews is the usage of keywords that allow for the relevant literature to be found and retrieved. Scientific writing does not impose any specific rule to authors for the usage of keywords in their papers (Hartley, 2008; Murphy, 2010); as a consequence, what frequently happens is that authors use various terms (or synonyms), all relating to the topic under investigation, for indicating similar concepts. An effective way to identify the appropriate keywords for the scope of the study is thus to start retrieving and checking some papers resulting from a tentative query, evaluate their relevance to the targeted topic or area of research and then, if relevant, check the keywords used and update/refine the query or make new queries (Bottani & Franchi, 2021). Following this procedure, two groups of keywords were delineated and combined to capture research papers relevant to this study (see [Figure 2](#)), as follows:

- Keywords related to the application context, such as *supply chain*, *logistics* or *supply chain management*;

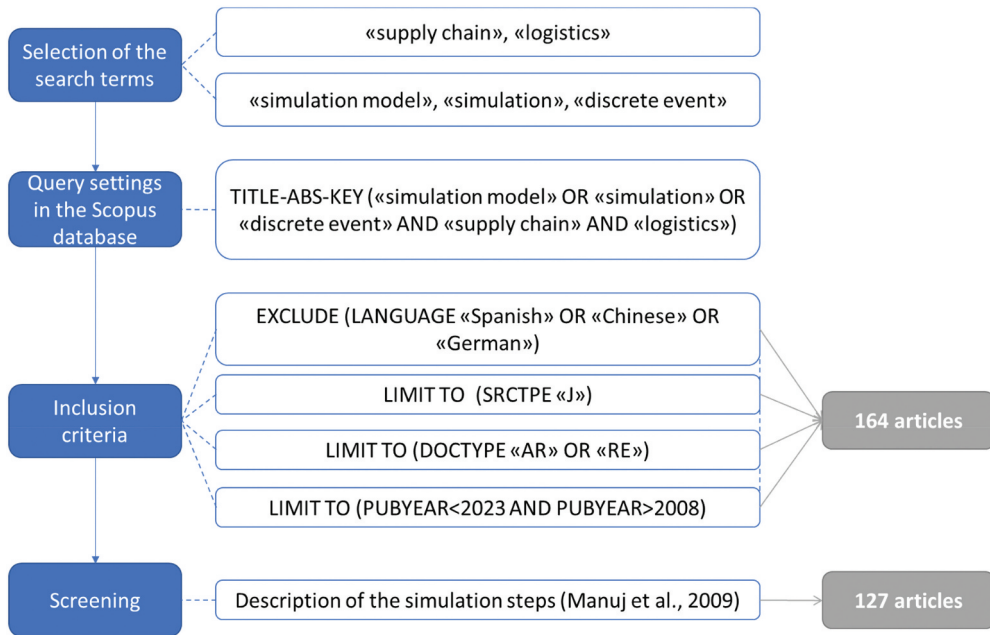


Figure 2. Papers selection process.

- Keywords related to the tool investigated, such as *simulation model*, *simulation* or *discrete event simulation*.

Looking at the query settings, the following inclusion criteria were adopted:

- (1) Papers must be written in English. Other languages were excluded.
- (2) Papers must be published on international journals, which are recognized as the primary source of scientific studies. Other publication types were excluded.
- (3) The paper type was set at ‘*article*’ or ‘*review*’, to complement the previous setting, as well as to ensure that the full text was available for download.
- (4) The publication timespan was set from 2009 to 2022, covering approximately 14 years, which is a typical timespan for scientometric studies (Haghani, 2023). The setting of this timespan is justified by the fact that the reference study (Manuj et al., 2009) was published in 2009 and that at the time of the query (November 2022), almost all papers referring to 2022 could be assumed to be available online.

Using these settings, 164 results were initially obtained and were screened by reading the abstract, title and keywords, to ensure that they were relevant to the present study. As far as the criteria for retaining the pertinent studies, the main one refers to the fact that the papers retrieved must deal expressively with DES, which is also the focus of the article taken as reference. In line with this, the preliminary screening led to the exclusion of papers that did not focus on that simulation technique. Hybrid approaches (e.g. DES coupled with ABS or SD) were instead retained, as they are quite common in simulation

studies (Brailsford et al., 2019). A final check was made by reading the full texts of the remaining papers to ensure correspondence with the inclusion criterion. Figure 2 shows the screening process just described, highlighting the final sample of 127 articles. The full list of studies retained can be found in (Bottani & Casella, 2024b).

2.2. Bibliographic and citation data extraction

The relevant pieces of information (i.e. authors, keywords, source title, year of publication, first page, last page, number of citations, publication type) of the 127 papers were extracted in .csv format from the Scopus database using the ‘export’ function and imported in MS ExcelTM for being elaborated. Data were extracted at the time of the query (i.e. November 2022). An update of the citations of all papers was made in January 2024 (approximately reflecting the citations received up to 2023), on the basis of the consideration that papers are likely to attract citations when some years have elapsed since their publication (Fronzetti Colladon et al., 2020; Ioannidis et al., 2016). These (more realistic) citation data were used in the analyses made.

Besides the data extracted from Scopus, the MS ExcelTM database was enriched by adding the classification of the journals taken from the Scimago Journal and Country ranking¹ database. This database categorizes journals based on various parameters, mainly relating to the citations received and the prestige of the journals where the citations come from, resulting in their grouping into four quartiles (Q1, ...Q4) for each subject category a journal belongs to.² Whenever a journal belongs to multiple Scopus subject categories³ with a different positioning, the best quartile was retained. Moreover, because the data extraction was made in 2022, the journal rank of the same year was taken, for consistency; if not available, for instance because the journal was no longer indexed by Scimago, the last available rank was used.⁴

2.3. Statistical analyses

2.3.1. Sample description

Some descriptive statistics were first made on the sample of papers and their key characteristics, for which the trend in time was evaluated. This is the case for the number of publications, publication type (open access vs. traditional), journals or number of authors per paper. Statistical analyses were also made, with the same aim of depicting the trend in time, on all the parameters used for classifying the journals, authors and papers (see Section 2.4 for the relating description).

2.3.2. Keyword analyses

Keywords (or research terms) are crucial in any research area, as they help researchers have access to papers, books and works related to their field of expertise (Amini et al., 2021). Indeed, keywords are deliberately selected or created by the authors themselves, with the aim to (correctly) delineate the main subject of their papers (Yang et al., 2018). Keywords are also related to scientometrics, as they are recognised to reflect research topics, and specifically, they are regarded as ‘unique’ topics inside a wider evolving theme (Zhang et al., 2016). Dedicated analyses were made on the papers’ keywords. The first set of analyses follows the approach by Fadlalla and Amani (2015), which highlights the key

topics covered by the published articles by evaluating the frequency of usage of the keywords among the papers reviewed and their persistency in time. The former index reflects the number of occurrences of a term, while the latter represents the continuity of a given concept over time and is measured as the number of years since a term was first introduced as a keyword (Bigliardi et al., 2021, 2022). By combining low/high values of the frequency and persistency, a matrix with four quadrants can be built, in which the topics can be classified as follows:

- (1) The first quadrant identifies keywords with high frequency and persistence, corresponding to *well-established topics*, which have been dealt with extensively and whose relevance has lasted over the years.
- (2) The second quadrant identifies the keywords with low frequency, but high persistence. This corresponds to *intermittent topics*, not particularly treated by researchers, or discussed in the literature in a discontinuous way.
- (3) The third quadrant identifies keywords with low frequency and low persistence, and thus reflects *emerging topics*, which have not (yet?) been treated extensively, probably because of their recent introduction. These topics can evolve in two directions, i.e. they may become less interesting (thus moving to the first quadrant) or they could become trendy topics, if their frequency of usage increases in time.
- (4) The third quadrant finally identifies keywords with high frequency and low persistence, framing a series of highly *trendy topics*, relatively new to researchers but very promising.

The second set of analyses made on the papers' keywords takes inspiration from Wang and Chai (2018), who have suggested that the corpus of keywords reflects the development stage of a given discipline. Accordingly, the evolution in time of the keywords categories previously determined, as well as the introduction of new keywords or the demise of previous terms, was traced. From a practical point of view, this means that the keyword categories were evaluated at different moments in time, and to this end, the timespan of the published papers was divided into three periods, i.e. 2009–2013 (period 1), 2014–2018 (period 2) and 2019–2022 (period 3). Sankey diagrams show the evolution of the terms across the three periods.

2.4. Journals and authors classification

The procedure developed by Bottani et al. (2022) was used for classifying and ranking the journals and authors of the papers in the sample; the proposed approach makes use of citation analysis, which is coupled with considerations concerning the authors' productivity. For the sake of clarity, some key steps of the procedure are described in the subsections that follow, using the nomenclature in Table 1; the reader is referred to (Bottani et al., 2022) for an exhaustive description of the classification method.

2.4.1. Authors' classification

Authors are classified using a revisited Pareto (also known as 'ABC') analysis, incorporating the number of papers published by each author and the number of citations received by his/her papers.

Table 1. Nomenclature used for the journals, authors and papers classification.

Acronym	Description
NP	Number of papers
LYP	Last year of publication
FYP	First year of publication
ACY	Average citations per year of authors
JCY	Average citations per year of journals
PCY	Average citations per year of papers
M	Mean (of a statistical distribution)
Subscripts	Description
J	Journal
A	Author

The first step for this classification is an evaluation of the number of publications of each author and, most importantly, of the average number of papers published per author $M(NP)_a$, which reflects the mean of the distribution of papers across the authors. The first and last year (*FYP* and *LYP*) of the paper(s) published by each author should be tracked. Then, the following classes are set for ranking the authors.

- Class A: $NP_a \geq M(NP)_a$: active authors on the selected topic;
- Class B: $NP_a < M(NP)_a$ and $FYP > \text{first year} + T/2$: less active authors but relatively new to the targeted field of study;
- Class C: $NP_a < M(NP)_a$ and $LYP \leq \text{first year} + T/2$: no longer active authors.

About the citations, which are used as a second parameter for classifying the authors, a preliminary analysis is to be made on the sample of papers for determining the total number of citations received by an author, weighted by number of publications and ‘age’ of the publication. This preliminary elaboration is necessary to get the *ACY* of an author, according to the following formula:

$$ACY = \left(\frac{\sum \text{of the author's citation}}{NP_a * \text{publication age}} \right) \quad (1)$$

In eq.1, NP_a is the number of publications (of the sample) written by an author, as defined previously. The numerator, i.e. the sum of citations received by the author, can be easily obtained by adding up the citations received by the set of NP_a papers of the sample published by that author, as they were extracted from the scientific database. Finally, the publication ‘age’ reflects the number of years elapsed from the publication of the paper. This parameter tries to normalize the resulting average citations, taking into account the fact that older publications have been available in literature since more time and their potential of being cited is higher. Hence, an alternative (and maybe simpler) way for computing the *ACY* is to immediately evaluate the publication per year of an author and then divide it by the number of papers authored. Again, by analysing the distribution of *ACY* values, it is immediate to determine its overall average, $M(ACY)$, according to which the following classes can be defined:

- Class A: $ACY \geq M(ACY)$: prominent authors;
- Class B: $M(ACY) > ACY \geq M(ACY)/2$;
- Class C: $ACY < M(ACY)/2$: not well-established authors.

By crossing the set of classes obtained above, a final ranking of the authors into nine classes can be determined. Classes will be labelled from AA (i.e. class A in NP_a and class A in ACY) to CC (with an obvious meaning of the acronym) and will then be assigned a score, according to the list below:

- Class AA (excellent): 4 points;
- Class AB or BA (good): 3 points;
- Class AC, BB or CA (average): 2 points;
- Class CB, CC or BC (weak): 1 point.

2.4.2. Journals' classification

A similar ABC classification is suggested for journals. To be more precise, the first step for journals' classification is an evaluation of the number of publications per journal and of the average number of papers published by each journal, denoted as $M(NP)_j$, which corresponds to the mean of the distribution of papers across the journals. The first and last year (FYP and LYP) of the paper(s) published by each journal should also be tracked. On the basis of these parameters, the following classes are suggested for ranking the journals.

