



Module

Dissertation [ACFA7003]

Dissertation Title

*"Circular economy as a driver to sustainability
in aircraft cabin interior [seating system]"*

Course

MSc Industry 4.0 Advanced Manufacturing

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Date : 28th February 2024

Declaration

I certify that the work in this dissertation was completed in compliance with UWTSD guidelines. The dissertation has not been submitted in part for any other degree, and all work is original except as noted by special references in the text.

Any views expressed in the dissertation are those of the author and in no way represent those of the UWTSD.



Signed

Date : 28th February 2024

Abstract

The circular economy's simple tag line " Everything is healthy food for something else". In other words, running an economy is like our nature runs its own business, nothing is wasted and we can say it's a closed-loop system. CE can provide tremendous support and is significant to society to lead in a direction for a more sustainable and ecological environment. In contradiction to using a product and then discarding it is reuse, remanufacturing, and recycling important pieces, where materials are not systematically leaving the loop. But what should these actions and business models be for company in the aircraft manufacturing industry has been addressed in this dissertation.

The Report explores the challenges and opportunities while implementing this sustainable approach of CE into the lifecycle of the aircraft seating industry. By implementing an approach to reuse, recycle, and CE strategies with the aerospace market in pursuit of sustainability goals. This research follows the literature review which defines the existing state-of-the-art in line with material, process, and improvement methods for developing products for global use.

Methods for sustainability to reach circular economy studied which also shows areas of improvement, current and future scenarios with quality standards. Methodological reviews and various industry 4.0 applications are taken into account to support this technology. This dissertation referred throughout with different seating industry, which have adopted this technology and gained success. This study is also captured in detail for such implementation in new aircraft seating organizations, which are at their initial stage. The approach of the circular economy strongly supports the execution of an adjusted aircraft ownership model, focussed on leasing and the concept of “aircraft-as-a-service” which is introduced and described.

The outcome states there are various benefits to CE. Reduction in carbon emissions to benefit society ecologically and to the company economically. This will lead to sustainable products with feasible alternatives. However, research shows that there are many considerations, actions, and challenges that companies must overcome. Implementation of industry 4.0 applications in existing industry has been captured to get insight of it.

Moreover, building on this research, future work will attempt to offer a more thorough examination of the less-discussed sections. Additional research on the Automotive and Rail industry has been captured to understand the product and design methodologies. Also will collaborate with funding sources. agencies, consultancies, and organizations to serve as direct contacts for businesses that are prepared to start such a project.

Further based on the various case studies captured during research and the comparison of different seating industries the conclusion is structured in subparts which cover the Co2 emission analysis, sustainable approach towards sustainability, People role implications, Interpretation from the Railway industry, Recommendations and finally the finding based on the qualitative analysis has been captured.

Acknowledgement

I gratefully acknowledge the generous help and support of the following during my work on this dissertation study.

The businesses across Wales, specially Safran seats GB who have taken the time to show me around their facilities and share with me the details of the challenges they face and the opportunities they wish to take. MADE cymru for excellent support for this MSc program.

The many colleagues from my organization & friends who have supported my work during this study and offered insights into the activities of aircraft seat manufacturers.

"Mr. Alan Mumby", lecturer, and dissertation tutor throughout this period of study. He was always available to help with all my questions & provided great guidance throughout my study. He has contributed to sparking my interest in circular economy.

I express my gratitude to all those who agreed to be interviewed and responded, since it helped me with my job.

Finally, I would also like to thank my wonderful wife "Sonali" for her constant support, patience, and motivation. Without her, I wouldn't be here or in fact anywhere.

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List of Abbreviations

AM	Additive Manufacturing
CE	Circular Economy
DE	Digital technologies
CE	Circular Economy
DT	Digital Twins
MFSD	Methods for Sustainable Development
OEM	Original Equipment Manufacturer
PET	Polyethylene terephthalate material (PET).
PaaS	Product as a Service
SD	Sustainable Development
ENT	Engineering and technologies
MU	Manufacturing units
FAA	Federal aviation Administration

Chapter 1: Introduction

1.1 Research Background :

Circular Economy is a restorative system that is in itself self-sustainable and where materials in the system are not discarded systematically. The goal of the CE is to always strive towards using materials at their highest value at every step of the process. This means min material waste & includes all parts of a product's life span from the design, production, distribution, usage, and recycled phases.

([Domone, J & Copus, M. 2021](#)).

With reference to the Aero expo information there are many aircraft seating industry, which works on wide range of producing there product to meet the sustainable approach. Circular Economy is a new research area for these seating industry as a manufacturer to approach sustainability and this project report will provide valuable insight into what impact the implementation of Circular Economy could have on seating products ([Aero Expo, 2023](#)).

The circular economy idea and some of its tactics in aerospace industry are shown in the figure.1 below. (Min waste, Min raw material & lesser emission)

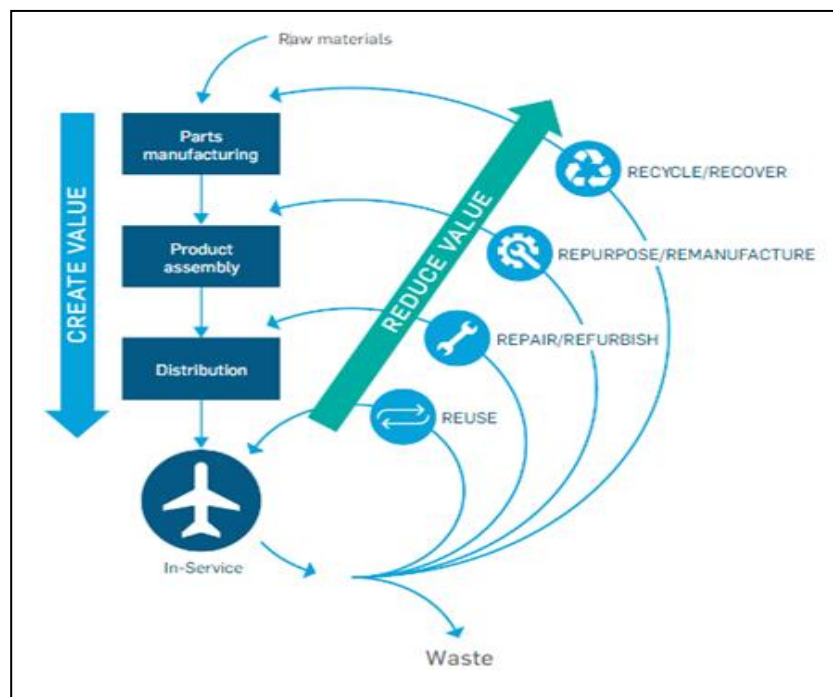


Fig 1: Circular economy model

Source: (Domone, J & Copus, M. 2021)

1.2 Purpose or Aim :

Aerospace seating companies as per the aero expo and the reference from few are in the first phase of investigating Circular Economy (CE) in order to see if it could be used to benefit society ecologically and economically ([Seating, 2003](#)).

The Aim of the dissertation is,

- To find existing processes, identify problems and introduce the concept of Circular Economy within the organization, as the company's has an ambitious policy to support the transition to carbon-neutral aviation by 2050 ([Shraeya Mithal, 2023](#)).
- To study existing case study's and analyse the implementation for the upcoming seating industry to become successful.
- It's worth investigating because the circular economy can play a critical role in solving complex challenges such as climate change and biodiversity loss.

1.3 The research question for this master project will be :

What are the challenges and opportunities when implementing this sustainable approach of Circular economy into the lifecycle of their products in the aircraft seating industry?



Fig 2: Research question

Source : General Representation for Google to specify Multiple questions

1.4 Objective :

By reviewing the literature in the relevant fields, giving a consistent case study throughout, and comparing the results to the literature, the dissertation's objectives will be met. The aircraft cabin design is most of the time matured and fixed as per the airline's restrictions. The below task are considered under specific objectives. According to the ref ([Velte and Steinhilper, 2018](#)) .

- Weight optimisation by appropriate material selection & its specifications.
- Inspect new technique by changing the manufacturing process..
- Investigate cabin interior as it is the most difficult part to perform a circular economy to minimize the impact of new technologies & product development by implementing CE.
- Define full-life strategies to minimize product impact & total lifetime maintenance.
- Explore the concept of Sharing, reusing, repairing, and leasing. As, product Service System is a useful concept for aiming toward sustainability. The focus is to keep the life cycle of a product or material in a closed loop.

1.5 Justification :

One can justify the term sustainability by equity and efficiency as ethical axioms. Regulations and customer perceptions of the impact products are evolving in an uncertain moment for sustainability. Manufacturers must seek to control their Co2 footprints in areas where the environmental effects of their operations are becoming more apparent, either by design improvement methods or manufacturing methods for their products. Any unusual- change will carry risks but this change is very important to save our planet from being irreversibly damaged. Previously, changes in material & recycling plastics were implemented in various sectors to reduce CO2 footprints. Info reference ([Geir, B. 2002](#)).

This dissertation goes beyond and provides details about the implementation and commercializing of such a project for beginners' organisation. Also included a consistent case study of a recently finished or approved project, which offers insightful information that other businesses can connect with.

1.6 Methodology :

In terms of methodology, a broader variety of literature sources, including books, journals, case studies, and scientific papers, will be used. This dissertation explores the different example from different sources to learn more and get detail information. Each part will talk about the research and followed by the study, what seating organisations did to become successful and outcome of their learning's form it. Seating info captured form the company website ([Safran group, 2024](#)) .

Below points highlighted for reference.

- HOW: The research process followed is qualitative research with sources from the company sites those are new to CE and present development projects in sustainability. Also to have an in-depth analysis, a few case studies and interviews within the group and suppliers will be captured with some analytical data for part lifecycle. Scope of interview were discussed prior to interview and concern about personal information were considered & kept optional.
- WHY: This method helps generate hypotheses as well as further investigate and understand quantitative data. This research method also gathers participants, experiences, perceptions, and behaviour. Management feedback and their thoughts captured which will help to explore this topic & will make it more interesting. This research will compare the aerospace and locomotive (Rail) industry to capture the seating difference and further analysis for sustainable product achievement is explored.

1.7 Ethical principle :

There are some consideration which need to be addressed about what is right and wrong when making choices. The sensitive information about other organisation in terms of their design to achieve sustainability will be referred in general terms. Their privacy and confidentiality is maintained. As this piece of work is based on literature review & with the help of resources, information is been studied and referenced appropriately. So that it doesn't copy's someone work. Below figure shows safeguarding sensitive information which needs to be taken into account . The personal identity is taken care and permission was taken prior to transcript the data into appendix section ([Licenik, R. et al. 2013](#)) .

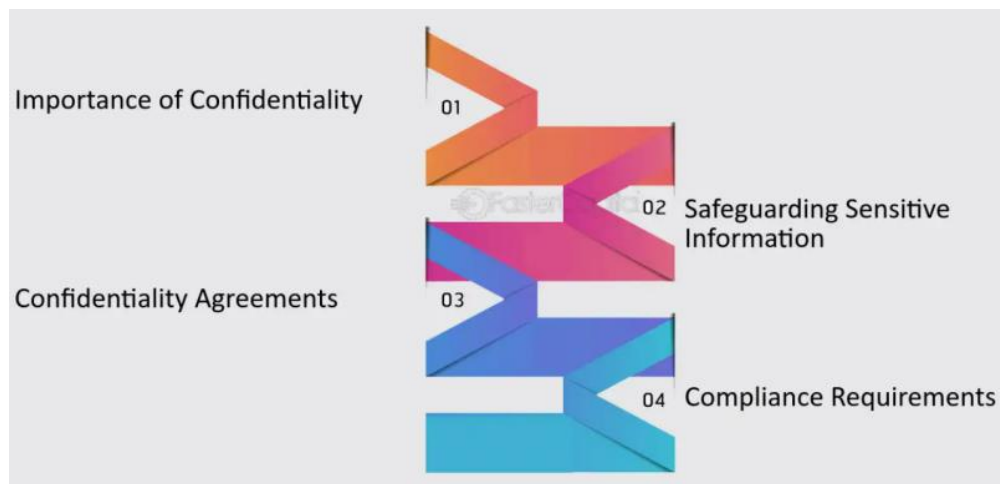


Fig 3: Safeguarding Sensitive info

Source : (Licenik, R. et al. 2013)

The Ethical principals are :

- | | | |
|-----------------|-----------------------------|----------------------------|
| 1. Honesty | 7. Accountability | 13. Respect for Colleagues |
| 2. Objectivity | 8. Intellectual property | 14. Social Responsibility |
| 3. Integrity | 9. Confidentiality | 15. Legality |
| 4. Carefulness | 10. Responsible Publication | 16. Animal care |
| 5. Openness | 11. Mentoring | 17. Human subscription |
| 6. Transparency | 12. Non Discrimination | |

Chapter 2 : Literature Review

2.1 : Introduction

This passage explains the consideration points and further its necessity as a part of this dissertation ([Morley J, 2021](#)).