- Class A: $NP_j \geq M(NP)_j$: journal that publishes frequently on the selected topic;
- Class B: $NP_j < M(NP)_j$ and $FYP > first\ year + T/2$: journals that have published less frequently on the topic, but have started publishing on that research field in recent times;
- Class C: $NP_j < M(NP)_j$ and $LYP \leq first\ year + T/2$: journals that have not published much on the topic and, most importantly, have not embraced the selected topic in recent times.

In the above set of classes, the first year is to be determined on the basis of the sample of papers under examination. Next, the total number of citations received by a journal (i.e. the sum of the citations received by the papers published on that journal) should be evaluated and normalised by dividing it by the number of publications and the 'age' of each publication. This preliminary elaboration leads to determining the JCY , namely the average number of citations per year received by each study published in each journal, according to the following formula:

$$JCY = \left(\frac{\sum \text{of the citations of the papers published}}{NP_j * \text{publication age}} \right) \quad (2)$$

The numerator of eq.2 can be easily obtained by adding up the citations received by the set of NP_j papers of the sample published on the same journal, while, as already mentioned, the publication 'age' reflects the number of years elapsed from the

publication of the paper. Otherwise, the number of citations per year can be preliminarily computed for each paper, which avoids dividing by the publication age in eq.2.

By analysing the distribution of JCY values, its overall average $M(JCY)$ can easily be computed and used to classify the journals as proposed below:

- Class A: $JCY \geq M(JCY)$: highly cited journal in the targeted field of research;
- Class B: $M(JCY) > JCY \geq M(JCY)/2$;
- Class C: $JCY < M(JCY)/2$: not well-established journal.

As can be seen from the above list, the suggested boundaries of the classes are $M(JCY)$ and $M(JCY)/2$. Obviously, these boundaries can be slightly adjusted on the basis of the numerical values of the citations in the database of papers, which in turn, can exhibit differences depending on the research field under examination (Waltman & van Eck, 2015). By crossing the above categories, a final ranking of journals into nine classes can be obtained, from AA to CC. A score will then be assigned to each class, according to the same ranking used for author classification, i.e.:

- Class AA (excellent): 4 points;
- Class AB or BA (good): 3 points;
- Class AC, BB or CA (average): 2 points;
- Class CB, CC or BC (weak): 1 point.

Compared to the Scimago ranking of journals, previously mentioned, it is important to mention that the classification described above does not capture the same aspects. Indeed, the Scimago database provides a general and wide ranking of journals in a given subject area, while the ABC classification used in this paper is obtained starting from a smaller group of papers and (most importantly) refers to a specific research topic, whose boundaries are significantly more limited compared to a Scopus subject category on one hand, but could somehow span across different subject areas on the other hand. Hence, outcomes of the two classifications cannot be expected to perfectly overlap. At the same time, however, it is also true that a Q1-ranked journal in Scimago is likely to obtain more citations regardless of the specific theme of the papers published, which could result in higher JCY . Hence, a comparison of the outcomes of the two classifications has been made, for evaluating whether the classification used in this paper somehow complements the Scimago ranking by capturing additional or different aspects.

2.5. Evaluation of the paper contents

The guidelines by Manuj et al. (2009) have defined a set of eight steps that delineate a rigorous process to be followed when applying DES in logistics-related studies. By reading the papers of the sample, these simulation steps were divided into sub-steps for a better clarification of the single phases of the development of the DES model. The full list of steps and sub-steps, for a total of 14 phases, is provided in Figure 3 for the sake of completeness.

It is important to recall that, for the purpose of this study, evaluating the rigor of a DES model for logistics means assessing its correspondence with the procedure by

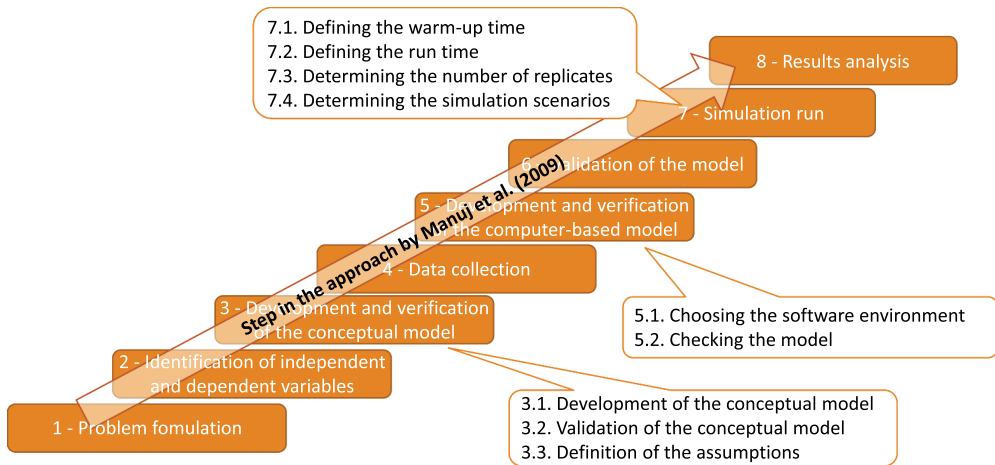


Figure 3. Steps in the approach by (Manuj et al., 2009).

Manuj et al. (2009) only. Hence, basically, the measure of the rigor of the model is the presence or lack of the steps/sub-steps in Figure 3, disregarding the relating technical aspects (e.g. the reliability of the validation process, the way it is conducted, its effectiveness, or the completeness of the results analysis). In this respect, it is also obvious that the steps listed in Figure 3 could be performed in various ways by the researchers; as an example, Kleijnen (1995) has explained that the validation of a simulation model (step 6) can be made in at least three ways, such as by obtaining real-world data, by comparing simulated and real observations through statistical tests, or by testing whether simulated and real responses are positively correlated. These considerations, together with other evidence available in literature, have been taken into account when screening the manuscript for determining the presence or lack of a step/sub-step in the DES model developed by the authors. While screening a paper, a score of 1 was assigned for each step/sub-step covered, while a score of zero was assigned if the study failed to implement that step/sub-step. The maximum total score (*TS*) a paper can get is therefore 14 points.⁵ The papers were then classified and ranked on the basis of the *TS* as follows:

- $TS < 4 \rightarrow$ weak: score = 1;
- $4 \leq TS < 8 \rightarrow$ average: score = 2;
- $8 \leq TS < 12 \rightarrow$ good: score = 3;
- $TS \geq 12 \rightarrow$ excellent: score = 4.

2.6. Scientometric analyses

Scientometrics, a sub-field of informetric, is a discipline whose aim is to measure and analyse the scholarly literature, focusing primarily on the impact of research papers and academic journals, the usage and interpretation of scientific citations (Leydesdorff & Milojevic, 2013).

Scientometric studies acknowledge that the success of any scientific paper is reflected by the impact it has on subsequent works, i.e. the number of citations received annually (Fronzetti Colladon et al., 2020), which consistently, is used in this paper as a measure of the paper's success. This value will be correlated with the whole set of relevant information previously derived about papers, journals and authors, such as:

- for authors:
 1. The author class. Publishing with well-established authors (e.g. doctoral supervisors) can influence scientific reasoning of the researchers and generate high-quality output, which can result in a more cited paper (Singh, 2018);
 2. The number of authors of the paper. Scientometric studies suggest that the number of authors plays an important role in enhancing the citation potentials of a paper (Fronzetti Colladon et al., 2020);
- for papers:
 3. The rigor of implementation of DES models, measured as the *TS* resulting from the number of steps detailed in the study (cf. section 2.5). The underlying assumption is that more rigorous papers, or papers in which the description of the model is more complete, include extra (or more precise) contents and as such, have greater potentials to attract citations, as more authors can take inspiration from these papers (Bornmann et al., 2014);

The keyword class: new (trendy) topics are expected to attract more citations compared to traditional topics, because of their timely relevance to the scientific community (Sjögårde & Didegah, 2022);

- for journals:
 5. The journal class. A prestigious journal in a given research area is more frequently searched for by researchers and therefore could attract more citations, suggesting a relationship with the success of the paper (Fronzetti Colladon et al., 2020). In addition, a prestigious journal is likely to publish papers describing more structured simulation models, or – reversing the line of reasoning – the rigour in the description of the simulation model is crucial for having a paper published in top journals. In both cases, this suggests a positive correlation between the journal score and the *TS*. Ultimately, top authors are expected to publish in highly ranked journals (Ioannidis, 2023), suggesting a positive relationship between authors' class and journals' class.

Overall, the relevant analyses made are listed in Table 2. Statistical elaborations (correlations, cross-tabulations or tests) were supported by the IBM Statistical package for the social science (SPSS), v.28 for Windows.

3. Results: statistical analyses

3.1. Sample description

An initial set of statistical analyses was made for delineating the trend in time of some basic characteristics of the sample of papers reviewed. As an overview, Figure 4 shows the distribution of the sample of papers by publication type (open access vs. traditional) and year, with the purpose of determining the trend in time of the publications dealing with DES in logistics and SCM. From that figure, it can be seen that the number of studies published per year was particularly high (16 papers) in 2019 and 2020, with a relevant

Table 2. Scientometric analyses made and rationale.

Item	Analysis made	Expected outcome	Rationale
Author's score	(descriptive statistics) Trend in time of the average and maximum author score of papers	Increasing trend	Prominent authors (higher author score) probably continue working in the area of DES in logistics and SCM, leading to a progressive increase in the average or maximum score of authors in recent papers (Brito et al., 2023)
Journal's score	(descriptive statistics) Trend in time of the journal score	Increasing trend	Authors are increasingly paying attention to publish in highly ranked journals
Paper's TS	(descriptive statistics) Trend in time of the TS	Increasing trend	Because the simulation steps have been detailed in a study of 2009, it could be expected that the rigor in the description of the simulation models progressively increases in time after the publication of the framework.
Number of authors per paper	(descriptive statistics) Trend in time of the number of authors	Increasing trend	The progressive maturity of the research field leads to the progressive establishment of collaboration mechanisms between authors (Bontekoning et al., 2004), (Koningsveld, 1987).
Author's score	(correlation analysis) Correlation between the average (and maximum) author's score and journal's score	Positive correlation	Highly ranked authors probably target highly ranked journals for their publications (Ioannidis, 2023).
Paper's TS	(cross-tabulation) Relationship with the journal score	Positive correlation	Papers with high TS are expected to be published in highly ranked journals.
Paper's TS	(correlation analysis) Correlation with the number of citations/year	Positive correlation	A more detailed description of the DES model is expected to result in a more successful paper, because of the higher completeness and variety of concepts to be cited (Hasan & Breunig, 2021).
Number of authors	(correlation analysis) Correlation with the number of citations/year	Positive correlation	When using online database for literature search, the title of a paper is crucial for having it retrieved and, hopefully, cited (Fronzetti Colladon et al., 2020), (Guo et al., 2018).
Author's score	(correlation analysis) Correlation between the average (and maximum) author's score and the number of citations/year	Positive correlation	Papers written by highly ranked authors could attract more citations (Tahamtan et al., 2016).
Journal's score	(correlation analysis) Correlation with the number of citations/year	Positive correlation	Papers in highly ranked journals could attract more citations (Tahamtan et al., 2016).
Keyword category	(T-test) Difference in the average citations/year of the papers as a function of the keyword class	Significant differences in the number of citations between the keyword categories	New (trendy) topics are expected to attract more citations compared to traditional topics (Sjögårde & Didegah, 2022).

increase compared to the previous years. The trend towards an increase in the research in this field is also confirmed by the dashed line in [Figure 4](#). In the last years (2021 and 2022), outcomes are slightly lower; nonetheless, the papers published since 2019 include more than 40% of the sample. The average number of publications per year is 9.14. The quota of open access (OA) papers has also progressively increased in time, reaching high

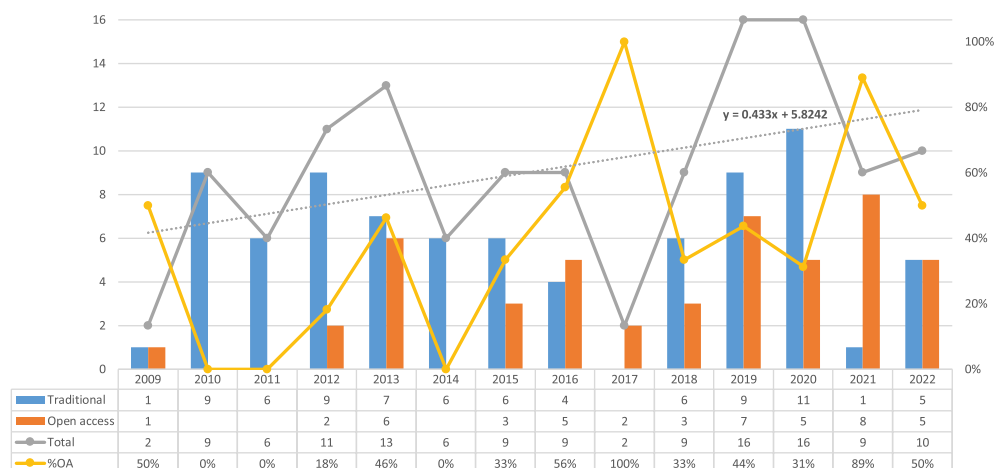


Figure 4. Publications per year and trend line.

percentages in the latest years (from 2017 onwards), and sometimes also overcoming the quota of papers published in traditional mode.