The impact of aviation on climate change is significant and growing. Other industries can reduce their carbon dioxide emissions more quickly because they frequently face fewer obstacles to change. The industry must consider non-operational variables such as resource consumption and waste generation, maintenance, aircraft disposal, interior furnishings, and aircraft operation to control its share of CO₂ emissions. Strategies for minimizing the non-CO₂ effects provide a big role in minimizing aerospace climate change. The design of recycled cabin components with advanced materials will control the CO₂ emission. As a result, this topic explains the main effects of circular economy strategies across several company domains that support the direction toward green business operations ([Murillo B, 2021](#)).

2.2 : Its necessity

Through the integration of the values of the circular economy into the layout of product structures, facilities, and other types of physical features, it is possible to mitigate greenhouse gas emissions. Also, simultaneously establish safer, more productive, and user-friendly neighbourhoods specified in stated ref ([Qi, C. and Shen, X.L. 2013](#)).

2.3 : Topic trends & values

The Circular Economy (CE) initially emerged in literary works in the first decade of the 1990s and continues to gain acceptance across scientific, establishing policies & along business communities ([Okorie, O., 2018](#)).

Academic investigations have additionally revealed a noteworthy prospect for using circular methodologies in our fast-developing industrialized framework, covering production procedures. Also, like Industry 4.0 (I4.0) which through data is facilitating the most recent progress in the field of digital technology (DT) ([Okorie, O., 2018](#)).

2.4 : Existing state-of-the-art in line

CE is a tool for addressing environmental issues and advancing environmentally friendly growth. The start of the art in aviation interior is currently using eco-composite in their product. The Eco-composite material is usually made from natural or recycled ingredients. The synthetic fibre in airplanes can be replaced with this. Also, versatile material made from carbon fibre can conduct electricity & used to protect the aircraft from lightning damage while in service. ([Soutis, C. 2015](#)).

2.5 : Findings

From the review, it has been observed that the CE is an important tool. This has to be considered for environmental growth. The selection of appropriate material can reduce the Co2 % and make the product more lighter. Advanced industry 4.0 applications will help to minimize impact and minimize lifetime maintenance. The recycling plays an important role to reuse the waste material. The recent study found that there are many organisation like AFRA which is leading industry dedicated for best environmental practise and sustainable development as well as recycling the parts ([AFRA, 2014](#)).

Apart from the aero industry other sectors like Locomotive & Automotive industry were also studied further, which will give a better idea while comparing the products and their technologies. This can also give an insight about their implementation, methodologies and ideas that can be shared for further sustainable product development in Aircraft seating systems.

Chapter 3 : Methodological review

3.1 : Introduction

As noticed in business studies there is a specific investigation process for qualitative research projects. This consists of various sources and sites which are companies, organizations, and universities for data. The goal of the review is to evaluate, locate, and compile the findings in an organized manner as per ([Eriksson, P 2015](#)).

The process of this research is divided into following steps as listed below.

- The initial first two steps are the data collection. This process includes resources for data, interviews and observation. The resources for this dissertation is for example : Documents, research papers , academic, companies papers and other literature review.
- Practically research is not straight fwd. It needs to go back or previous steps to understand the problem and refine it to continue with different approach as per ([Eriksson, P. 2015](#)).

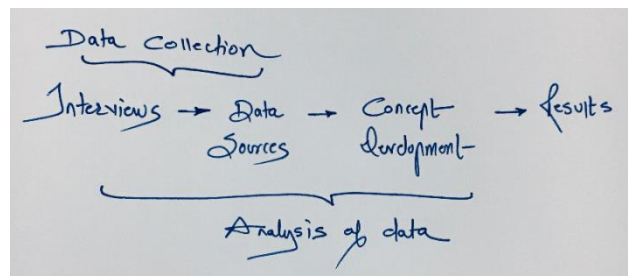


Fig 4: Research processes

Source : Image captured form hand written notes

The first phase of research is done with pre-study including interviews for mainly gathering the data. Interviews were conducted with our regular employees and the higher manager to get overall ideas about people's thinking. Question based on general ideas about CE with an open forum. During the procedure of the question and answer session. notes were captured and engaged with the interviewee to transcribe the whole discussion. The research method followed is qualitative which is done to identify the potential need. This methods

(interview, Observation, and focus groups) are the common method for qualitative research in the pre-study ([Joanna Chrzanowska, 2010](#)).

3.2 : Source used in research

The collection of data includes both literature review and interviews. Many topics were searched on internet, research papers and academic books that help to understand the topic and research problem studied ([Ghauri, P. 2020](#)).

3.3: Qualitative data research

To identify the potential needs, gathering the data from the interviews was the first task of this qualitative research. Initially, the people interviewed were the company's or OEM (Original Equipment Manufacturer) internal employees who are into manufacturing of seating components. These employees were from different backgrounds at SAFRAN. The higher managers and employees had different experiences and were having different experiences other than the aero industry with their wide experience in respective departments. The important dept considered were ENT (Engineering and Technology), MU (Manufacturing unit) and aftermarket design.

The main purpose was to gain as much as information possible from various prospective. To get an insight into the company the data gathered from the interviewing employees helped to understand the complexity of the business. Form interview information about product lifecycle and further the potential problems were investigated. Some examples of questions are captured in appendices for reference. Refer to page 80 in appendix section.

The questions asked in the interview were unstructured which means they are not very systematic. This was to get more information about the product and its processes. The purpose was to get their opinions and personal experience in CE concepts and oncoming technologies ([Ghauri, P. 2020](#)).

Analysis was done based on the interview. There were few interviews conducted. The average age of the members was around 28 to 45 years. The people interviewed had a direct relation with manufacturing organisation. The data was divided into two groups: R&T was the one and another product development. while others were non-technical without a manufacturing background. Before conducting the interview, the purpose of the interaction was discussed, and let them know that it going to be transcript for reference. The use of their personal information is kept optional. The discussion was noted and further transcribed with their comments and segregated as per questions and highlighted in the Appendix section from Page 80 of this dissertation. The below graph shows people who responded in line with the transportation industries. There preferred options were captured in terms of seat comfort and long distance travel.

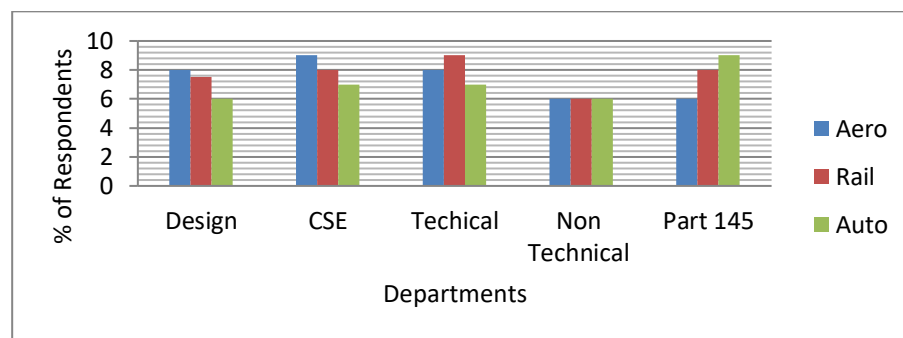


Table 1: Department Distribution

Source : Graph developed from hand written transcript

3.4 : Potential Issues and findings

In qualitative studies, the two main ethical issues include security and the researcher's function as a tool for gathering material. In this approach, much time was spent gathering data from different people's thinking. Interacting with people was excellent but a bit time-consuming. With ref to the interviews & people's thinking, it's been observed that the biggest barrier to a circular economy is financial support, setting up the supply chain system, customer behaviour, and redesigning the complete products. (Refer to the Appendix sub-section on page-80 for people's responses).

Chapter 4 : Role of Industry material in climate change

4.1 : Introduction

It is important to create a plan for making things work better and can last longer. During the design phase, it has been observed that more than 80% of a product has an impact on the environment. In the past, not much attention was paid to selecting the material as per need and being able to use the things or product again and again in the future. Also, make sure to upgrade them as time passes. This means that there is a situation today where a few steps could have a big positive impact on the environment of aircraft cabins.

4.2 : Current Approach / Linear economy

Historically, the world economy has operated on a take-make-waste linear methodology, which means that goods are collected, and utilized a single time, followed by thrown away as trash. This strategy has resulted in significant ecological impacts like emissions, global warming, and decreases in biodiversity in addition to broad shortages of resources. The below fig shows the linear process followed from take to waste. Humans depend on natural resources for economic growth. More growth leads to more consumption of natural resources.

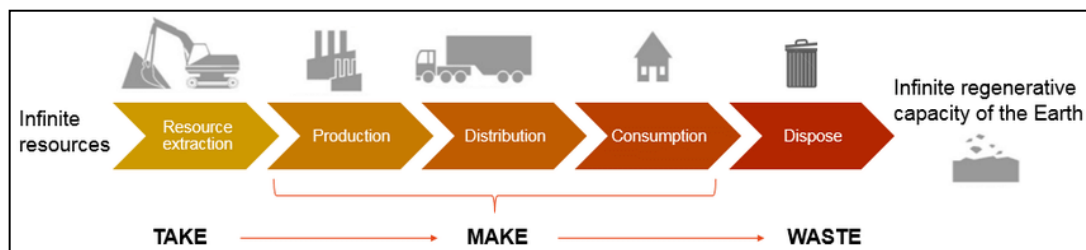


Fig 5: Current Linear Economy

[Source : \(Ncibi, MC. 2019\)](#)

A simple example to understand the existing linear economy in mathematical learning can be described. Let's say $A=B$ and $B=C$ then it's only logical to conclude that $A=C$. In short the thought process is famous for its logic that the distance between the two points is a straight line [\(Ncibi, MC. 2019\)](#).

4.3 : Aircraft lifecycle Current approach

From the beginning, the industrial aviation sector has grown out of a linear economy in which the utilization of natural resources is a key factor in determining the economic value of products such as spare parts and aircraft. The individual who owns the airplane typically keeps it in operation for the duration of its service life by buying new parts for malfunctioning ones. The product was often discarded as trash after its useful life came to an end. This method was predicated on the idea that reuse and recycle had little value and that labour costs were high and cheap material costs. But raw resources are becoming more expensive and there is a limited supply. The end-of-life phase of the aircraft was long neglected, and they were frequently just kept in as shown in fig below . This photo captured for reference from well known site in Arizona. Recently the end of life aircraft is chanelled to recycling organisations who use the material for other application ([Shraeya Mithal. 2023](#)).



Fig 6: Bone yards Pinal Airpark in Arizona

Source : ([Media wiki, 2024](#))

4.3.1: End of life process

This section describes the existing process followed when an aircraft comes to its end of life. Understanding this will give us insight into how work has been carried out and the efforts to sort the parts in different sections for proper recycling. Recycling plays an important role in slowing down the use of natural resources and leads us toward a circular economy.

The airplane is mainly segregated into two different phases.

The first one is to list and take out the parts that can be used in other aircraft subject to all regulations and standards. In terms of certification, the old aircraft is still certified as per the information gathered from the reference ([Sabaghi, M. et al. 2015](#)) .

In the second phase, the aircraft is dismantled and recycled. when the aircraft is dismantled the certification is no longer available with it. This is the general process but a systematic approach in a well-organised organization would be where the dismantling process is carried out as per owner acceptance and decision. Technical and valuable parts removed from the airplane will be returned to the aviation office with some repairs on it and then returned to service. This is performed with documentation and authorized personnel ([Yang, YN; Keivanpour, S; Imbeau D, 2013](#)).

Dismantling is focused on component level separation which involves cutting and shredding of fully disassembled parts. The material is not traded as second-hand aircraft as this operation is not undertaken by any maintenance organisation. Furthermore, the track of dismantled material is kept to reduce the damage to the environment. The dismantling process involves the separation of aluminium which can be recycled up to 60% & non - recyclable polymers and composite material. The recyclable is segregated into different alloys and being tracked. On the other hand un-recycled items are delivered to landfill. Which is also been documented.

Chapter 5 : Circular Economy

5.1 : Introduction

The economy can be explained in two principles which can be Linear or Circular. As described in earlier section 4.2 (page 22) the linear system is a system that takes the form of the resources and is disposed of. This is the way that current manufacturing companies work. Many studies emphasize that the linear way is not sustainable as compared to the circular economy. Numerous areas can benefit from a CE. One of the method of keeping the part in circular loop is additive manufacturing which is explained in further chapter 6.2 (page 33). The design method like cradle to cradle is great approach for CE. The value of the product gets degraded when it is wasted. The principle of CE is to use this material in continuous cycles, minimum natural processes, and minimize waste. Performing this will increase the product value ([Lieder, M. and Rashid, A. 2016](#)).