The papers of the sample were published on 85 different sources. Most of the journals (65, >76% of the total – Figure 5a) have published one study only in the selected area of research, while the greatest number of papers published by the same journal is 7 (reached by one journal only, i.e. *International Journal of Production Research* – Figure 5b).

Overall, *International Journal of Production Research*, *Vaccine*, *Sustainability* and *European Journal of Operational Research* were the journals that published the greatest number of studies (from 4 to 7) and taken together, cover approx. 19% of the sample. The journal *Vaccine* could seem to be off-topic, as it is classified among the medical journals and not among the engineering ones. On the basis of this consideration, the papers published on that journal, i.e. (Assi et al., 2012, 2013; Haidari et al., 2015; Lee et al., 2017; Mueller et al., 2016; Wedlock et al., 2019), were checked accurately and were found to be almost all related to the usage of DES in modelling the vaccine supply chain, which makes them consistent with the intended aim of this review. The relevance of this journal to the DES literature is also confirmed by the recent review by Vieira et al. (2020), that quotes numerous references from *Vaccine*. Out of the 85 sources, the first one that focuses expressively on simulation is the *Journal of Simulation*, which ranks sixth with 3 papers published (Byrne et al., 2010; Mittal & Krejci, 2019; Rabe et al., 2020). Overall, these outcomes indicate that DES is a methodology used for optimizing logistic processes in very different contexts, from industrial to medical ones, as reflected by the variety of journals that published studies on that topic.

Looking at the journal classification by Scimago, it emerged that 80 papers were published in Q1 journals, followed by 25 papers in Q2, 17 papers in Q3 and 5 papers in Q4. If evaluating the trend in time of the distribution of papers per journal quartiles (Figure 6), it is easy to deduce that from 2017 onwards, researchers have paid particular attention in targeting high-ranked (i.e. Q1 or Q2) journals as an outlet for their papers, while almost disregarding journals in low-ranked quartiles.

The studies reviewed were published by approx. 400 different authors. The majority of articles analysed have been written by two, three or four authors, and in particular, the

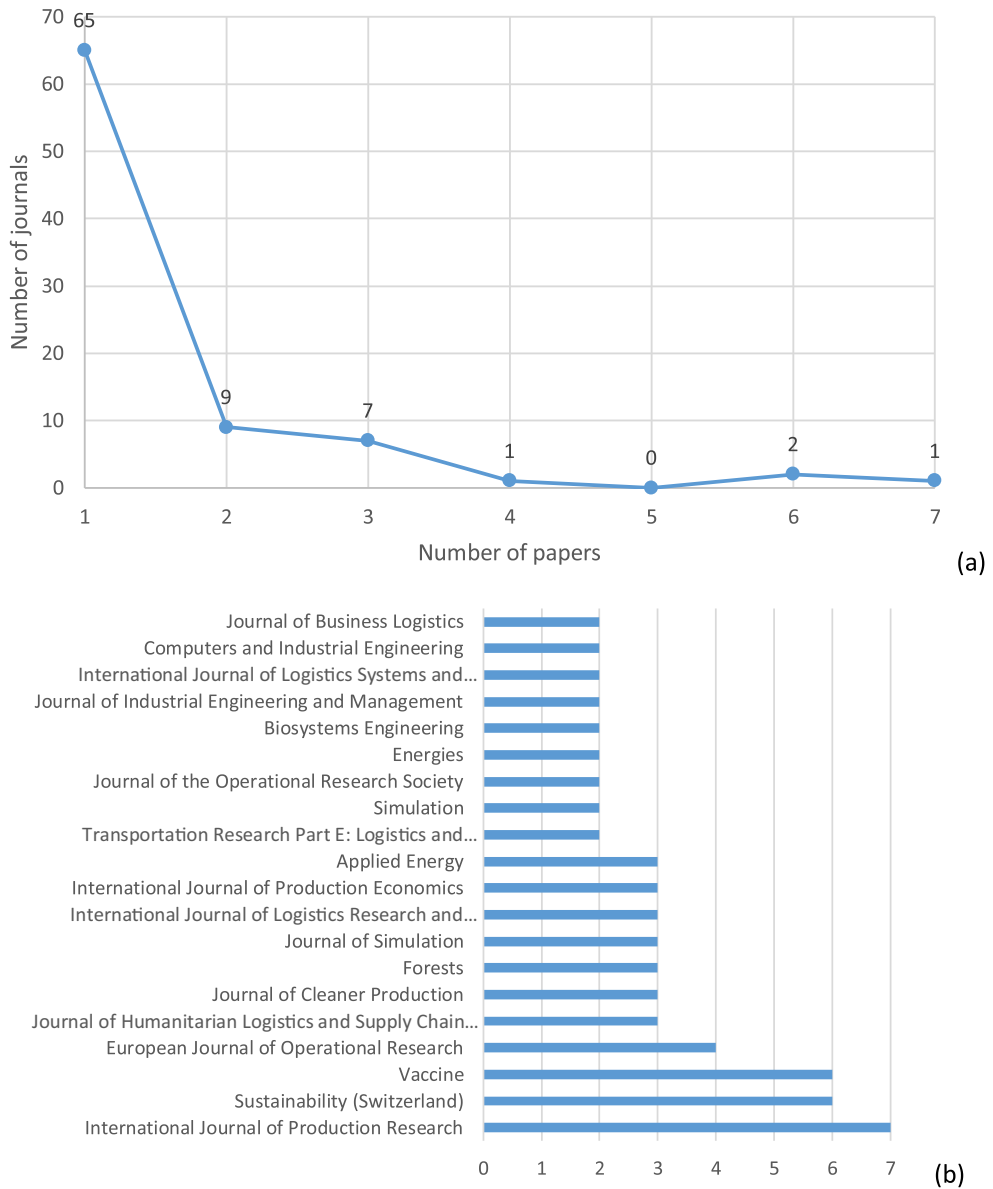


Figure 5. Number of papers published per journal (a) and top journals (≥ 2 papers) (b).

most frequent number of authors is 3 (found in 41 papers, 32% of the sample – [Figure 7a](#)). In a limited number of studies, more than 10 authors collaborated ([Assi et al., 2012](#); [Haidari et al., 2015](#); [Lee et al., 2017](#); [Wedlock et al., 2019](#)). These studies all come from the healthcare field and have been published in the previously discussed journal *Vaccine*; this is a possible indicator of different publishing behaviours in terms of number of authors in the healthcare area, compared to the engineering area: indeed, collaborations do not spread uniformly across different disciplines, with some scientific fields being naturally more prone to incorporate collaborations ([Qin et al., 1997](#)). The

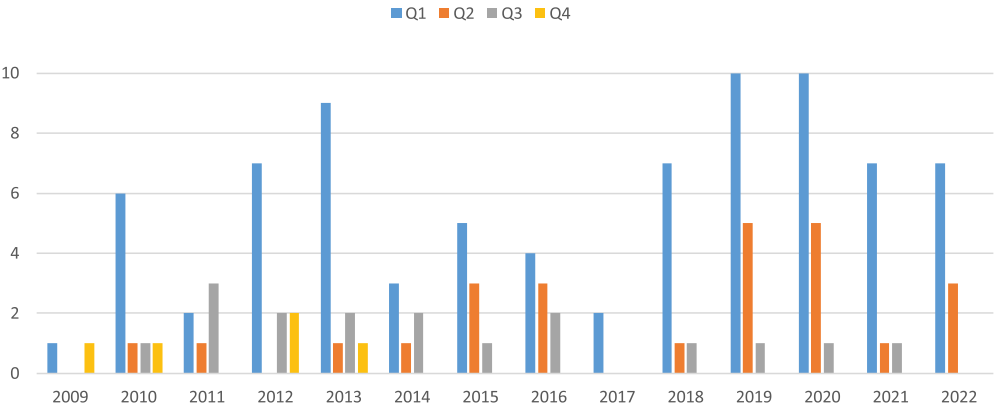


Figure 6. Papers vs. journal quartiles.

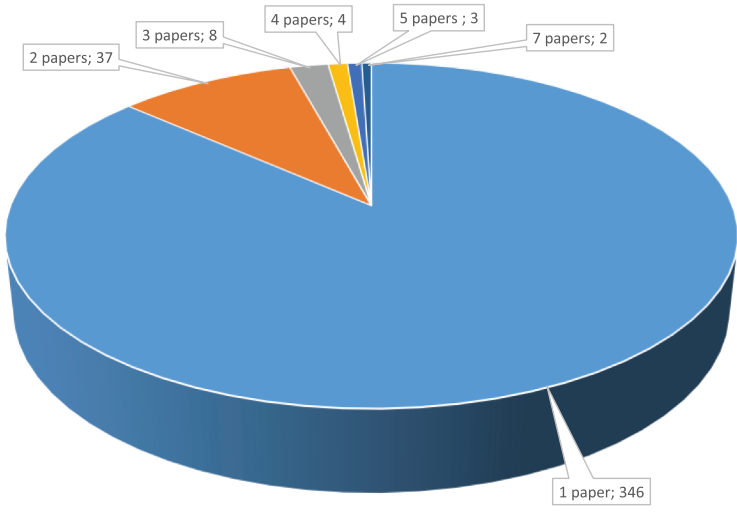
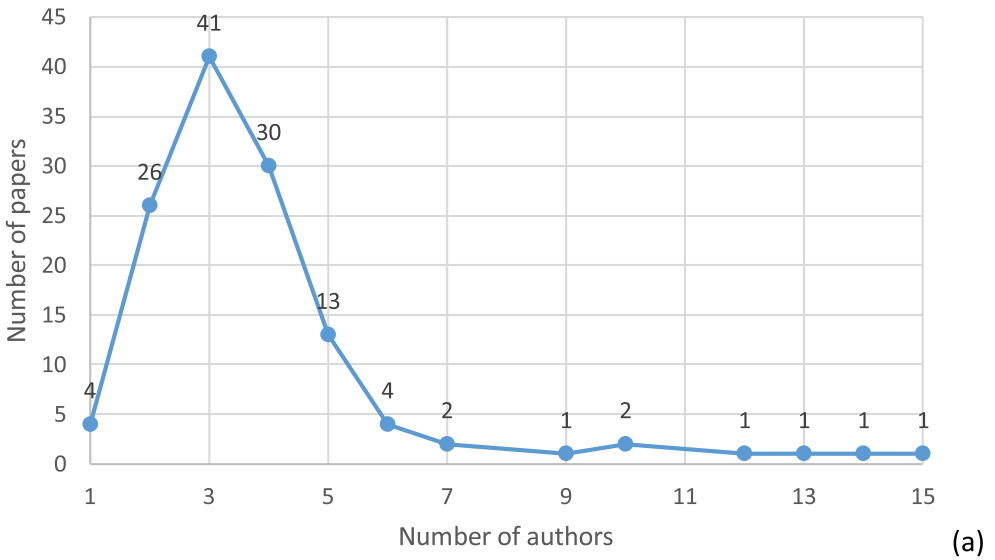


Figure 7. Distribution of the number of authors (a) and papers published per author (b).

average number of authors per paper is 3.82. As far as the scientific production of the researchers (Figure 7b), most of the authors have published one paper only; the maximum number of papers published by the same author is 7.

The evolution of the average number of authors per paper across the years (Figure 8) is also interesting to be analysed and shows a slightly increasing trend, from 2.5 in 2009 to the peak of 7.5 in 2017; more recent values are always between 3 and 4.75. This evolution is also confirmed by the trendline (dashed line) and its equation. Various explanations could be conjectured for this trend. One could be related to the establishment of more sound collaboration mechanisms between authors, which leads to wider research groups and ultimately, to more authors per paper. This is also a typical symptom of progressive maturity of a research field (Bontekoning et al., 2004; Koningsveld, 1987).



Figure 8. Trend in time of the average number of authors per paper.

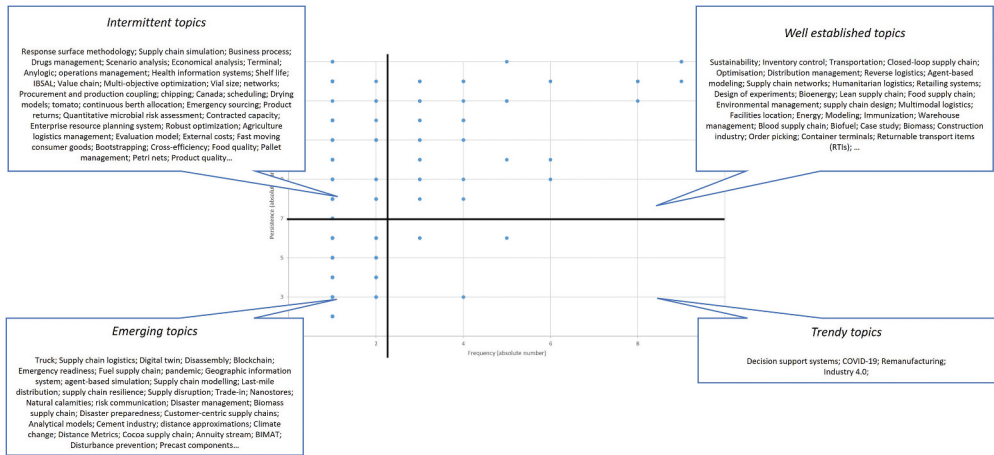


Figure 9. Results of the keywords analysis.

3.2. Keyword analyses

3.2.1. Mapping of the topics

A first keywords' analysis was conducted by evaluating the various terms based on their frequency and persistency. Two papers were excluded from the analysis because they lack the authors' keywords; six terms used to make the search query on the Scopus database were excluded as well, as their frequency is obviously expected to be high and could bias the classification of the remaining terms. Moreover, a screening of the terms found confirmed that authors can use slightly different keywords to express the same (or a similar) concept (e.g. 'transport' and 'transportation'); this is to be expected, because as mentioned, as in scientific writing there are no strict rules for defining the keywords. Singular or plural forms or small changes in the spelling of the same word are also possible; these terms were obviously treated as a unique entry. Overall, 352 single terms were found, which were subject to the analysis (the full list of keywords can again be found in (Bottani & Casella, 2024b)). An extract of the terms with frequency ≥ 2 is proposed in Appendix (Table A1) together with the relating classification. By combining the frequency and persistency parameters, a graph that allows to categorize the literature on DES in logistics and SCM has been built, with two axes and four quadrants. The x-axis defines the frequency; the boundary between high and low values (vertical line) was set at frequency = 2, which is the average value of frequencies (rounded to the closest integer number) across the whole set of keywords. The y-axis defines the persistence, and the relating boundary (horizontal line) was set at persistence = 7, reflecting half of the time-span of the sample of papers. Figure 9 presents the results of the keywords' classification.

Overall, 38 keywords (10.8%) were found to belong to the category of the *well-established* topics; most of these terms describe core themes of logistics and SCM, such as disruption, sustainability, food supply chains, closed-loop supply chain, distribution, supply chain design or order picking. It thus emerges that those topics are also of central interest to the area of simulation, which is evidently used as a tool for analysing disruptions in logistic systems, or for observing the behaviour of specific supply chains without the need for reproducing these systems. Similar considerations can be made for the topic of order picking, which has been frequently approached using simulation because of the difficulties in applying analytic or exact models (Casella et al., 2023). Because of the relevance of these topics, it is to be expected that simulation will also be used in the future for analysing them. Other keywords in this quadrant describe methodological tools typical of simulation studies, which evidently have also been applied to the logistics and SCM area; examples of these tools are agent-based modelling, design of experiments or optimization.

Four terms only belong instead to the *trendy* topics; they refer to decision support systems, Covid-19, remanufacturing and Industry 4.0. The newness of research about COVID-19 is self-evident, as the pandemic was observed in 2020 for the first time. Similar considerations can be made for topics related to Industry 4.0: although this term is less recent compared to Covid-19, the keyword classification highlights that the usage of simulation in this area is, on the contrary, relatively new. Also, Industry 4.0 is an active field of research (Machado et al., 2024), and evolutions of relating topics are likely to arise; it is not by chance that we already start talking about Industry 5.0 (as the natural

advancement of Industry 4.0). Hence, simulation studies in this area are expected to move towards the well-established quadrant in the future.

The category with the greatest number of terms is that of the *emerging* topics (173 keywords, 49.18%). Most of the terms in this group introduce new or specific topics; this is, for instance, the case for blockchain or digital twin. These topics also attracted the highest number of citations/year (>9). It can be conjectured that in studies dealing with blockchain, simulation is used as a tool for modelling and analysing the systems under examination. Other terms, instead, describe very specific aspects, such as the region/country in which the study has been carried out (e.g. Côte d'Ivoire), or the software package/methodology used in the study (e.g. fuzzy AHP, MCDM or Arena).

Finally, *intermittent* topics include 137 terms (38.92% of the keywords). As per the previous category, these terms refer to very specific topics, such as the aspects of the supply chain or logistics process under examination (e.g. cross-docking), or again, the methodology or software package used for solving the problem (e.g. Anylogic), or the context in which the study has been carried out (e.g. food).

3.2.2. Topics evolution

The analysis shown in the previous section was deepened by evaluating the trend in time of the keywords' category, by dividing the timespan into three periods, as mentioned earlier. An overview of the number of single keywords identified in each period is shown in Table 3, together with their classification into the categories previously mentioned, and the total number of papers published in the period (which has obvious relationships with the resulting number of keywords). As can be seen from Table 3, in general the number of single keywords increases across the three periods of analysis; assuming that each keyword expresses a single concept, such an increase reflects the development of the discipline in time, also fuelled by the increased number of papers published (Wang & Chai, 2018). A second consideration from Table 3 is that the *emerging* keywords, in particular, experience the greatest increase; as these terms typically denote recent topics, that have not been addressed extensively, this outcome further confirms the development of the discipline under examination, and in particular, its expansion towards new topics. Again, this behaviour is in general typical of research fields that tend towards the scientific maturity (Wang & Chai, 2018).

Figure 10 shows the evolution in time of the keywords categories. From this figure, it is easy to see that moving from the first to the second period of analysis, most of the *intermittent* topics disappeared, while a limited quota remained in all the three periods maintaining the same classification. Similarly, some well-established topics of period 1 remained unchanged for all periods of analysis; it is to be expected that the relating terms, therefore, denote core topics to the field of DES in logistics. Some of these terms, indeed, refer expressively to either logistics or simulation (e.g. closed-loop supply chain, design of experiments, inventory control, multimodal logistics, optimisation, transportation), while, interestingly, other terms describe interrelated topics (e.g. sustainability or environmental management),

Table 3. Number of keywords per period.

Keyword category	Period 1 (2009–2013)	Period 2 (2014–2018)	Period 3 (2019–2022)
Intermittent	84	59	9
Well-established	28	31	31
Emerging	0	31	145
Trendy	0	3	4
Total keywords	112	124	189
Number of papers	41	35	51

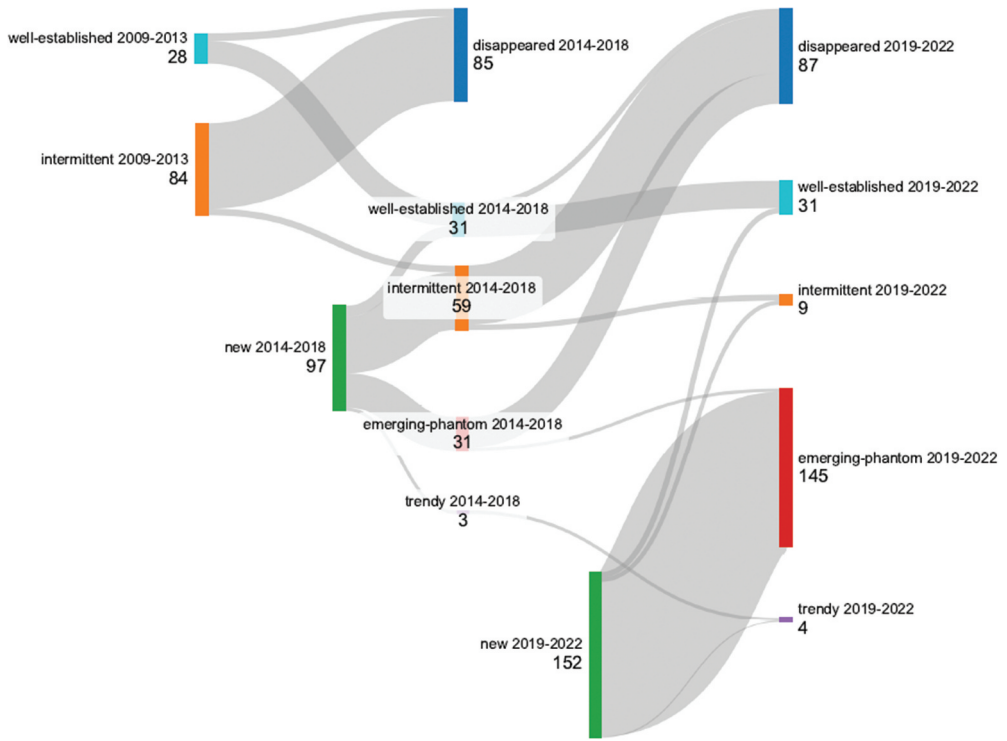


Figure 10. Evolution in time of the keywords' classes (Sankey diagram).

which have gained importance in the field. Figure 10 also shows that the number of new keywords is quite high in both periods 2 and 3, and that, in the last period, most of the newly introduced terms fall into the *emerging* topics. Obviously, it would be interesting to trace the evolution of these terms across the next years for checking their progress.

4. Results: journals and authors ranking

4.1. Authors' classification

As recalled earlier, 400 different authors were found in the sample of papers under examination, and most of them have authored just one paper. The $M(NP)_a$ computed on the list of authors scores 1.225.

The first and last year (*FYP* and *LYP*) of the paper(s) published by each author was tracked as well, by elaborating the publication data extracted from Scopus. For the sample of papers under examination, the timespan T of the publications ranges from 2009 to 2022, as a result of the query settings, and therefore $T/2 = 7$. Hence, the boundaries for the authors' classes are as follows:

- o Class A: $NP_a \geq 1.225$
- o Class B: $NP < 1.225$ and $FYP \geq 2016$
- o Class C: $NP < 1.225a$ and $LYP < 2016$.

The total number of citations received by an author (ACY) was obtained by adding up the citations/year received by all the papers written by the same author and dividing by *NP*, previously determined. The resulting average number of citations/year *M(ACY)*, scores 4.32; hence, the boundaries of the citations’ classes were defined as follows:

- o Class A: $ACY \geq 4.32$
- o Class B: $4.32 > ACY \geq 2.16$
- o Class C: $ACY < 2.16$.

The ABC cross-analysis made on the authors of the sample led to the results in Table 4 and Figure 11. For being more effective, Figure 11 provides the aggregated outcomes in terms of the number of authors belonging to each class. Detailed classification of all individual authors is available in (Bottani & Casella, 2024b).