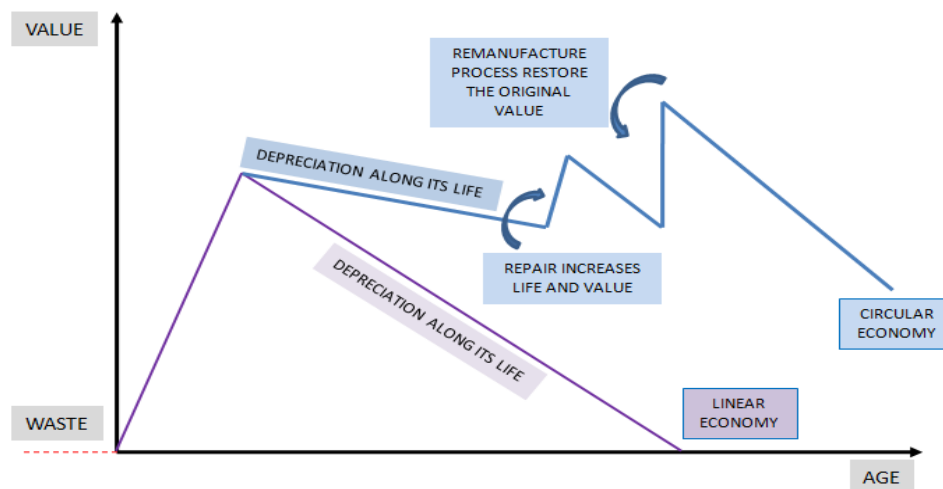


Fig 7: Product life in Linear and Circular economy

Source : (Lieder, M. and Rashid, A. 2016)

Cradle to Cradle design led to the creation of an industrial system that was entirely beneficial when the environmental, social goals and positive economic are pursued. There are two types of metabolism which are biological metabolism and technical metabolism.

This Cradle to Cradle design provides a framework that creates goods and processes that convert the raw material into nutrients. The best example is captured in the Appendix section 11.4 (Page 62), which shows the existing application in the automotive industry. This example supports achieving sustainable material that leads towards the circular economy.

In addition to the materials that are built from natural resources and plants, biological nutrients can also contain potentially manufactured components like biopolymers that can be suitable for use by other natural systems and for human activity as well. On the other hand Technical nutrients are defined as materials or minerals that tend to be in a closed loop and used as products or services due to their durability property [\(McDonough, W. 2002\)](#).

5.2 : Smart product (Strategies) in circular economy

The below table gives the basic goals of CE strategies from R9 to R0. This strategies really builds greater impact on moving towards Circular from linear economy. Each 'R' explained in short below [\(Potting et al 2017\)](#).

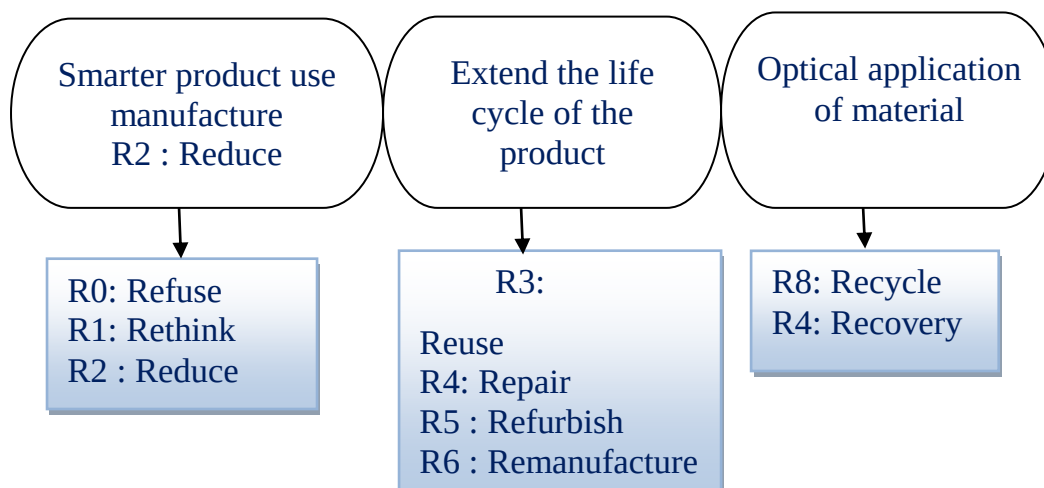


Table 2: CE strategies

Source: (Domone, J & Copus, M. 2021)

R0-Refuse: Number of travel can be controlled (Fly Less). Recently during the COVID-19 pandemic, the approach to refuse air travel reduced the impact of

aviation on the environment. Business travel is comparatively reduced and a potential increase in speed trains overland ([Venter, Z. 2020](#)).

R1-Rethink: Circular economy-focused aircraft design and utilization. In which the standardisation helps in maintaining the parts application and qty. The same part can be used in multiple position as required. Choosing correct recycle material & the concept design for disassembly implementation. Example : Implementation of composite material in the seating shroud will help the reduce the weight and minimum material waste.

R2-Reduce: Get rid of all the trash and include recycled materials. Reducing the raw material required for manufacturing & lowering the buy-to-fly ratio. Weight optimization can be achieved by changing the shape of the component and implementing advanced manufacturing processes like additive manufacturing.

The CE approach tends to increase the life of the part & the following strategies are related to it ([Potting et al. 2017](#)).

R3-Reuse: If any part is in good condition it can be reused on other assy. This will leads to reduction in raw material and the energy. The components for the in-service flights can be reused. To apply this methods few points need to be followed like , keeping the record and review load cases of each component etc.

R4-Repair and R5-Refurbish: An increasing number of items can now be repaired through novel procedures. Refurbishing parts could reset fatigue lives. New processes implementation will reduce the energy required and the old parts can be easily refurbished. The traditional ways of manufacturing may cause more energy as compared to new technologies like additive manufacturing which is further explained in detail in the upcoming chapter 6 (page 31) ([Hatcher, G.D., Ijomah, W.L. and Windmill, J.F.C. 2011](#)).

R6-Remanufacture and R7-Repurpose : Remanufacture is the one in which the existing part is reworked and refitted into a new part different from the original but can do the same operation. Repurposing is related to the operation in which assemblies are reworked so that they can perform new functions. Mainly for increasing the value of the component reference from website ([Airbus, 2024](#)).

R8-Recycling: This is reclaiming the component value when its life ends. In the last decade more attention is given toward the aircraft numbers reaching to end of life retirement age. During upcoming years more aircraft will be in recycling stage approximately it will be 12000 in next 20 years ([Sabaghi, M. et al. 2015](#)). Research shows that Airbus as a manufactures of aircraft has conducting voluntary approach to demolish & recycling entire aircraft product. The other company Tarmac aerospace is also involved in this process of demolishing. The weight wise percentage of recycle is about 92% ([TARMAC Aerosave, 2020](#)).

5.3 : Circularity in aircraft cabin

Material marking: The barrier likes to share information among manufacturers, distributors, and recyclers. To tackle the problem of data transparency across the interior product life cycle, data exchange could be a viable approach. The car industry is a good example to follow since important information is put into databases that are accessible for industry inspection and are prominently noted.

Branding : Cabin weight includes seat, bulkhead, and other interior product which has a particular challenge to reuse due to various factors like : Its customisation, brands, specific shapes, airline logos , pattern with signature and laminates as well with digital interface. This interface integrated with problems like : Seats can be sold to other operator reducing secondary service life.

5.4 : Sustainable Material selection

For sustainable cabin products, material selection is very important. This drives the weight of the component which plays a major role in sustainability. The various parts that comprise an aircraft seat are constructed from a broad range of

non-metallic materials. These are classified into basic areas as shown in Fig 8. All must pass the FAA (Federal Aviation Administration) standard which shows the flammability character of that part. The materials used in aerospace required high tensile strength , fatigue and available in minimum cost.

(Skoczylas, J & Samborski, S. 2019).

- Foam : These are mainly the cushions that are moulded to the required shape and then bonded together with the help of adhesives. Foams have requirements like flammability, comfort, and wear.
- Upholsteries : Material used includes wool , leather , polyester, vinyl and nylon which are fire resistance.
- Moulder parts : Seating components has many plastic moulded parts which included, laminates , strips trims, table tray and arm rest. Material like Poly carbonate (PC) , acrylonitrile-butadiene-styrene (ABS), and vinyl's are considered (Ortego, A. et al. 2023) .
- Structure : Aluminium is widely used in structural parts , however, some companies uses carbon composite structure to control the weight. The aircraft section which are pressurized are mainly lined up with the thermal insulation. This insulation is large quantity as compared to non metallic material in aircraft.

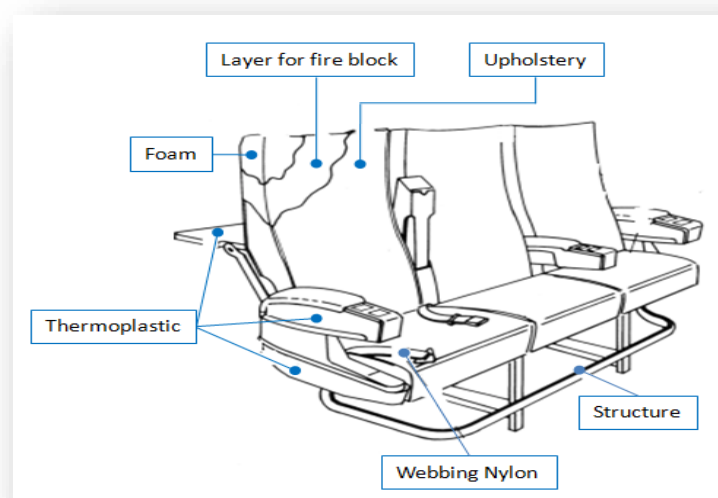


Fig 8: Installation of typical seat

Source : (Ortego, A. et al. 2023)

Further, this section analyses the recent material used like composites which are commonly used to reduce weight. Composite makes the part lighter and produces the same strength as that of metal with higher stiffness. The types of composite matrix are polymer matrix composite, metal matrix composite, ceramic matrix composite, and smart composites. To fabricate the sandwich panels Honeycombs and honeycomb materials are used which provide great strength. The structure consists of a honeycomb panel with a face sheet on top and bottom which are bounded with adhesive. The below Fig 9 shows the basic composite layup (Skoczylas, J & Samborski, S. 2019)

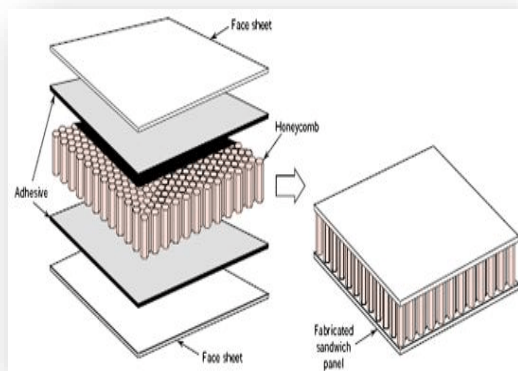


Fig 9: Composite Honeycomb structure

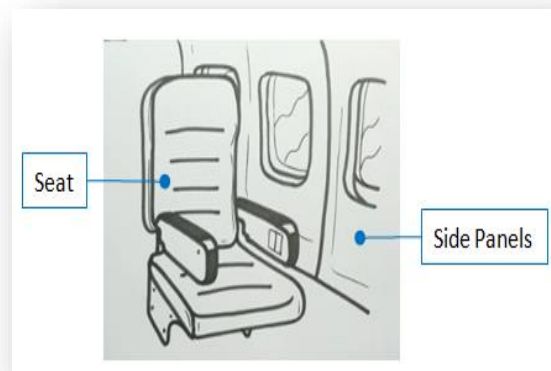


Fig 10: VAC form side panels

Images source : (Skoczylas, J & Samborski, S. 2019)

Fig 10 shows the aircraft overall seats we example for composites used in aircraft seating. Apart from this vacuumed forming process also plays an important role for developing cabin interior panel along the side wall surrounding the seats. This process will help to develop non structural panel in min cost because its ecological and used all recycle material. This vac from process is cheaper than the compression moulding process and techque is fast and covers all other rework on upholstery (Mauricio & Piedra, Saul. 2021).

5.5 Barriers and challenges in CE

The following points captured regarding the barriers & challenges.

- The cost is considered a barrier to the process from linear to circular. This is because the material used for development is available at a higher cost as compared to the existing materials. Also, most of the organizational investors are still focused on the short-term goal and think that implementing this circular economy will be risky. This also develops a fear of losing the customer ([Rodrigues Dias, V.M. et al. 2022](#)).
- The law and the government regulation are also part of the economic barrier to CE. This can be explained with example with any food items, in which the expiry date encourages disposal and leads to plastic waste. Gov. regulation of green packaging will be used more in the future.
- Limitations on recycling are also considerable barriers. Research shows that very small amount of plastic is recycled in products. The value parts like carpet fibre are made from recycling bottles. Fully CE requires innovation in technologies, which are recently seen in the automotive industry seat covers highlighted further in chapter 10.4 on page 58 ([Ellen MacArthur Foundation, 2015](#)).
- Poor Waste management as per article is one of the factor that acts as barrier. Particularly, the study shows that the Chinese government is promoting CE and has legislated as part of its development plan ([V.G. Venkatesh. et.al. 2019](#)).
- The other one is the complexity of the aerospace product and its long life cycle. This also reduced the implementation of new sustainable technologies. This further leads to issues with the certification for regulatory factors.
- The other barrier to CE adoption is the certification issue from the regulatory factors and supply chain, as it is very precise in the aero industry, and sustainable material providers are limited, so dependency gets created. Implementation of software-based simulation like digital twins as highlighted with reference in chapter 6.3 on page 37.

Chapter 6 : Industry 4.0 application for Circular Economy

6.1 : Introduction

Industry 4.0 has completely changed the way companies create, produce, and market their goods. These are build on 9 pillars as shown in below Fig 11.

Industry 4.0 makes the bridge form physical to digital world. These technologies are used by many businesses. Today this has gain rewarding collaboration making the product quickly with creativity due to which the manufacturing line become more effective and productive.

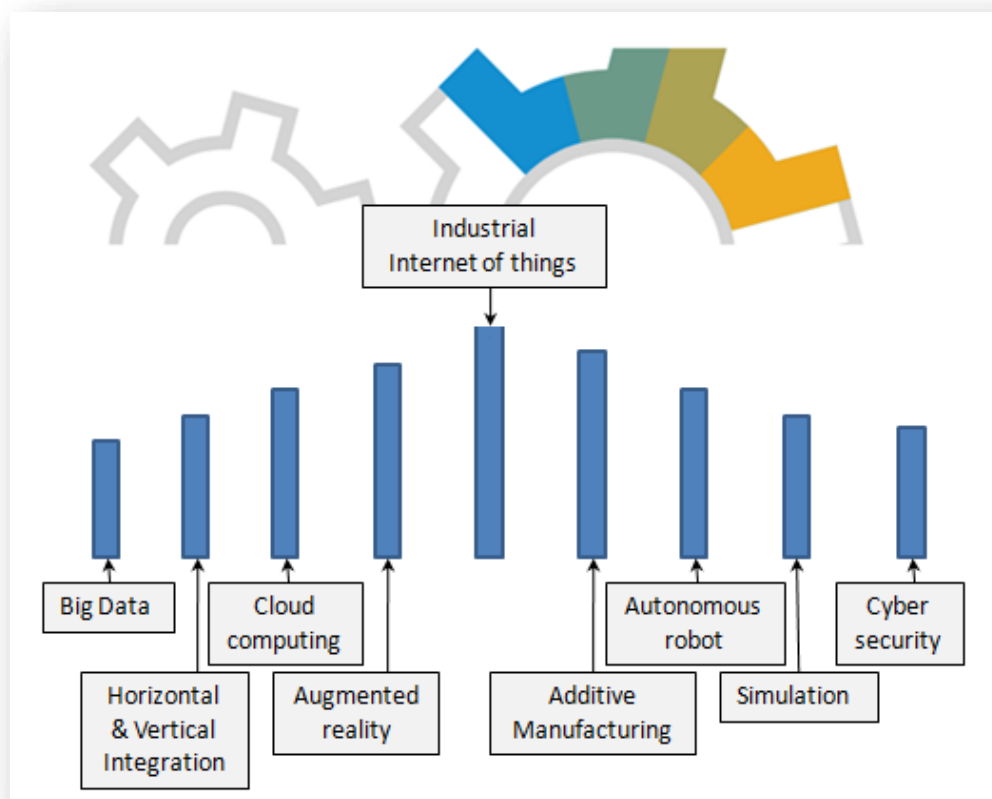


Fig 11: Pillars of Industry 4.0

Source : Concept from (SAP website I4.0 tech) manually drawn

Industry 4.0 technology helps to promote circular economy practices. Their primary goals are returning, minimizing weight, and refurbishing. The product lifetime may be watched and precious resources optimized even with big data analytics and IOT networks. Below are two industry 4.0 technologies studied for understanding the CE.

6.2 : Additive Manufacturing

Additive manufacturing is the process that involves 3d printing in which a three-dimensional object is created by layer-by-layer deposition method. It is computer computer-controlled industrial process. There are seven types of AM methods as shown in Fig 12 below, out of which material extrusion and powder bed fusion are typically used for interior plastic parts. Composite AM is based on material extrusion. AM can contribute to several stages of CE, it can control or minimize the amount of energy and material consumed because it places material only if required ([Rolfe, B & Gibson, I. 2022](#)).

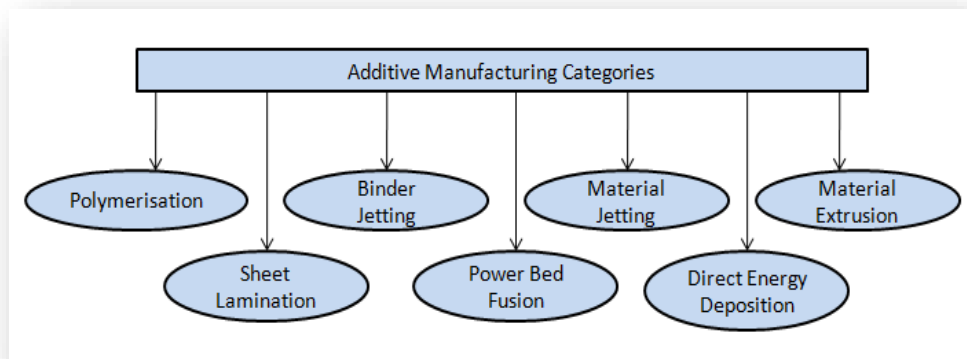


Fig 12: Additive Manufacturing Categories

Source : Concept from ([Rolfe, B & Gibson, I. 2022](#)) manually drawn

In the aero industry, this technology is incorporated for replacing the vacuumed-formed parts with AM parts. In the seating industry, the parts made from vacuum forming require a tool that costs additional to modify later if any design change is requested from the customer. This can be avoided with AM parts as they are cost-effective and material can make complex parts form digital models quicker than vac form and injection moulding. AM can support initial production repair, refurbishment, and remanufacture. Inventory can be made digitally where the digital model can be saved to make when required ([Hettiarachchi, B.D., Brandenburg, M. and Seuring, S. 2022](#)). Outdated parts can be made without tooling which saves a huge cost. The tentative parts made form AM in general seating is shown graphically in Fig 13 on next page.



Fig 13: Basic AM parts in general seating

Source : Image captured from stratasys.com

6.2.1: Case study - AM Implementation project 1.

This section explores the additive manufacturing project already implemented within the seating industry for cost saving and minimizing the cycle time to support customer requirements. This also gives us an insight into the way this technology is been adopted by manufacturing industries to make their product more sustainable and contribute to CE. Manufacturing industry like SAFRAN which is the world class seat provider for aerospace seating industries been explored during this study. The innovative process was developed by investing in a 3D printed machine to introduce the AM process in its organization for seating parts. This will reduce the cycle time and cost of tooling during the vac form process ([Safran, 2022](#)).

- What's so special ? It was new investment by purchasing 3D printing machine to overcome vacuum forming process. This further lead to the development of weight optimization projects for aircraft interior parts and contribute to circular economy.
- The problem: During the on-wing inspection, an in-service issue was captured about a beam crack on the B777 aircraft due to a damping effect. Supplier needed to modify metallic parts which was costing high as there were around 3200 parts on 45 aircraft. Also, man hrs were expensive to assign for this task.

- Corrective action : The actual solution was to trim the electrical bracket for which the man hrs were estimated very high. The alternate solution was developed to create a damper which will be located between the structural beam of the aircraft seat and the electrical support box to prevent it from collision between 2 parts.
- Pros AM : Minimise the NRC as tooling , Reduce the industrialization lead time, solution for fast technical validation and it offers flexibility.

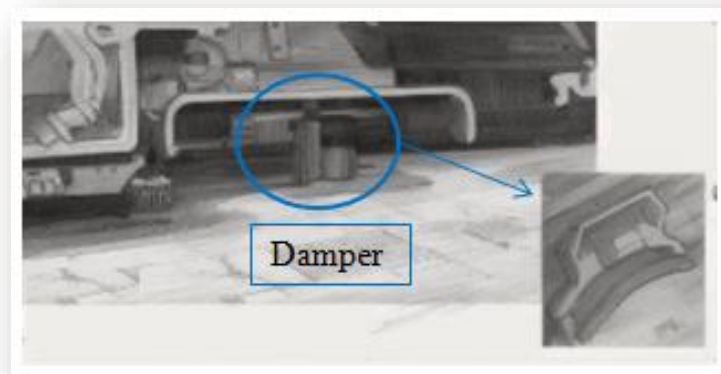


Fig 14: AM damper support

Source : Image sketched from projects concept (Safran, 2022)

6.2.2: Case study - AM Implementation project 2.

The case study below is regarding the aircraft seat buckle. The scope of the project was weight optimisation & to produce component sustainable and recyclable ([Mellor, S. 2014](#))

- What's so special ? This something new area to look into for implementing different material to overcome the machining process & minimising cost. This is the component which is used in seating industry in large amount & innovation within this will definitely leads to an sustainability and contribution to CE.
- The problem: This is an innovative thinking to make this part by circular economy point of view. Also, cost saving on metallic material and weight optimisation which is a key point while designing any component.

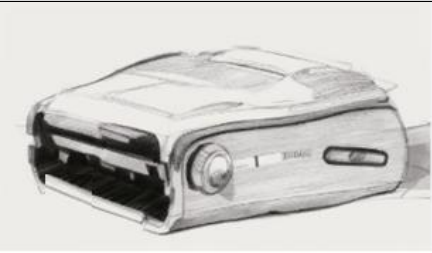
Traditional Design Seat belt Buckle	AM optimised design Seat belt Buckle
	
Weight approx : 155g	Weight approx : 70g

Table 3: AM optimized design

Source: Saving project/Crucible Industrial Design Ltd.; Roland Berger

- Solution / Findings: This bracket was designed and manufactured with additive manufacturing process with material as Titanium. The weight reduction was about 55 % than the existing .
- Savings : This change for an Airbus A380 with all seats (854 seats) and which means reduction in 72.5kg. Which further resulted in fuel saving and aircraft lifetime ([Mellor, S. 2014](#))

Challenges in AM : The big challenge in Additive manufacturing is the certification process. The aircraft part process and development steps are similar to parts manufactured by conventional process. The main difference observed is that in conventional the material qualification stage is already captured and the design can be easily found in the database. This material-related information is not available in AM parts. For this, the AM machine should be qualified and quality inspection is necessary. Other challenges ([Wadea, A. et al. 2019](#)).

- Void formation between the two layers.
- Appearance of staircase effect which effects quality and external look.
- Small build volumes challenges. Scaling down is not feasible.
- AM can be used to create weapons & this is the reason AM has limited its spread in some countries.

6.3 : Digital Twins

The digital twin is the exact representation or we can say, a replica of a real object. This is generated with the help of a sensor that performs the characteristic of that physical thing which is further processed to get a digital copy. Aircraft is characterized by its long life span and security documents. To satisfy the needs of the customer it's been regularly retrofitted with advanced or new cabins. During this process, engineers might face challenges in retrieving the old data & generally, there is a lack of a digital database. To support this digital twins has been introduced which is an approach to model-driven data. In the sub- section below, existing example highlighted in which this technology is successfully implemented and gain high quality results. Below Fig 15 shows general virtual representation of Digital Twin. The implementation of digital twins in the aerospace industry has been captured in the upcoming sub-section. These technologies have reduced the workload and helped to understand the flight staff to do their tasks quickly without any guidance related to new products installed in the aircraft cabins. Further leads to circular economy which is feasible with a phased adoption strategy that is in line with other Industry 4.0 technologies. ([AIAA Digital, 2023](#)).