As shown in Figure 11, most of the authors were classified as ‘weak’ (classes BC, CC or CB, 60.75% of the sample), followed by ‘average’ (classes AC, BB or CA, 20.5%), ‘good’ (classes AB and BA, 16.0%) and ‘excellent’ (class AA, 2.75%).

Because a paper is typically authored by more than one researcher, it is not immediate to delineate a trend in time for the authors’ score. In an attempt to obtain it, a synthetic evaluation of the relating authors was assigned to each paper of the sample by tracking both the average and maximum values of the authors’ score, and their evolution in time was traced. As indicated in Table 2, what could be expected is that prominent authors in a discipline continue working on the

Table 4. Aggregated results of authors’ classification.

	AA	AB	BA	AC	BB	CA	BC	CB	CC
TOTAL	11	29	35	14	48	20	132	29	82

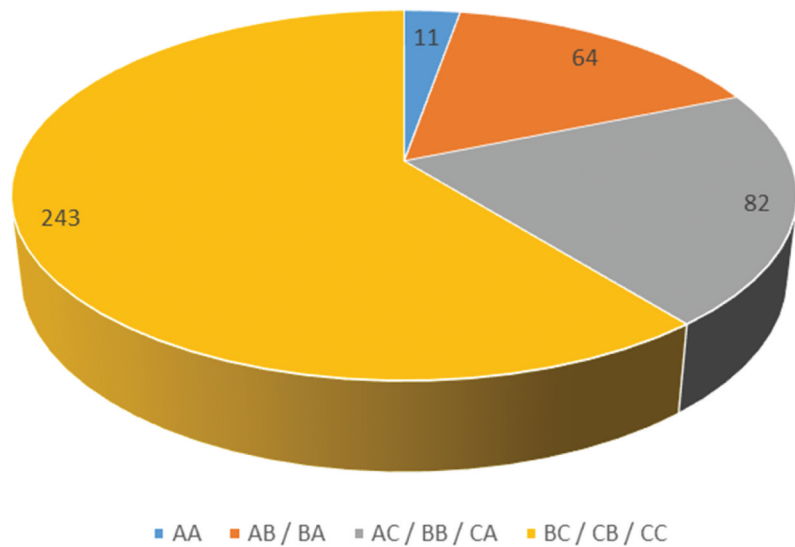


Figure 11. Authors’ classification.

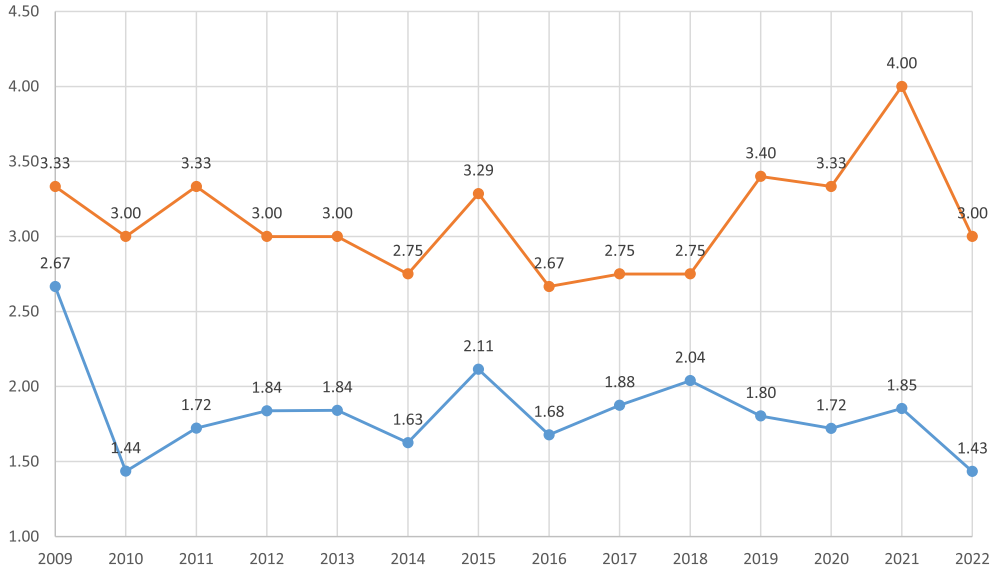


Figure 12. Trend in time of the average and maximum authors' score of the papers.

same discipline, thus gaining ever increasing popularity (Brito et al., 2023); hence, higher score for authors in the area of DES and logistics could be expected in recent years. This should lead to a progressive increase in average or maximum score of authors of a paper in time. Actually, results (Figure 12) do not fully support this consideration, and no particular trends emerge either on the average or the maximum value of the authors' score per paper; it is therefore to be concluded that prominent authors are too few compared to not well-established authors, which, taking a different perspective, suggests that many new authors have entered the field of simulation and logistics during the timespan under examination.

4.2. Journals' classification

The average number of papers published by the journals in the sample is $M(NP)_j = 1.51$. The first and last year (*FYP* and *LYP*) of the paper(s) published in each journal was tracked by making some elaborations on the data extracted from Scopus. The publication timespan does not vary compared to the authors' classification, and, therefore, the boundaries for the journals' classes are as follows:

- o Class A: $NP_j \geq 1.51$
- o Class B: $NP_j < 1.51$ and $FYP \geq 2016$
- o Class C: $NP_j < 1.51$ and $LYP < 2015$.

As far as the citations, the total number of citations received by a journal (*JCY*) was obtained by adding up the citations/year received by all the papers published on that

journal and dividing by NP_j , previously determined. The resulting average number of citations/year, $M(JCY)$, scores 2.34; hence, the boundary of the citations classes were defined as follows:

- o Class A: $JCY \geq 2.34$
- o Class B: $2.34 > JCY \geq 1.17$
- o Class C: $JCY < 1.17$.

The ABC cross-analysis made on the journals returned the results in [Table 5](#) and [Figure 13](#) (which aggregates the outcomes into the four classes). The detailed classification of all journals is available in Bottani & Casella (2024b).

As can be seen from [Figure 13](#), 11 journals (12.94%) turn out to belong to class AA; for the sake of clarity, these journals (which are actually all well known in scientific literature) are *International Journal of Production Research*, *Vaccine*, *Sustainability*, *European Journal of Operational Research*, *International Journal of Production Economics*, *Journal of Cleaner Production*, *Applied Energy*, *Biosystems Engineering*, *Computers and Industrial Engineering*, *Journal of Business Logistics*, and *Transportation Research Part E: Logistics and Transportation Review*. Instead, the most numerous class is the last one (corresponding to the aggregated categories BC, CB and CC), as it could be expected in a Pareto analysis, and includes 49.41% of the journals.

The ABC analysis was compared to the Scimago ranking of the same journals. Results of the comparison ([Table 6](#)) show that the ‘excellent’ journals (score = 4

Table 5. Aggregated results of journals’ classification.

	AA	AB	BA	AC	BB	CA	BC	CB	CC
TOTAL	11	5	9	4	9	5	16	8	18

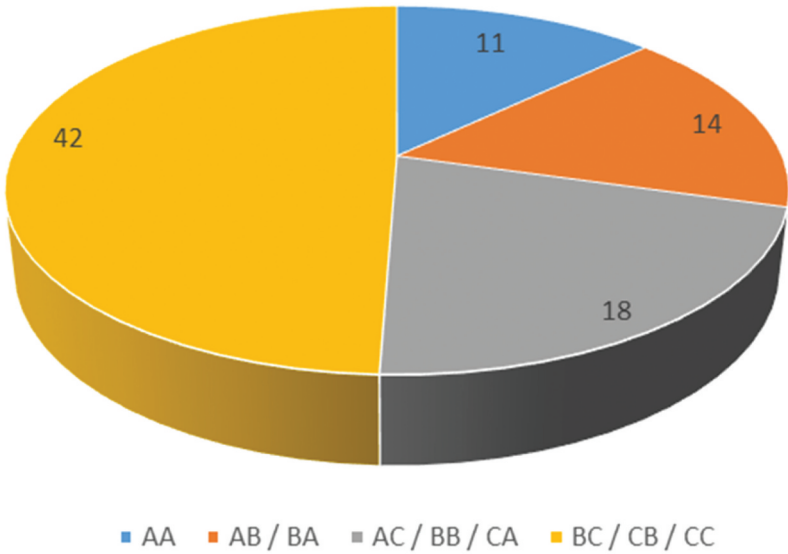


Figure 13. Journals’ classification.

Table 6. Comparison between journals’ classification and scimago rank.

JO_score	Q1	Q2	Q3	Q4
4	11			
3	9	2	3	
2	7	9	1	1
1	16	10	12	4

according to the ranking made in this study) all belong to the first quartile of Scimago; this suggests that the classification made following the approach by Bottani et al. (2022) correctly captures the top-journals. Results for ‘good’ journals (score = 3) also show correspondence with the Scimago ranking, as these journals are mainly listed in Q1-Q3 categories. Nonetheless, 16 Q1-ranked journals felt into the ‘weak’ category defined in this study; probably, this result is due to the low number of papers published by those journals in the area of DES and logistics.

It has been observed earlier in the paper that in the latest years, authors have paid particular attention in publishing on Q1- or Q2-ranked journals; a similar analysis was thus made looking at the journal classes resulting from the journal score computed in this study. Outcomes (Figure 14) confirm the trend previously observed, as in the last years journals with a greater score are more numerous compared to the remaining categories.

5. Results: paper contents

By mapping the presence of the steps/sub-steps delineated by Manuj et al. (Manuj et al., 2009) in each paper of the sample and assigning the corresponding score, the outcomes in Figure 15(a–b) were obtained. From Figure 15(a), it can be seen that a minimum number of six steps have been detailed in all papers of the sample, and consequently, no papers

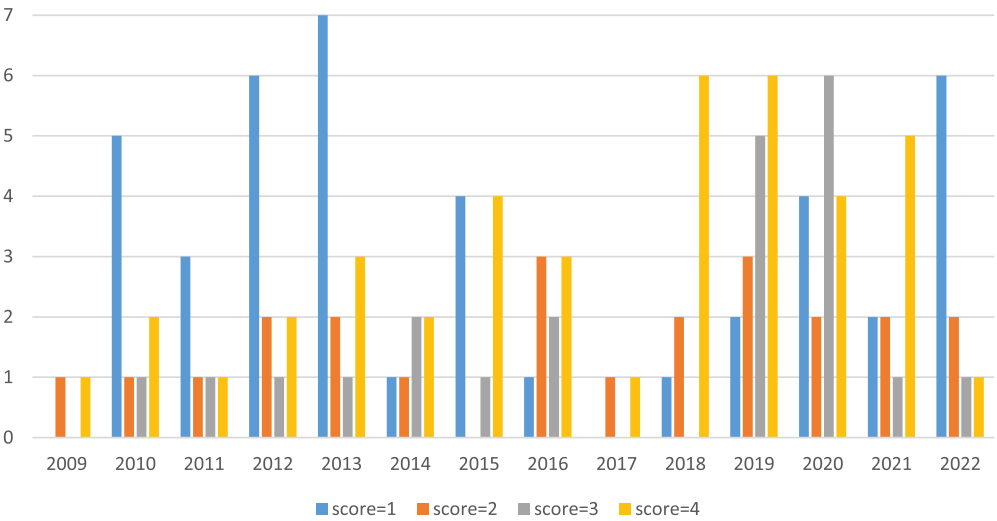


Figure 14. Trend in time of the number of papers vs. journal classes.