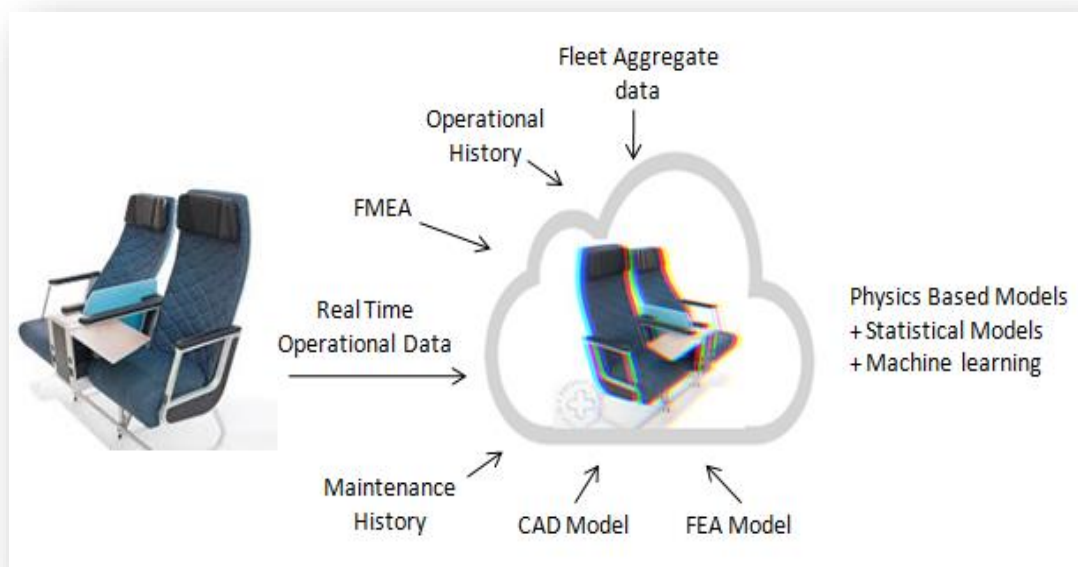


Fig 15: Digital Twin virtual representation

Source: Ref from (Entso-S), seat model replication created

6.3.1: Case study - Digital Twins project

A study from KLM Airways captured the understanding of the practical scenario where the digital twins application had benefited the team in their regular tasks.

- What's special ? Improving work efficiency in ground crew members for the new aircraft cabin interior captured in this piece of work. This reduced the operational time without any manual guidance. This technology is been incorporated in KLM maintenance manual ([KLM Airlines, 2022](#)).
- Challenge: To provide training to ground staff without trying the actual aircraft visit. (Staff should be trained digitally to new cabin product installed, this will reduce the travel time and access to airplane on site).
- Innovative Product : Matter port Pro2 3D cameras.
- Solution: Produce Matter port digital twins of the aeroplane companies which will be made online to access for different uses, ground crew training & for ultimate safety with flexibility. This will also leads to reducing the organization carbon footprint ([Martinez-Gutierrez, A. et al. 2023](#)).
- Result: The benefits of this technologies lead to lower the Co2 footprint. Travel movement was reduced and multiple version for training through virtual method. This helped to gain pre flight cabin walk experience. Cabin and hospitality promotion & also shorten the cleaning time for the cabin crew members by 30%. Travell of team members and stakeholders reduced, otherwise they need to travel to airport or visit KLM base airport to see the actual issue or findings

Digital Twins helped the cabin crew to know the location of newly installed cabin products like galleys, compartments, and lavatories and gave an idea about the cabin walk. Also, the large group of staff can get together around narrow spaces during virtual tours, which is a difficult task on a live airplane. Digital twins are added to the KLM fleet assessment and the manuals management documents ([KLM Airlines, 2022](#)).

6.3.2: Application in Aircraft Seat Certification

This section explores the digital twin application and its implementation in the certification process of aircraft seating. This section leads us to the fact that this technology has played a vital role in terms of customer/passenger safety.

Seat certification is a very important procedure that ensures product safety and integrity. The same level of passenger safety is achieved by the analytical procedure of modelling and simulation technologies by digital twins. This resulted in the collaboration of the largest aircraft manufacturer BOEING with the seat supplier for seat dynamics ([AIAA Digital, 2023](#)).

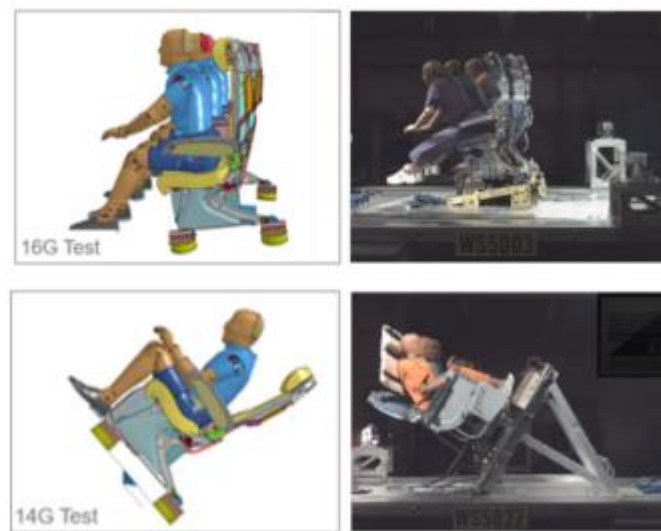


Fig 16: Simulated Digital twins certification test
Source : ([AIAA Digital, 2023](#))

With the help of a dynamic simulator, there is a reduction in number of certification tests performed. The results are quick and easy and lead to producing superior seat designs within the customer deadline. Fig 16 shows the typical testing simulated image for better knowledge. In general, these (Industry 4.0) technologies have been used to drive smarter test processes. DT have been used to drive smarter certification testing, first-pass quality, on-time seat installation, optimal design flow, optimal cost for seat design and certification, and above all enhanced passenger safety ([AIAA Digital, 2023](#)).

Chapter 7 : New business model "Product-as-a-service" for CE

7.1 : Introduction:

Over the last decade, the circular economy has made an excellent journey. Today many organisation have presented their individual CE or action plans. To implement CE, it's important to make a systematic transformation in how the product is made, its use, and its benefits to society. Service-based model or Product-in-service (PaaS) is the key element in this transformation from the very beginning ([Reim. W., Parida V and Ortqvist, D. 2015](#)) .

This section will explore the necessity to create for CE and the existing organization that had already implemented within their organization. Based on the same study the same concept will benefit the aircraft seating industry.

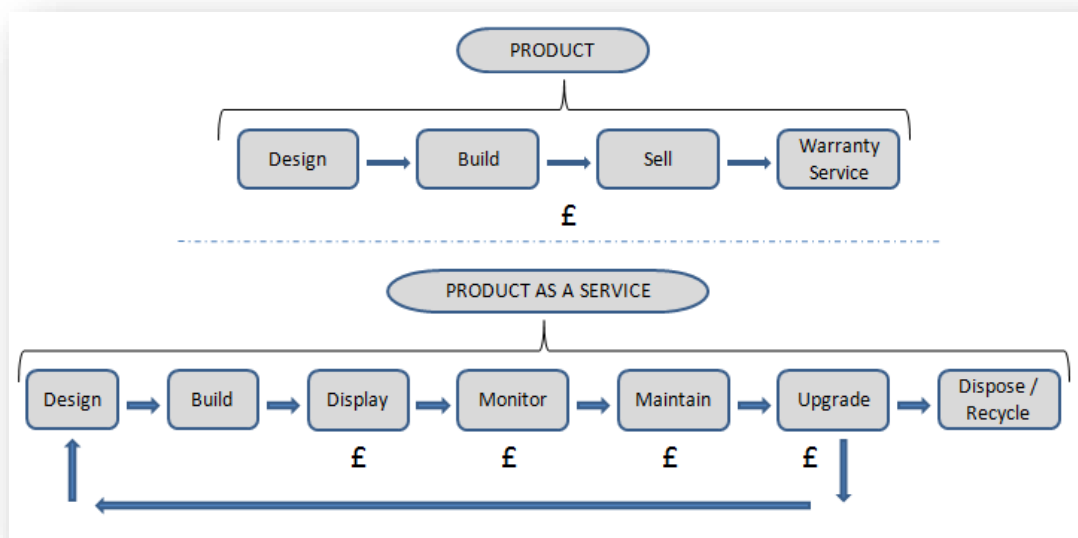


Fig 17: Product to Product as a service

Source: Ref from (engineering.com) manually drawn

In the PaaS business model, the main difference from the product service is that the provider has ownership or we can say control of the product over the use phase. The above Fig 17, shows the basic flow chart which makes it easier to understand the process. Revenue generation is comparatively more as it gains during each step compared to product service due to its stronger incentive in

utilising the product. As the resources controls the Life cycle , this PaaS model leads to circular economy ([Ellen MacArthur Foundation, 2015](#)).

This type of leasing model has been implemented by manufacturers. An example of one of the manufacturers studied to get the reference and get an insight into their success, which will be a leading example to use this method to achieve CE in the Aero industry.

7.2: Case study - Rolls Royce's leasing model.

This section presents the overview of Rolls Royce's business model for the aircraft aero engine. They named this program as "Total care" which allows the company to track the flight data history and allows to propose smart maintenances, extension of life and strategies ([Sebastian W & Anming Z, 2023](#)). The Implications of this process states that this leasing offering is via real time communication , through which the company can monitor its engine. The unexpected failures can be easily identifies and possible maintenance to avoids any downtime. This leads to increase in utilisation of aircraft in CE pathway.

Benefits to industry:

With this approach, the manufacturer allocates the lifetime service for the parts, and the subscription cost becomes a key point. Operators do not need to source big funding or capital for initial airplane purchases. This leasing methodology leads to economic growth and resource consumption towards CE. Research shows that there is growth in aftermarket services, as this was provided in civil aerospace as a "Total care" package comprising the menu to select services as per cost per flight hour. In this company maintain engine & plan maintenance. ([Morwood, D. 2018](#)).

This business model includes patterns which are as specified below.

Performance : This is servitised service linked to engine service. This kept available for Rolls-Royce engine to fly every time and all time.

Recondition: This is the other one which is related to engine parts (individual component).

Resource recovery: This is the one which deals with the material recovery over the engine lifetime. This packages allows the aftermarket service to do business form the selected menu on agreed scale per flight hr. This way the Rolls Royce planned maintenance basis on behalf of customer.

Customer satisfaction: With ref to data from ([Palmer, T. 2015](#)) the customer report is in positive side. The feedback received from the customer on engine availability is 75 %, Reliability 71% , maintenance which are not schedule is 65%, operation is about 80% , secure cost is 82% and value for money is about 71%. This total care has definitely shown rise in their business by 90%. This also helped then to build good relationship.

7.3 Approach Analysis:

SWOT analysis as specified in reference ([Palmer, T. 2015](#)) shows critical areas that result in hurdles for the creation of circular business models. This analysis is important to assess internal factors to understand the company performance and check internal factors that might affect the business ([Phadermrod, B., Crowder, R.M. and Wills, G.B. 2019](#)).

 <u>Strength</u> Value proposition Capabilities of digital info Partnership for business model	 <u>Opportunities</u> Air travel has been increased Digitisation within the industry
 <u>Weakness</u> New engine technical challenge	 <u>Threats</u> Customer requirements change Regulatory pressure Cost and security for specific material

Table 4: SWOT Analysis

Source: (Phadermrod, B., Crowder, R.M. and Wills, G.B. 2019)

This model is the perfect example of lifecycle of product and enabling CE. Based on this investigation , Aircraft seating products leasing will help to grow the airline industry with high customer engagement. This process will have the full ownership of the product and leads towards sustainable product.

Chapter 8 : Technologies for sustainability

8.1 : Roadmap for cabin sustainability

Technology development is the key for greener cabins. The drivers of areas like materials , comfort, electronics entertainment and circular product promotion has high potential to reduce operational and non operational impact. The steps are:

- Talk and engage
- Assets and priorities
- Collaborate and commit
- Measure and report
- Educate and communicate

8.2 : Technology indicators

The technology indicators in the aircraft industry are as stated below [\(Evans, A, Strezov, V. and Evans, T.J. 2009\).](#)

- Cost: The cost indicator highlights the present cost, it should be reduced in line with the maturity and manufacturing technologies.
- Weight: The indicator may vary, it could be lighter or heavier as per the integration in aircraft either by adding or replacement of other technologies.
- Impact: This includes the non-operational items such as reducing toxicity and recyclability.
- Benefits: where ever relevant it combines three indicators with weight reduction.

8.3 Energy-Efficient Strategies for Aircraft Interiors

Regarding energy consumption the additional factors to consider in aircraft interior apart from Co2 emission. Implementing energy efficient strategies will help to overcome. The list are explored below for reference ([Wang, L. et al. 2021](#))

Lightweight material:

Fuel consumption is reduced due to the lightweight material in interiors. The carbon fiber material can be used which can offer weight reduction and also increase fuel efficiency.

Air-conditioning system:

To control the energy consumption the air conditioning system in the aircraft interior should be optimised. Advanced technologies like smart systems for cooling and ventilation can help to control energy without any customer comfort.

LED lighting:

This light can reduce energy & this item has a longer lifespan. This has the feature of dimming to save more energy.

Recyclable material:

The environmental impact can be controlled by using recyclable material so that less waste is generated. Using bio-based materials will promotes CE in the aircraft industry.

Cabin Layout:

Optimising the cabin layout will lead to space utilization and the capacity of travellers will increase. This way the use of space will reduce flight travel. Ultimately min energy consumption.

Chapter 9 : Method for Sustainable development [MFSD]

9.1 Sustainability

Sustainable development can be defined as the method of development that seeks the requirements of the existing generation without affecting the upcoming generation to fulfil their own requirements. In another way, it's a change that is environmentally, economically, and socially sustainable.

It's important because this method recognizes that these three things are interconnected and must be kept in an equal ratio for a lifetime or must be balanced to have excellent well-being for all. Sustainability protects the environment, and reduces poverty, and quality increases. It also adapts to the upcoming challenges for the environment ([Merlina Missime. 2018](#)) .

9.1.1 Key principal of sustainability

Implementation of below listed principle of sustainability will play important role into development. It will be truly ensure that development meets to existing and future generation. Reference form ([Shuai, C. et al. \(2021\)](#)).

- The principle of sustainability includes the project which is economically profit the organisation but without effecting the environment.
- Approach must be precautionary as a key principle. Development is done without having potential harm to environment and human being.
- Involvement of stakeholders is the one in which the development includes the local communities , stakeholder in planning for knowing the people need and concerns.
- Discussion making which requires dedicated approach that includes the policies and procedure . This requires collaboration with different sectors.
- Equality& fair justice , In which the development are shared fairly. This addresses the important issue like poverty.

As a sustainability component to achieve a circular economy, methods for sustainable development (MFSD) are presented. The five level of FSSD framework of strategic sustainable development are as follows.



In this levels on top is the system where the company is placed in the society. The sustainability principle are taken into account during second stage Success. In this the analysis of the component and compliance check is performed. In Strategies application of guidelines implemented which leads to success. The next one is Action were organisation make real actual and practical difference. Further is the concept level were the tools with various method used to support the actions.

9.1.2 Material criticality

According to the longer-term perspective, material criticality is important to understand their sustainable level. It is based on the sustainable principles. The list of material criticality will aware the company about the impact of their material in the society. According to reference [\(Lapko, Y, Trucco, P and Nuur, C. 2016\)](#) the three dimensions that classify the material criticality are : Vulnerability, Supply risk and Sustainability risk.

Assessment of such material and listing down will allow us to know the supply disruption of material in the system.

9.2 : Recycling and circular Economy

This section elaborates the recycling importance toward sustainability and the improvement in future aircraft lifecycle.

Overview :

Recycling is an important part of the circular economy. Some assumptions like CE is something doing better in recycling is not the case. More than that, though, it's mostly about repurposing trash or reusing raw materials to create new goods. Although recycling reduces greenhouse gas emissions, it is still environmentally preferable than disposing of waste in a landfill. Reducing the amount of items we acquire and reusing what we already have is the best thing we can do. The circular economy model based on 3 principle as per ref ([Ellen MacArthur Foundation, 2015](#)) are waste elimination , circulate material & regenerate nature.

At the moment aerospace industry reclaiming value which is from the end of life is more in demand. In the next 20 years say around 10000 aircraft are about to come to their end of life or retirement stage ([Thomas R, \(2019\)](#)). The strategy of CE and smart end-of-life on an aircraft can increase the parts volume and material that are in the market. This will reduce the demand for raw materials. The approach of aircraft decommissioning is shown in below fig 18.

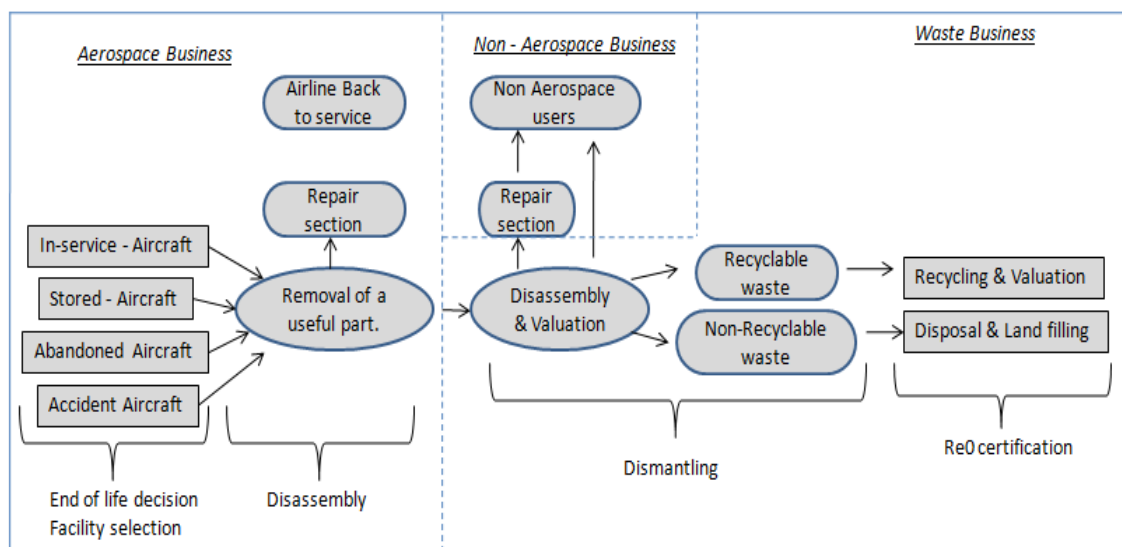


Fig 18: Aircraft decommissioning process

Source: Ref from (Thomas R, 2019), manually drawn

The current procedure to management of decommissioning in aircraft is shown in above includes some part of circular economy. Here the metal waste are directed toward shedder and further melted down to create new material. The one which is not recycled are sent to landfill. Challenges in aircraft recycling is due to disassembly thinking designing methodology, thermo set resins are unable to recycle which are mainly in composites.

9.2.1 Improvement opportunities in Aero industry

The recycling phase could be the phase at the end of an extended life in the next generation. Better composite recycling techniques will be required to recover value from the many composite airframe parts that are now in use or scheduled for production. Although thermoplastic resin composite materials are not as robust as thermo sets, a lot of research is being done on their utilization, which may help improve the material's capacity to fit into circular plans. The labour cost can be reduced by using robots for disassembly which will also improve the safety. They can be used to remove the rivets and manage the mix of material sent for recycling and shredding. Also government grand's can be useful to establish recycling units ([Seton-Rogers, S. 2015](#)).

Recycling Improvements:

Findings from the study show that there are improvements in the recycling process, such as CE designing consideration for future projects with more recycling material application. Implementation of automation will reduce labour costs and improve safety. Government grants will be useful to develop recycling facilities.

9.3: Environmental Impacts of Recycling Aircraft

This section describes the environmental relation, whereas per ([Howe et al.2013](#)) the whole environmental effect during the recycling process should be mapped. The utilization of the resource and the energy should be considered and analysis of these points should be done. The point is that the structural material in aircraft seating is for one-time use and the use of fibre composites is gradually increasing which leads to minimum fuel consumption for the aircraft. But the other side of it is, that this material is not easily recyclable. The further analysis and the problematic material in aircraft cabins have been explained and tabulated in a further chapter to get an insight into it.

The recent study by [Scheelhaase, J. et al. \(2022\)](#) shows that the recycling rate in dismantling the aircraft is around 60% of the weight of the airplane. The reference also shows that many aircraft have just parked for many years, their parts are made up of metals & many components can be resold. Composite is widely used so an efficient recycling method must be followed, The two different composite material require different processes to recycle the composite waste during the manufacturing of the parts and the composite material remains at the end of life as specified in the article [Scheelhaase, J. et al. \(2022\)](#)

9.3.1: Future Development in Recycling

The future market for recycling is designed by the development pathway where the fleet model timeframe is defined on the aircraft time and the year of operation in service as per the academic article. The paper shows that the pathway set up to 2050 forecasted air transport. Depends on the body structure and aircraft category methodology implemented. Wide body has about 24 years and narrow body slightly more approx 25 years of service than retired. The barriers that can be seen as per the above reference of the market are : Aircraft fleet growth , Retirement numbers globally, Parts and material prizes of reused aircraft , Environmental regulations for recycling and the technology options for recycling like composite parts ([Gelhausen, M.C. et al. 2022](#)) .

The topological method for composite material recycling is the main challenge and driver in the aircraft recycling industry. On the other side composite recycling should be very precisely considered economically. The condition were that resources like labour should be considered which would lead to minimizing the percentage of emission & at a controlled level as per paper by [Koskela, Marileena and Vehmas, Jarmo, \(2012\)](#).

Thus, because these operations allow for the return of valuable resources used in aircraft construction to be employed in a circular economy, airplane recycling can be seen as a significant step toward sustainable aviation. The major challenges face by the airline industry will be as listed below based on the above study.

- The number of aircraft into the market will be increasing and the retirement of aircraft will also increase over a medium or long term. This is leads to grown in the recycling industry which will increase the revenue of aircraft recycling .
- In the upcoming scenario for weight optimisation , aircraft will composites is expected but the cost for recycling composite also increases due to which the economy will get effected as per [Howe et al.\(2013\)](#).
- The public awareness activities will proceed due to the environmental load from society.

Chapter 10 : Own research on other industries' sectors

10.1 : Introduction

This piece of work is an additional own research that is investigated to get more insight into the seating industry. Other seating products in different industries like Locomotives (Railways) have been studied. The Airline seats sound luxurious, so the same level of seating captured from the Rail industry to have insight into their design methodology and aesthetic to have sustainable products. This comparison might lead to new developments in the seating industry to develop their product more sustainably by taking references from each other.

10.2 : Seating in Aircraft industry overview

An airline seat accommodates passengers arranged in multiple configurations. This configuration is in the form of several rows along the fuselage and is commonly known as a LOPA. In other words seat map where space constrained is the key point to consider. The typical seat plan is shown below in Fig 19 for reference. Generally, the seating arrangements depend upon the airliner's requirements. First-class units are luxury items.

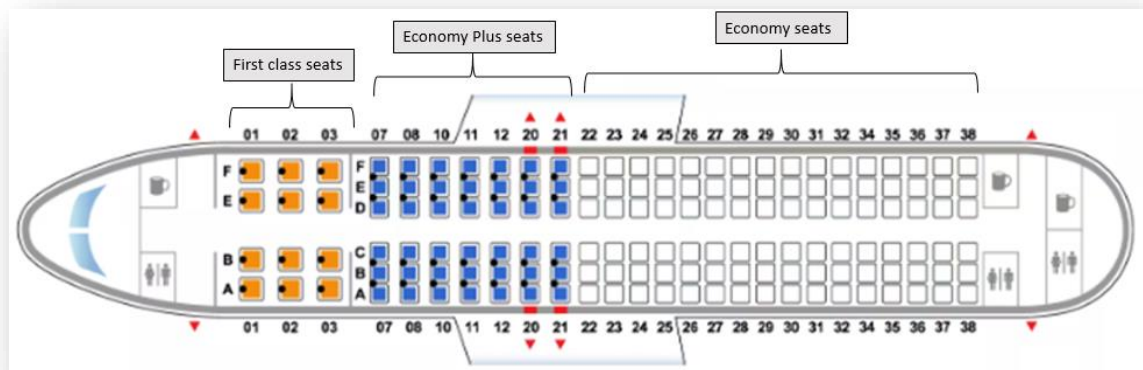


Fig 19: Typical Seat LOPA in Aircraft

Source: (Seat Guru, 2009)

The aircraft seat's technical representation of different classes is shown in fig 20. The seat pitch valued as per the study ([Safran , 2024](#)) on economy class seat pitch is between 28 to 33 inches. Business class seats are around 63 inches and the first class is more specious about 95 inches. ([Seat Guru, 2009](#))

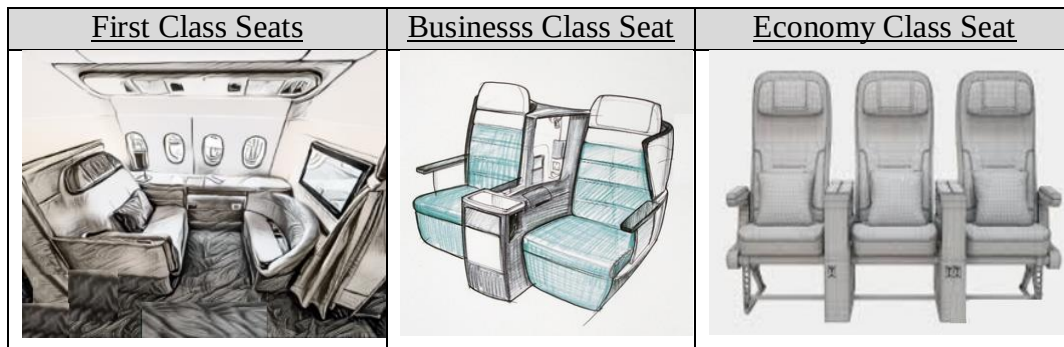


Fig 20: Typical Seat Class in Aircraft

Source : [Businessinsider.com](https://www.businessinsider.com)

10.2.1 Airbus Aircraft Seating Study

According to the article on Airbus A320 , this is one of the aeroplane which is still in production for last decades. The below study is based in this single aisle airliner cabin ([Airbus A320, 1999](#)) .