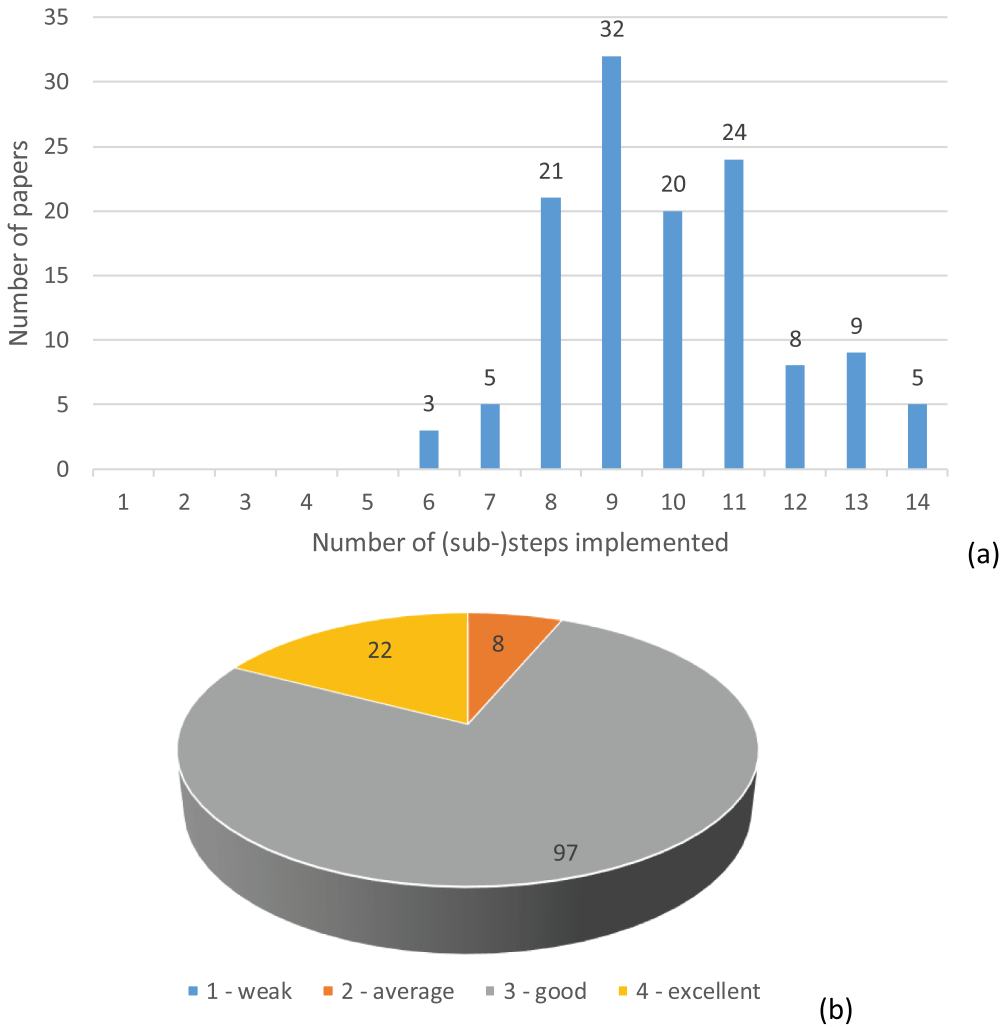


Figure 15. Distribution of the number of steps (a) and papers' classification by number of steps (b).

were classified as 'weak' with respect to their contents. At the same time, the full set of steps was observed in five papers only (3.9% of the sample); the 'excellent' class, including papers with 12 steps are detailed, accounts for 22 studies (17.2% of the sample).

A more detailed analysis (Figure 16) shows that some steps of the procedure by Manuj et al. (2009) have been (almost) universally implemented in the studies reviewed; this is the case for steps 1, 2 and 4. Other steps, i.e. 5.1, 7.4 and 8, have been detailed in a good percentage of articles (>90%). Moreover, although validation, as the process of determining whether a simulation model is an accurate representation of the real system, is a crucial aspect of simulation (Law, 2013), step 6 (model validation) has been detailed in approx. 65% of the studies only. By the way, Manuj et al. (2009) themselves have acknowledged that many studies in logistics and SCM report 'only a few' of the steps delineated in their approach, and noted, in particular, that the validation of the model is not frequently delineated. According to the same

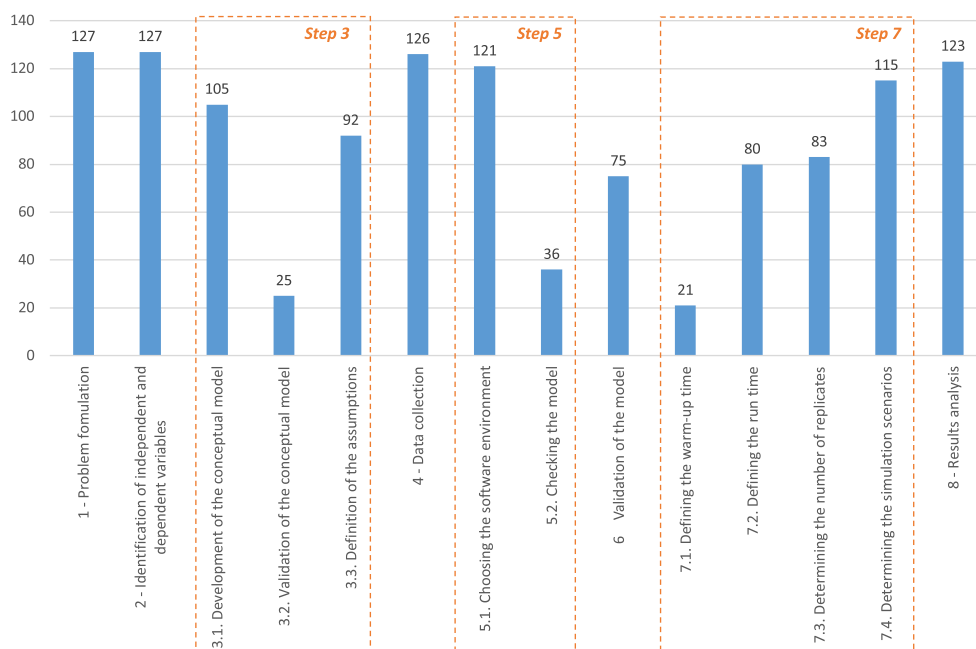


Figure 16. More popular and less popular simulation steps.

authors, another step rarely treated is step 3 (development and validation of the conceptual model). Outcomes of this study are only partially aligned with this consideration, because step 3 was divided into sub-steps for a more accurate analysis. More precisely, the attention paid by researchers to sub-step 3.2 turns out to be low, with only 20% of the studies reviewed addressing the validation of the conceptual model; on the contrary, sub-steps 3.1 and 3.3 have been typically addressed by researchers. Sub-steps 5.2 and 7.1 have been somehow neglected as well and have been detailed in 25% of the papers only.

Various explanations could justify these outcomes. A simple one is that the importance of the different simulation steps varies depending on the type of study carried out, resulting in some steps being not applicable nor the relating description strictly necessary, without compromising the validity of the study. It could also be conjectured that the rigor in the description of simulation model is crucial for some scientific journals only, and probably, to journals dealing with methodological aspects of simulation; on the contrary, other journals, less focused on the technical aspects of simulation, might not request the full details of the model development. This point will be tested later, by correlating the journal classification with the results in terms of paper contents.

Because the framework taken as reference in this study was published in 2009, it is also possible to conjecture that papers published immediately after that year have not taken into account the approach by Manuj et al. (2009), merely because of lack of knowledge of this study (cf. Table 2). Indeed, typically 2–3 years must elapse for an article to gain success among the scientific community after its publication (Fronzetti Colladon et al., 2020; Ioannidis et al., 2016). Therefore, the trend in time of the number of steps applied and of the score obtained by the papers was evaluated, to check whether later studies got a greater *TS* compared to older ones. Results (Figure 17) do not support this

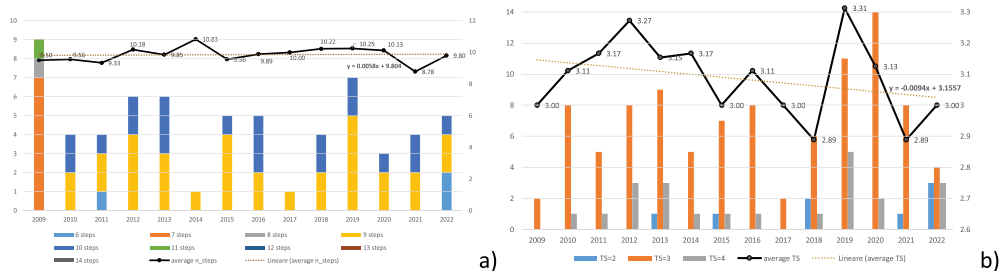


Figure 17. Trend in time of the number of steps (a) and papers' TS (b).

consideration, as no (positive or negative) trends in time can be identified for the number of steps detailed in the studies reviewed nor for the TS obtained for the papers. Papers classified as 'average' ($TS = 2$) and 'good' ($TS = 3$), for example, were found in almost all years of the timespan, with higher frequencies compared to the remaining classes. Similarly, 'excellent' papers span across various years (e.g. since 2010), without showing a prevalence in recent times. The lack of specific trends is also confirmed by the average value of TS (dark line in Figure 17b) whose range of variation in the timespan is very limited (from 2.89 to 3.3). These outcomes seem to suggest that overall, the approach delineated by Manuj et al. (2009) is not fully taken as a benchmark in simulation-related studies, but nonetheless, good quality papers exist.

In line with Table 2, it is reasonable to expect that the rigor of implementation of simulation studies will affect the possibility of a paper to be published in highly ranked journals. Indeed, a rigorous description of the contents in typically requested in highly ranked journals (i.e. Q1 journals or AA journals); otherwise, it would be relatively hard to have a paper published on prominent journals, as they normally have high rejection rates, and thus, the quality of the paper's contents must be particularly high to fit those journals. Results (Figure 18a–b) show that the percentage of journals in class AA or in Q1 increases when moving from $TS = 2$ to $TS = 4$, suggesting that a highly ranked journal is somehow likely to publish papers in which the rigor in the description (and therefore the implementation) of the DES model is high as well. However, the correlation between TS and the journal quartile does not appear to be significant ($p = 0.55$); a similar result is observed for the correlation between TS and the journal class ($p = 0.5$).

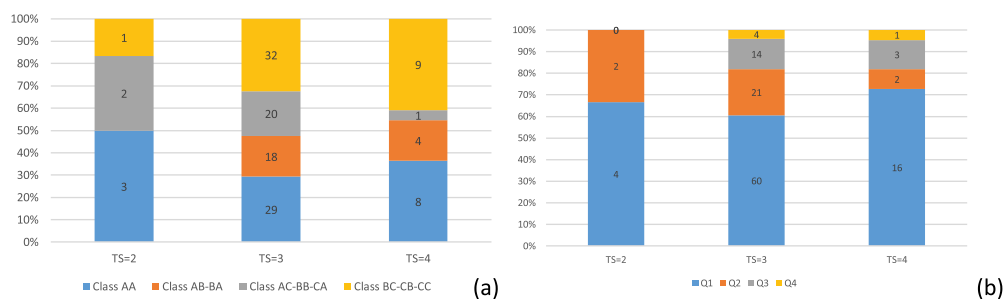


Figure 18. Paper's TS vs. journal classification.

6. Results: scientometric analyses

As mentioned in section 2.6, scientometric studies suggest that the success of a scientific paper, measured in terms of the citations received, depends on various aspects, including, among others, the authors' prestige and number, the journal characteristics and obviously, the scientific contents and quality of the manuscript. Starting from the last point, for the sample of studies under examination, the content quality has been measured with the *TS*, which reflects the rigor of the implementation of the simulation model; hence, the relationship between the *TS* and the citations/year received by the papers was first analysed. One paper was found to have a very high number of citations/year (>150), while all remaining manuscripts in the sample had less than 25 citations/year; hence, the outlier paper was excluded from the analysis for providing effective outcomes. Results (Figure 19) suggest a possible relationship between the *TS* and the citations/year received by the paper, which, however, is not statistically significant ($p = 0.48$); this outcome, therefore, does not fully support the consideration that being more rigorous in the description of the simulation approach leads to a greater success of the study.

Similarly, although a slight increase in time of the number of authors was observed among papers in the sample, this point does not seem to have any impact on the number of citations of the paper (Figure 20). However, this result could be partially biased by the fact that recent papers have slightly more authors compared to older ones, but probably have less citations, because of their newness.

On the contrary, the (average) score of the authors of a paper seems to be positively correlated with the citations received by the same paper (Figure 21). The observed correlation is also significant at $p < 0.01$. The same analysis was made on the maximum author score, obtaining a similar outcome, i.e. a positive correlation significant at $p < 0.01$. It can be concluded that writing a paper with highly ranked authors could be a strategy for attracting more citations.