Specification of aircraft seat:

Aircraft seat configuration depends upon the airliner , which size aircraft is been used and based on its application . The typical seat configuration for Airbus - A380 according to the reference seats configuration are 3-3-3 for economy, 1-2-1 for business class and 1-2-1 but minimum number of seat ([Seat Guru, 2009](#)).

Installation methods :

Usually the aircraft seats have complex way of installation methods . If we consider an example of first class or business class seat, proper support panel of around 1" or 1.5" designed which is known as Plinth. This can be metallic or composite in material. If composite then additional operation to insert the blocks and inserts for fixation is performed. Seats are placed on the plinth which are mounted on seat tracks with foot fittings. Seat track and foot fitting are the complex attachment and involves metallic parts, approximate 3 -4 fixing points required for proper installation of suite. This contributes to increased weight component & complex way of installing.

Materials & component breakdown :

The material used in interiors plays an important role in the circular economy. The material used to design a product or part should be recyclable. Regarding the information captured for dismantling/recycling companies information in the academic journal specified below , a typical cabin breakdown of interiors according to weight and material captured. The analysis considered passenger seating , panels, IFE system, sidewall, decorative parts, and finishes. The below table shows the problematic materials and further the product where it's been used. Its application indicates where engineers are looking for sustainability and gives information to address them ([Junior, R & Jefferson, G. 2015](#)) .

Material	Part / Product	Concern
Cadmium/ Nickel	Brackets	Demanding & Toxicity
LCD	IFE units & systems	Compactness high density.
Copper	Wiring harness	Routing, Drip shield requirement
Carbon fibre reinforced plastic (CRPF)	Structures / air ducts	Recycling issue & harmful dust.
SS (Stainless Steel)	Seat belts, Support bracket & Blocks	Compact leads to high density
Polyvinylidene fluoride (PVDF)	Seating parts, frames & lining	Carbon, health & safety. Toxic production.
Polyethylene terephthalate (PET)	Cabin trims, Insulation blankets.	Toxic manufacturing & disposal waste.
Perfluoroalkoxy alkenes (PFA)	Lavatories and galleys	Waste disposal & Toxic.
Nylon / PA	Seat track cover , dividers & seat belt	Carbon , emissions & persistent.
ABS	Seating component	High smoke, non-biodegradable, Toxic fume.
Al. Alloy	Seat pan , frames & brackets	Energy demand . medium density,
Composite panels	Seat shroud / Plinths	Recyclability, waste
PVC	Cable lining, ducts	Excess waste & Toxic
Leather	Seat cover / Trims	Livestock
Foam	Cushions	Recycle after life , Availability.

Table 5: Cabin Problematic Materials

Source: ([Junior, R & Jefferson, G. 2015](#)), manually tabulated

According to research paper ([Hall. A, Mayer. T, Wuggetzer. I & Childs. P 2013](#)) . Cabin design plays an important role in business motivation. Innovation is considered based on the consumer's requirements and passenger experience. The outcomes of approving optimization are from digital communication and design thinking with advanced engineering analysis for cabin design with a win-win approach. Based on the material analysis , the scope of sustainability to be focused on below listed problematic products for development in aircraft interiors as shown in Table 6 .

Cabin Item	Part / Product	Development
Seats	Seat back rest	Composite / Glass fibre
	Structures	Min. Al Alloy / use bio plastic
	Cover	Bio synthetic leather
	Cushions/ Foam	Foam material / Aerogel
Fasteners	Supporting Bracket	Adhesive for fixing
Electrical equipments	Display / LCD/ Wiring	Light weight alternative / AM technologies implementation.

Table 6: Cabin Problematic product development

Source: (Hall. A, et al. 2013), manually tabulated

Environmental impact :

Flying from point A to B within 45 min is great achievement but for this lot of energy immense for lifting out huge aluminum structure with passengers. Burning this fuel will contribute to global warming as well as the other concerns as per reference ([Gossling, 2018](#)) are like Noise, aircraft infrastructure, waste generation & if any incident impacts the environment. As per the report from statista , the carbon footprint of air travel is comparatively more than rail travel. The Statista graph showing mode of transport captured in Appendices section on page 79 ([Ian Tiseo, \(2023\)](#)).

There are number of seat supplier for aircraft , few of them are : Sarfan Seats GB, Recaro Seats, Pitch Seating, Acro Seats, Collines Aerospace etc..

10.3 : Seating in Railway industry - Overview

Railways has excellent transportation capacity as compared to other mode of transport and also strict safety standards. Railroads in terms of ranking is the most popular public transportation options. Furthermore, it has been shown that trains are the most environmentally friendly mode of travel because a larger percentage of railroads are run by electrified trains. This significantly lower Co2 emissions per passenger kilometre when compared to flying or driving as per the (Concepcion Roman, Raquel Espino, Juan Carlos Martin, 2007) for ref.

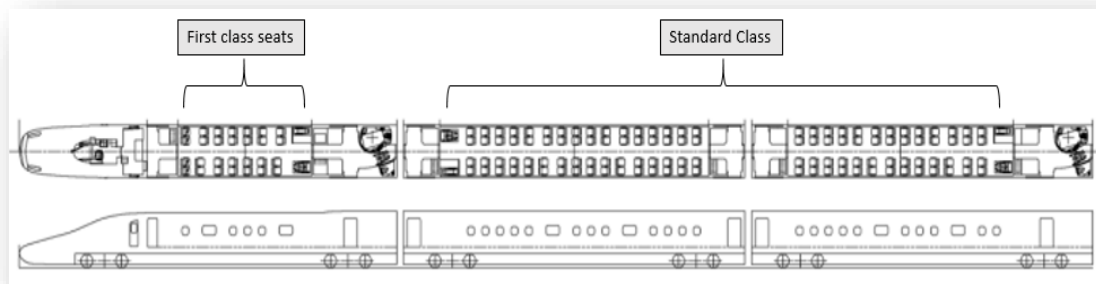


Fig 21: Typical Seat LOPA in Railways

Source: Ref (Wiki Seat), labelled manually

The train seats are generally classified into Luxury class and standard class. The upcoming section explores the Swiss Railway seating arrangement and design to achieve a circular economy. Seat layouts are generally arranged transversely so that two seats can be placed near each other which is commonly referred to as 2+2 seats as shown in lopa in fig 21 & General Representation in fig 22 for ref.

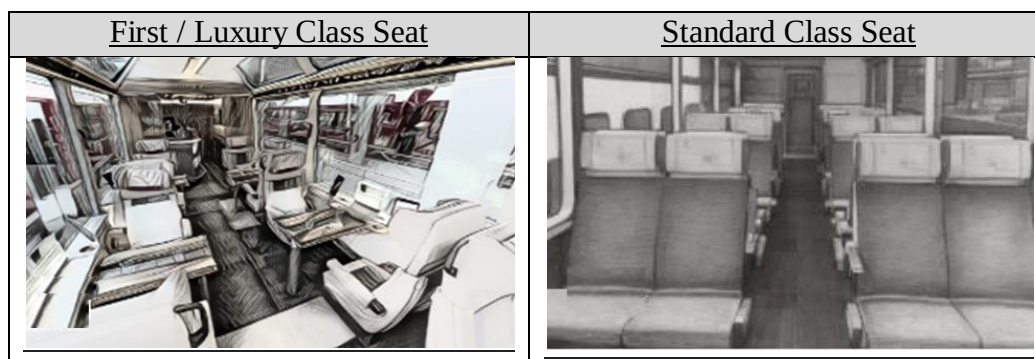


Fig 22 : Seatings in Railways

Source: (Glacier Express. 2023)

10.3.1 Swiss Railways Seating Study

Swiss Federal Railway is the national railway company with the largest transport in Switzerland. As per Wikipedia, it has been ranked number one among the European rail systems in 2017. Swiss railway also has an excellent narrow gauge railway line ([Glacier Express. 2023](#)) that covers the longest distance from Zermatt to St.Motiz. The train Glacier Express is the one that explores the Swiss Alps with scenic views excellent luxury class seating and a cabin interior. This section explores the luxury seating incorporated in Swiss trains & studies the design technologies of seat manufacturers to develop such products. Also, the Materials and aesthetics are incorporated to have a sustainable product with circular thinking.

Seat Manufacture - BorCAD

The seat manufactures for the swiss railways is BorCAD. the info found form reference ([Glacier Express. 2023](#)), the concept of interiors and the terminology captured form automotive interiors. The swivel chair idea was dropped due to space constrain. The excellence class consist of panoramic single arrangeg 1+1 accross the cabin with face to face tablets installed in such a way that everyone has an window preferences. Also an Spinning bar seat at the end of car. for

Cabin Item	Part / Product	Specifications
Seating	Seat back rest	Lightweight/non bulkiness
	Structures	Fixed inclination on std seat.
	Cover	Automotive concept
	Cushions/ Foam	Tisca carpet
	Configuration	Single / Double / Folding
	Fixing method	Wall and foot / foot to foot / Cantilever
	Armrest	Fixed (min Mechanism)
Fasteners	Supporting Bracket	Adhesive for fixing
Electricals	Display / LCD/ Wiring	Concealed wiring / Use of console near window.

Table 7: Cabin product specifications

Source: (BorCAD, 2024), manually tabulated

10.3.2 Case study : BorCAD Cost saving project

This company is in the seating industry and supplies first and second-class seats to the rail industry in the European region. One example is the Excellence class or we can say Luxury class seating incorporated into Glacier Express, which is the famous scenic train in Switzerland. Due to extra demand by the supplier to reduce their product cost, a new cost-saving project was initiated by this company to increase profitability by minimizing the material cost with step by step approach. This study gives insight into reducing the material cost and thinking towards weight optimization with product circularity ([Burroughs, D. 2021](#))

Challenge : To gain profit in there product, as there was fall due to customer cost requirement, fluctuation in wages and new operational unit requirement.

Solution: Implementation of cost saving on product which will generate profit and circular design as future prospective.

Impact : Quality and relibility issue due to reduction in direct product cost.

Project Implimentation:

This was a new approach that linked to other procedures like design changes & further strategy of the product. Apart from this, the company studied the product requirements, and a re-evaluation was done. There were many possible ways to save costs by modifying the customer requirement by validating the changes without any risk ([BorCAD, \(2024\)](#)).

- Change implemented was , first reduce the number of sub parts by 50%. This will leads to reduce in production & material cost.
- Sub assy level structure was modified to reduce assy cost. Discussion with supplier change in in-house welding to std finished offer, which reduced the welding time and transition cost.
- System changes like purchasing process, production system, assy technologies & elimination of manual welding implemented.
- In-house work and few were outsourcing to supplier to reduce cost ie.(modification in cost onership).

Result : Multinational team work on this project leads to direct cost saving and after running this project for around 10 months , they able to run the test and solution to customer without affecting quality of the product.

So with this study we can capture the things like process improvement also plays an important role in creating an product more reliable . Reduction in number of sub assay parts and keeping the mechanism simple will reduce the complexity of product and also result in controlling the weight of the product.

10.4 : Promoting CE in Automotive Seating - Example

With reference to the article form automotive industry news related to their seating product that they are making their seats cover for their new product AUDI A3 from the recycle plastic. This sounds very interesting that seat covers are made from recycle plastic bottles which very impressive industrial process helps promoting sustainable circular economy ([MoDo, 2020](#)). A small study done below to know how this company had implemented this .