As shown in Figure 22, a positive relationship (significant at $p < 0.01$), was also found between the author score and journal class, indicating that highly ranked authors are

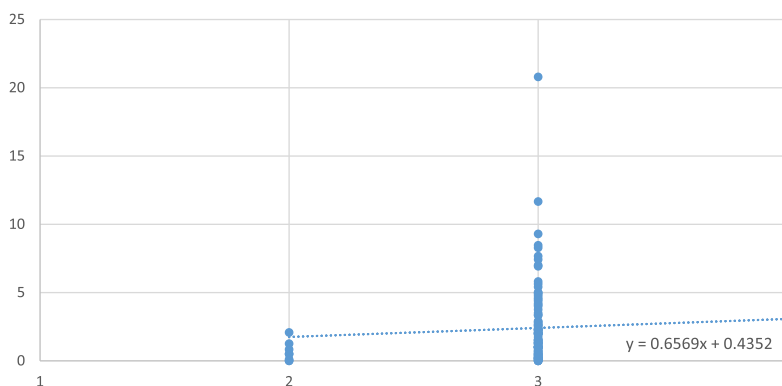


Figure 19. Citations/Year vs. *TS*.

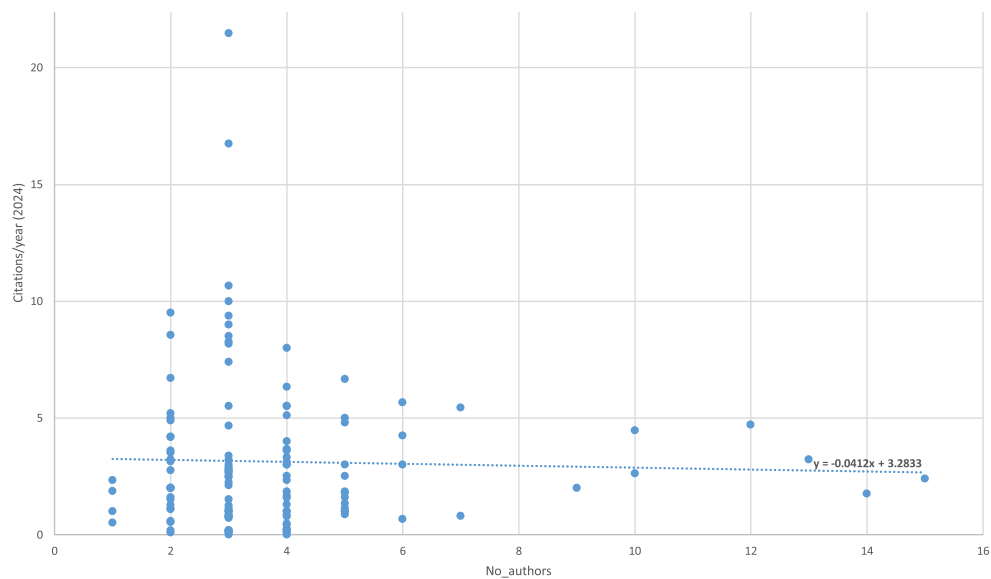


Figure 20. Citations/Year vs. number of authors.

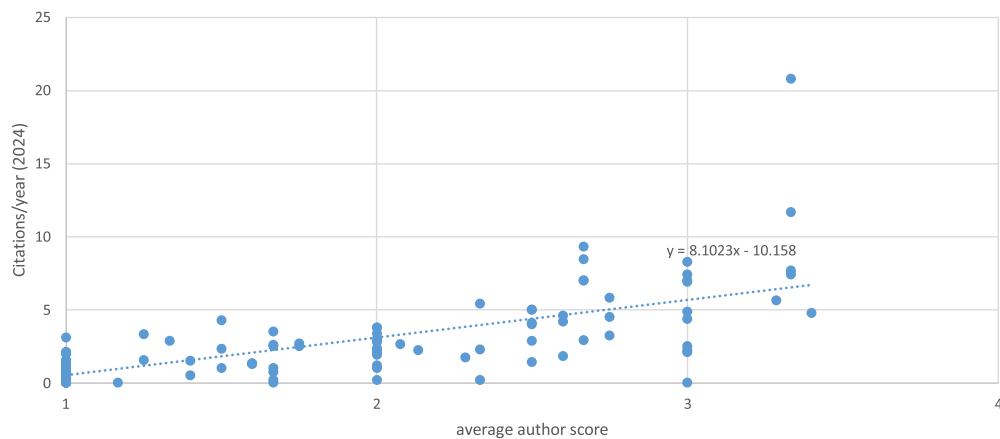


Figure 21. Citations/Year vs. average author score.

more likely to publish in top journals. This reinforces the previous consideration that writing a paper with top authors is a winning strategy.

As far as the relationship between the paper topic and its success, the average number of citations/year received was first computed for the different classes of keywords (Table 7), referring to the classification in section 3.2.1. Papers dealing with *well-established* topics have obtained an average of 8.11 citations/year. Supply chain disruption is the topic that attracted the highest number of citations, reaching >100 citations/year, followed by food supply chain with >75 citations/year. None of these concepts is new by itself, but probably, the outbreak of the COVID-19 pandemic (which is instead a relatively new topic, as observed earlier) led to an increase in the popularity some of

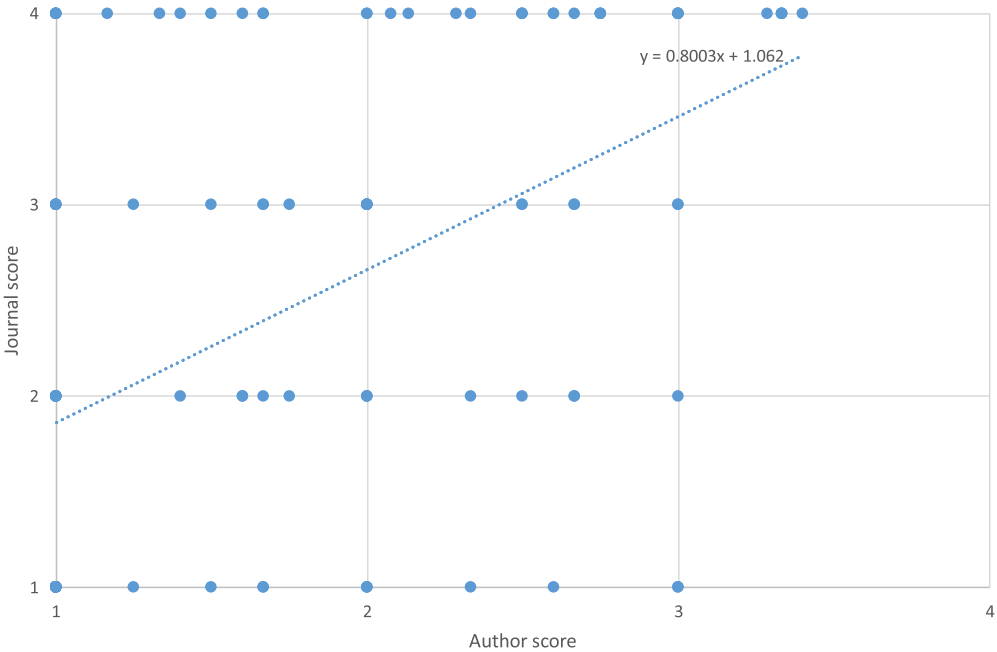


Figure 22. Journal class vs. average author score.

Table 7. Citations/Year vs. keyword class.

	Keyword class							
	Well established (n = 38)		Intermittent (n = 137)		Emerging (n = 173)		Trendy (n = 4)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Citations/year (2024)	8.11	19.91	2.50	2.78	5.56	16.31	24.91	36.54

these topics among researchers (hence the high number of citations). Indeed, the COVID-19 was a special case of supply chain disruption (Ivanov, 2020), and its impact on the food supply chain was one of the topics most frequently investigated by researchers (Hobbs, 2021; Rinaldi & Bottani, 2023). *Trendy* topics are few in number, but all of them had a considerable resonance in the scientific community, as demonstrated by the high number of citations/year received by the relating papers (24.91 on average, with a peak of ≈ 80 citations/year for Covid-19). *Emerging* and *intermittent* topics are more numerous but appear to be less relevant in the scientific landscape – which by the way is in line with the low frequency of these terms. More precisely, the average number of citations/year of papers dealing with emerging topics is 5.56, while papers dealing with *intermittent* topics have received an average of 2.50 citations/year. A peak of >20 citations/year was observed for the *intermittent* topic of food quality, confirming the relevance of simulation studies in the food supply chain.

The significance in the difference between the average values of the citations was evaluated by comparing the various classes through t-test.⁶ Results, shown in Table 8, clearly indicate that *trendy* topics attract more citations compared to other topic cate-

Table 8. Comparison of the average citations/year vs. keyword class and significance.

	Well established	Intermittent	Emerging	Trendy
Well established				
Intermittent	$p < 0.001$			
Emerging	$p = 0.164$	$p = 0.038$		
Trendy	$p = 0.050$	$p < 0.001$	$p = 0.005$	

gories, with a difference in the average number of citations received which is always significant at $p < 0.05$ (Field, 2005). *Well-established* topics also exhibit significantly higher citations/year compared to the *intermittent* topics.

7. Discussion and conclusions

From the outcomes presented in the previous sections, some remarks can be made. Looking at the research field, a first general consideration is that the usage of DES models in the logistics and SCM area has attracted increasing attention in the years, with >40% of the papers reviewed (51 out of 127) published since 2019; this confirms the timely relevance of this theme in the literature and implicitly, provides a justification for this study. Literature appears to be quite dispersed in terms of journals (85 sources for 127 papers), probably because none of these journals expressively focus on the specific topic of DES models in logistics, dealing, instead, with wider themes (e.g. simulation in general or logistics/SCM). The only exception seems to be the *International Journal of Production Research*, which published a quite relevant number of papers (7 documents). This latter journal also falls into the top class of the classification made in this study, as well as in Q1 according to the Scimago ranking; these categories were found to have been privileged in the recent years by researchers, suggesting that authors are paying increasing attention to the publication outlet. In this respect, it is to be mentioned that some countries expressively value the publication in top-ranked journals; this is, for instance, the case for the evaluation process of national research carried out in Italy, started in 2010, which still assigns parts of the research funds based on the outcomes of that evaluation (Abramo et al., 2020). Under these circumstances, it is to be expected that researchers target top journals for publishing their papers.

The set of analyses made on the authors also highlighted a fragmentation of the literature, with >400 different researchers who contributed to the topic under examination; moreover, authors have typically written one paper only, which reinforces the previous consideration. Most of the authors turned out to be classified as ‘weak’ according to the procedure followed in this study, which indicates that they are relatively new to DES modelling in logistics, either in terms of number of documents or of popularity of those documents. At the same time, it was observed that the average number of authors per paper has slightly increased in time; hence, it could be conjectured that some collaboration mechanisms among authors started being established, which is a possible indication of the progressive definition of this research area as an independent research field (Bontekoning et al., 2004; Koningsveld, 1987); it would be interesting to deepen this aspect in future studies to check the maturity level of the research field – this is an ongoing research activity of the authors of this paper (see (Habibzadeh & Yadollahie, 2010)). Obviously, other explanations, and in particular, the logics behind the enrolment

of academic people, could justify the increase in the number of authors per paper. Indeed, in some countries, authors are requested to reach a minimum number of publications for being entitled to apply for an academic position, and from a merely mathematical perspective, achieving this target is easier if the number of authors per paper increases.⁷ From the present study, no specific conclusions can be drawn on this point, because the sample of papers under examination is limited to a specific discipline and to a defined topic, which prevents the possibility of capturing a general behaviour of researchers. Future studies, with dedicated scientometric analysis, could confirm or contradict this consideration.

Looking at the topics treated in the sample of papers, keyword analysis showed that the core themes of logistics and SCM literature typically belong to the area of the *well-established* topics, thus indicating that these themes are also central to the field of research under examination. *Trendy* topics or *emerging* topics depict less debated themes, but with potential to become *well-established* in the next years, thus gaining popularity in literature. Indeed, the growth of a research field typically lead to higher average citation rates for new publications within the field (Sjögårde & Didegah, 2022); hence, these themes could be suggested as research topic on which researchers should focus their attention in future studies. Another symptom of the progressive maturity of the field is the increase in time of the number of unique keywords detected in various periods of the timespan. Indeed, next to a quota of keywords that are central to the topic under consideration and that were detected in the whole timespan, the presence of new terms has been observed in more recent studies. Most of the newly introduced terms fall into the *emerging* topics, confirming the progressive expansion of the targeted research field towards new themes. Obviously, it would be interesting to trace the evolution of the emerging topics across the next years, to check their persistence or decline.

As far as the rigour of implementation of DES models, this paper has first deepened the approach proposed by (Manuj et al., 2009), including some sub-steps which resulted from the review, leading to a detailed list of 14 phases for a rigorous implementation of a DES model in logistics and SCM. The evaluation of the paper rigor showed that, in general, the quality of scientific publications is good and has not significantly changed over time. Nonetheless, authors have paid attention to the description of some specific simulation steps, while other steps are rarely detailed in the studies reviewed. A logical consideration from this outcome is that, probably, describing all the steps of a DES model is not always essential; rather, depending on the specific study, some steps could be omitted without jeopardizing the quality of the paper, as well as its potential of being published on highly ranked journals. Taking a more general perspective, this outcome also implies that the study by Manuj et al. (2009) has not (yet?) been taken as guideline by researchers when developing and implementing DES models in logistics; otherwise, almost all steps suggested by these authors would be described by researchers. This consideration could sound strange, as that study expressively focuses on DES models in logistics, and it is, therefore, unexpected that studies in this field do not follow the procedure delineated by Manuj et al. (2009). Obviously, it would be desirable that the present study will encourage authors to look at that framework when developing simulation models, to further raise the quality of their research articles on DES application in logistics. Having said that, conjecturing an explanation for the non-use of the Manuj et al.'s

(2009) framework is challenging; the simplest consideration is that other studies are probably taken as reference by researchers when developing DES models in logistics or SCM. However, this point has not been deepened in this paper and is left for a dedicated evaluation in future studies.

As far as the success of the papers, in terms of the citations/year received, a summary of the findings from the scientometric analyses is provided in [Figure 23](#).

As can be seen from this figure, the citations received by a manuscript were found to be positively correlated with the topic treated and the author score; in turn, the author score exhibits a positive correlation with the journal score. Taken together, these outcomes suggest that to enhance the potential of publishing successful papers, a winning strategy is to carefully select the topic to be investigated. Trendy topics, in general, are expected to be few in number: in the sample of studies reviewed, four trendy topics only were found (i.e. decision support systems, Covid-19, remanufacturing and Industry 4.0). This makes it easy to recognise successful areas of research, which helps precisely identifying the currently under-studied domains and consequently directing research studies towards the relating themes; also, trendy topics proved to have the highest potentials to attract citations, with significant differences with the remaining topic classes, and thus can lead to successful papers. It is also easy to see that none of the trendy topics found refers directly to the simulation area; this implies that, obviously, simulation is to be seen as the tool for studying the selected trendy topic, rather than as the core theme of the paper. Working with authors recognised in the field of DES modelling is a second important aspect for enhancing the success of the paper; therefore, establishing collaboration mechanisms with recognised research groups in this field is suggested. Highly ranked authors also are more likely to publish on highly ranked journals, which is always desirable and is a typical target of researchers.

Looking at the non-significant correlations, this study has not demonstrated the existence of any relationship between the rigor in the implementation of DES model (*TS* of the paper) and likelihood of having a paper published in highly ranked journals. This relationship was somehow expected, and in fact has been partially observed, but without statistical significance. This could be due to the limited number of papers in the sample, which prevented the possibility of capturing differences in the paper rigor among

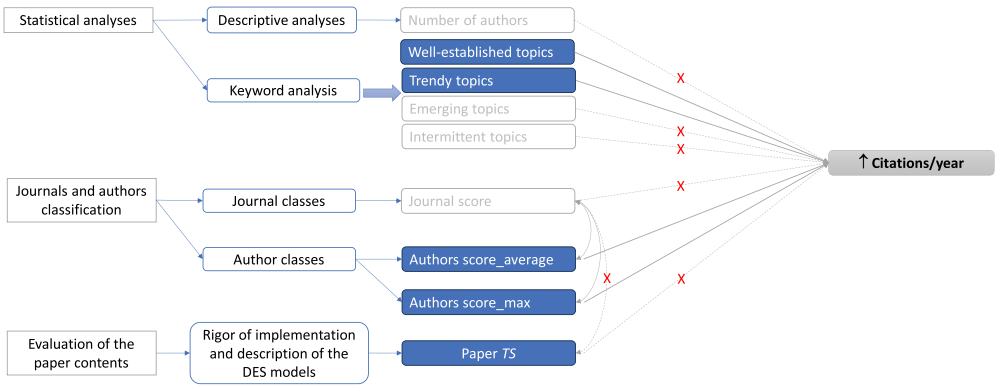


Figure 23. Summary of the analyses and results.

the different classes of journals; this is exacerbated by the fact that most of the papers reviewed are actually published on Q1 journals, while other classes are significantly less numerous. A more specific analysis of these aspects is therefore left for future studies. Similarly, despite the progressive increase in the number of authors per paper, no relationships were found between this aspect and the success of the manuscript in terms of citations, as instead suggested in scientometric studies (Fronzetti Colladon et al., 2020). This could be due to the fact that in engineering studies, the number of authors per paper is in general low, and thus, it is difficult to capture differences in the success of the paper as a function of the number of authors. An alternative explanation could be that more recent papers are likely to have more authors (because of the increasing trend in the number of authors per paper) but are also likely to have less citations (because of their newness). Again, a more focused analysis of this aspect is left for future studies.

Compared to the available reviews on DES modelling in logistics and supply chain, it is evident that the present study takes a different perspective, thanks to its scientometric view and as such, it contributes to the literature by highlighting aspects that have never been captured in the previous research. Besides the suggestions made while commenting on the results of this paper, other recommendations for future research could be derived. As an example, additional variables that are recognised as predictors of the paper success could be analysed, to derive additional guidelines for prospective authors; this is the case for some characteristics of the manuscript, such as the document length (Bornmann et al., 2014), the title length (Habibzadeh & Yadollahie, 2010; Jamali & Nikzad, 2011), or the usage of a particular language when writing the title (Rostami et al., 2014). Also, the same analysis made in this paper could be repeated for a difference branch of simulation (e.g. SD, which has been frequently compared to DES modelling – Tako et al. (Tako & Robinson, 2012)) to check whether the results obtained in this study remain valid. Finally, authors are currently working on a wider scientometric study of DES models in logistics, in which the sample of papers is larger and was obtained without setting any timespan for the Scopus query (Bottani & Casella, 2024a). Such a study could be effective in capturing the complete evolution of the topic and in fully evaluating its scientific maturity, thus offering deeper insights on the DES model in logistics.

From the set of considerations above, it is evident that the contribution of this paper is mainly scientific, which is in line with the inherent nature of a scientometric study; practical implications, instead, are more limited, even because of the technical aspects of the DES models were not explored while analysing the studies. Therefore, some future research directions could also be delineated in this respect; for instance, mapping the technical details of the DES models or the benefits achieved when using these models could be useful to practitioners, for understanding the potential of DES usage in logistics and SCM, and complementing the results of this study.

Notes

1. <https://www.scimagojr.com/>
2. <https://www.scimagoir.com/methodology.php>

3. For the full list of subject categories: https://service.elsevier.com/app/answers/detail/a_id/15181/supporthub/scopus/
4. A note in the database was added to the corresponding column to highlight this particular situation.
5. The choice of assigning one point to each step was made in line with other studies available in literature, e.g. who used a similar approach to rank survey studies carried out in the operations management literature. We acknowledge that, depending on the kind of simulation study, some steps do not necessarily need to be taken, or could be less important; however, it is hard to take this aspect into consideration when analysing different manuscripts, and this is why the same importance has implicitly be assigned to each step.
6. incorporating the Bonferroni correction, because of multiple comparisons with the same set of data.
7. Again, as an example, this could be the case for Italy, in which the scientific qualification mechanisms forces candidates to reach a minimum number of publications (cf. <https://www.anvur.it/attivita/asn/asn-2018-2020/indicatori-e-relative-soglie/>).

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Data availability statement

Data openly available in a public repository that issues datasets with DOIs. The data that support the findings of this study are openly available in (Bottani & Casella, 2024b).

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Appendix

Table A1. Frequency of keywords and year of appearance (extract of terms with frequency ≥ 2).

Keyword	Frequency	Persistence	Year of first appearance	Class
Sustainability	9	15	2009	well-established
Inventory control	9	15	2009	well-established
Transportation	9	14	2010	well-established
Closed-loop supply chain	8	14	2010	well-established
Optimisation	8	13	2011	well-established
Distribution management	8	14	2010	well-established
Reverse logistics	6	14	2010	well-established
Agent-based modeling	6	9	2015	well-established
Supply chain networks	6	10	2014	well-established
Humanitarian logistics	5	10	2014	well-established
Retailing systems	5	13	2011	well-established
Decision support systems	5	6	2018	trendy
Design of experiments	5	15	2009	well-established
Bioenergy	5	13	2011	well-established
Lean supply chain	4	9	2015	well-established
Food supply chain	4	12	2012	well-established
Environmental management	4	14	2010	well-established
supply chain design	4	14	2010	well-established
Multimodal logistics	4	13	2011	well-established
Facilities location	4	11	2013	well-established
COVID-19	4	3	2021	trendy
Energy	4	12	2012	well-established
Modeling	4	11	2013	well-established
Immunization	4	12	2012	well-established
Warehouse management	4	8	2016	well-established
Blood supply chain	3	11	2013	well-established
Biofuel	3	13	2011	well-established
Remanufacturing	3	6	2018	trendy
Case study	3	9	2015	well-established
Biomass	3	10	2014	well-established
Construction industry	3	13	2011	well-established
Order picking	3	8	2016	well-established
Container terminals	3	12	2012	well-established
Returnable transport items	3	14	2010	well-established
Forest biomass	3	13	2011	well-established
Risk	3	12	2012	well-established
Healthcare supply chain	3	9	2015	well-established
Supply chain disruption	3	10	2014	well-established
Hybrid methods	3	11	2013	well-established
Vaccine supply chain	3	11	2013	well-established
Industry 4.0	3	6	2018	trendy
Bullwhip effect	3	14	2010	well-established
Truck	2	5	2019	emerging
Supply chain logistics	2	5	2019	emerging
Response surface methodology	2	11	2013	intermittent
Digital twin	2	4	2020	emerging
Supply chain simulation	2	11	2013	intermittent
Disassembly	2	4	2020	emerging
Business process	2	13	2011	intermittent
Drugs management	2	8	2016	intermittent
Scenario analysis	2	13	2011	intermittent
Economical analysis	2	14	2010	intermittent
Blockchain	2	4	2020	emerging
Emergency readiness	2	4	2020	emerging
Terminal	2	8	2016	intermittent
Anylogic	2	11	2013	intermittent
operations management	2	11	2013	intermittent
Fuel supply chain	2	6	2018	emerging

(Continued)

Table A1. (Continued).

Keyword	Frequency	Persistency	Year of first appearance	Class
pandemic	2	3	2021	emerging
Geographic information system	2	6	2018	emerging
agent-based simulation	2	5	2019	emerging
Health information systems	2	8	2016	intermittent
Shelf life	2	12	2012	intermittent
IBSAL	2	13	2011	intermittent
Supply chain modelling	2	3	2021	emerging
Last-mile distribution	2	6	2018	emerging
supply chain resilience	2	3	2021	emerging
Value chain	2	11	2013	intermittent
Supply disruption	2	5	2019	emerging
Multi-objective optimization	2	9	2015	intermittent
Trade-in	2	4	2020	emerging
Nanostores	2	6	2018	emerging
Natural calamities	2	4	2020	emerging
Vial size	2	9	2015	intermittent