Scope : Company wants to produce innovative part of seat which is durable Seat cover with good quality but completely recyclable. Seat covers were developed in their R&T department made out of PET bottles ([Welle, F. 2011](#)).

Process : They began with washed used bottle shredded into small flakes to get further into granulate. This granulate further melted and converted in threads. This thread is used to create plastic yarn. This further creation of fabric for the seat cover with multiple quality checks. The lamination process is carried out to finish the product made form fully recycle material. ([Ortego, A. et al. 2023](#))

Result : Excellent Progress on sustainability and in process to create seat covers entirely from single material that would be 100% Polyethylene terephthalate material (PET).

10.5 Design Insight in Trains

10.5.1 Vision of more sustainable design

The design vision of the train is divided into two parts. The first one is short-term vision and the second one is long-term vision. Train interiors are mainly focused on number of seating capacity and the travel zones. The circularity in trains as per the article by [Jagadeesh, P. et al. \(2022\)](#), shows the study to utilize synthetic fibres in a polymer matrix would be exciting in the interiors of trains which will make the product more lighter and recyclable.

In the seat, the design vision like the reconfiguration and standardization can be implemented. Material like latex foam is used instead of PU foam. Latex foam is made from natural resources and it is very durable plus can be easily decomposed.

Similarly, the approach of circular reconfiguration in the side panel replaces the non-recyclable composite panel with a honey comp core sandwich panel. This also can be combined with reversible tape to increase sustainability.

The future road map in trains as per the research article by [Simonse, L., Hultink, E., & Buijs, J. \(2015\)](#) says that the road map is a visual of design innovations created as per timeline which makes designers more creative for challenges.

Chapter 11. Other Stories on CE Implementation

11.1 Future Prediction by Airlines on 3D printing parts

In line with the post ([Beau J, 2019](#)) by British airways the industry 4.0 technology is been planned to get implemented in other parts of the aircraft parts like Hospitality items , Tray table, side wall, storage units, electrical units , switches & aircraft shells. This post gives an idea that more and more components are been designing and thinking towards circular process to get there product more sustainable. The other areas where this can be implemented are like after sales , Obsolescence issues , Alternatives solutions, Parts replacements and decentralization.

As specified in an article by ([Kobenko, S. et al. 2022](#)), the 3D-printed seat folding table which is mainly used in aircraft situated inside the structure explored. This table consists of multiple sub-assy fasteners like screws and rivets. The manufacturing processes for these parts are mainly CNC machining, Cutting, and VAC forming. The table is assembled with the metallic support and that support is fixed with fasteners which come up 7 parts in total. The application of ultem material one-piece table implementation saved the operation cost and the weight of the new component was reduced by 46 %. The assembly is much more simplified by reducing the number of sub-level parts ([Kobenko, S. et al. 2022](#)),

11.2 Story of Jamco seating

The contribution to the sustainability goal is been achieved by seat manufacturer Jamco Corporation by developing their aircraft seat. In their product, the manufacturing is done by advanced composite panels, metal alloys, and plastics. The seats are lighter than traditional and also good in durability. To control the weight, this organization (BorCAD) reduced the sub-assy parts as researched in chapter 10 (Page 57) and minimized the decorative panels/surfaces. For example, in an aircraft with a wide body in which all business class seats are replaced by this seat around 900 pounds saving in weight can be achieved. Thus this reduction in weight translates to a fuel saving of approximately 40 gallons per flight which is comparatively impressive. Apart from fuel saving the designer lowers the operating cost by reducing the inventory ([Lucan, D. \(2019\)](#)).

Sustainability for the full lifecycle

The practical efficiencies of cutting emissions, fuel use, and repairs are only one aspect of aircraft interior sustainability. Airlines are searching for providers with options that completely complement every facet of their sustainability plans This entails reviewing the complete lifetime, starting with the production process and ending with the service life. The seats for the Jamco seating industry significantly reduce the environmental impact minimising the amount of material required and minimum waste. The inside story is that the cabin plays an important role, selecting an interior with low environmental impact will achieve high returns with fuel saving and non-operational benefits. This will also show commitment to a greener world ([Yang, Q. and Song, B. 2006](#)).

11.3 Story of Adidas footwear

While researching on circular economy , to understand the exact phenomenon the other industry product (out of box) were captured. This really motivates how the branded companies are thinking toward becoming more circular. The example below highlighted is an item used in our day to day life.

The shoes company Adidas has great example implementing CE and tag lined as "*Shoes that you don't own*". Adidas an multinational company is thinking to design a footwear with recycling in mind. Its product shoes are going to made form only one material , No glue is uses in the manufacturing process. The material will be thermoplastic polyurethane (TPU) & assembled with the help of high temperature. The company website show this shoes under "Ultra boost" category. In line with the research reference the shoe competitor has also started thinking toward circular products. The company say that the shoes customer will never own , it will be returned back after the customer finish them using. We can contribute to keeping goods in use and garbage out of landfills if the end can become the beginning ([Schaer, C. 2021](#)).

This project was initiated to control plastic waste, implementing a closed loop. Getting the waste back to raw material. The incredible waste on beaches, islands, and coastal areas is targeted to collect the waste and proceed further with this innovation of becoming circular. This example is in line with the product as a service idea & the same can be implemented by the aircraft seating company to move towards CE.

11.4 . Kia goes deep in Sustainable Material

A recent study on one of the automotive companies that is working on the sustainability principle, where they are using sustainable material in their car parts. They are working towards utilizing the plastic recovered during ocean cleaning from the Pacific. Kia an automotive company using this material for their future models. They had identified various materials that they will implement on their vehicle, which are tabulated below for reference.

Sr no	Material	Details
1	Bio plastic	Based on Biomass Material like ; Vegetable oil , corn extract and sugarcane. (Interior Trim parts)
2	PCM	Recycled material used for Doors garnish.(Post consumer material)
3	Bio Polyurethane	Alternative to leather - Plant based material
4	Recycled PET	For Fabric - from PET bottles
5	PET carpet	100% recycled PET form fishing net
6	Bio Polyurethane foam	Used for headrest in seating system
7	BTX free paint	Interior trims (No benzene chemical used for formation)
8	Bio paint	From rapeseed oil , for switch panels.
9	PET yarn	Seat Stitching
10	PET felt	Used for sound-attenuation in interior

Table 8: List of Sustainability items

Source: (Schaffner, C. (2023), manually tabulated

The company calculated the weight difference after implementing this and found that comparative weight reduction was achieved. Further bio fabrication tends to be a major goal for this company (Schaffner, C. 2023) .

Chapter 12 : Analysis of results

12.1 : Introduction

This section concentrates on the comparison of different industry seating product. To get the more insight on luxury seating the rail industry as explored in chapter 10 on page 51.

12.2 : Manufacturer Sustainable practices

The study shows a methodological guide to implementing materials according to the gain and weight optimization program. Some of the strategies involve light and non-hazards material. The selection of material used by the train seat manufacturer is shown in Table 7 (page 56). The material selection helps to control the weight of the parts which makes the whole seat assy lighter, which result in low carbon emission.

12.3 : Other factors for sustainable product

Research shows that the aircraft seat is more complex in terms of mechanism and other moving sub-assemblies. This increases the manufacturing cost and number of sub-assembly parts. This causes the product to become more heavy. But as per the seat manufacturer for the rail industry has proven its cost-saving project in weight optimization. This states that the product can be made simpler by reducing maximum sub-assemblies and process improvement will lead to control of the weight of components. Thus this leads to sustainable growth economically and environmentally safe. Also looking at the usage, people should prefer train journeys for short distances to minimize CO2 emission. In terms of space , rail industry has designated space to cover comfort requirement like IFE units kept in line with the console attached to window. We're as the Aircraft side wall has space constrained to incorporate units along the window. (Ref fig 20 & 22)

Chapter 13 : Conclusion

The aircraft seating industry has opportunities with multiple ways to develop and go circular which will contribute to sustainability. Furthermore, based on this study, additional research will try to provide a more in-depth analysis of the less-discussed portions. Implementing this will also work in conjunction with funding agencies, services, and other businesses to act as a point of reference for companies ready to begin a project of this nature. The below subsections highlight the investigation and findings.

13.1 Co2 Net zero approach

After researching the various industry approaches towards circular economy it states that reduction in carbon percentage is very much beneficial for the environment and the organisation economically. Different processes and technologies lead to sustainable products with possible alternatives in the seating industry which are the most important parts of Aircraft associated with the passenger. To gain the CO₂ net zero the aerospace industry has to consider the materials used in their product and emissions caused by the production process. To overcome this the solution would be shifting the linear model to the circular economy model. As CE minimizes the energy which is required and further environmental impact.

13.2 Sustainable approached toward improvement

This research highlights the main Industry 4.0 technologies (AM & Digital twins) that play an important towards CE shown in chapter 6 (page 32). The technologies Additive manufacturing provides benefits in the production process by including more efficient material, minimizing the waste & making the part lighter which further leads to energy saving. The industry example highlighted on page 34 with case studies about companies who have implemented this technology and are successful in achieving their goal. Thus this is a powerful enabler of the circular economy which minimises the emission. Also, it impacts on organizational innovation and business models. The application of digital

twins in the seat certification process (Ref page 39) will reduce the number of tests by 70 % due to simulation. The product at the end of life should be fully recycled, which will reduce the demand of raw material (Ref page 47). The case study highlighted (Ref page 38) gives an idea about how this technology can add value to processes by remote monitoring, Planned maintenance, and improved performance. The product as a service is a very positive approach towards sustainability highlighted in chapter 7 (Ref page 40). This focuses the product to be in a closed loop & focuses on the product function when approaching sustainability. The live example studied in this section guides us to implement the same strategy in other industries to grow economically & environmentally.

13.3 People role implication:

In terms of economy effect, CE can develop demand for the new businesses such as reverse logistics. The company which supports the product end to end support will be re-introduced. Employment will be increased in the re-use and recycling industry as compared to other sectors highlighted on page (49 & 50). People must develop their skills & should be up to date with the new technologies in the market. Technologies like AI, AM and digital twins.

13.4 Comparative research interpretations

To have indebt analysis, the seating product compared with respect to rail industry. The excellent part of this research in this section captured on chapter 10 (Ref page 51) shows the difference about rail seating structure and design methodologies followed by the manufacturer for achieving sustainable product in min cost. The weight optimisation cost saving project implementation will definitely grow the business environmentally and economically. The other points also get into mind that collaboration with other industry will help to become more circular. Further looking at statista report as mention on page (54 & 79) , the carbon footprint of air travel is more as compared to rail industry , which states to minimise short distance air travel.

13.5 My Recommendation

Thus further work is recommended to see the benefits of reducing the carbon footprints mainly associated with the product management, circular. This cabin sector should be aligned with the automotive and rail industry for knowledge transfer to have sustainable products. Expand the material overview further which will indicate sustainability impact and weight percentage. Presenting this insight in the roadmap will communicate the priorities to stakeholders. It should be noted that each product has its value and is different. Understanding the best one is important to apply the same knowledge to their specific business. The future production in airline industry will implement AM technologies as per the article highlighted on page 60.

13.6 My Findings

Based on the qualitative analysis conducted via discussing with people of different departments and hierarchies, it came to mind that more knowledge sessions should be conducted within the workplaces to elaborate on this circular economy subject. So that everyone will start thinking of our environment. The implementation of this methodology as highlighted on page 15, of this research really helped to interpret the findings. On average, most of them don't know about circular products. The answer session was more towards comfort and aesthetic looks of seating, but achieving that with eco-friendly material is a challenging task that needs to be understood. Most of them feels CE is just recycling, so adequate knowledge sharing is necessary. The material that needs to be addressed is composite. Agreed with the technical expert view towards minimizing composite thought it plays an important role in weight reduction. Instead of that, an advanced thermoplastic composite should be implemented for weight optimization. The case study explained in the report and the people's thinking points of view match and are in line with this research. Comparison with the other seating industries helped to analyze the product specification and areas of development to make aircraft seating products more sustainable.

Based on the question answer sessions, the opportunities that can solved the CE challenges are by critically analysing the material in early development stage by listing down the criticality list. This will avoid material dependencies. AM technologies can use the material more efficiently. Organisation should take closer look on product lifecycle and combined services to keep in loop.

Also, after analysis, it came to mind that economic advantages have encouraged businesses to implement circular methods. These are the findings that tell about this research and the own research about the other industries added value to think about circular economy and adapt their practices for further sustainable products.

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Chapter 15 : Appendix

15.1. Carbon footprints data

This is the data captured form the Statista shows that the co2 emission form the aircraft industry is comparatively more as compared to rail industry. Below graph for reference which leads to thinking that for short distances Air travels can be avoided to keep our planet more green. (Refer Page 50)

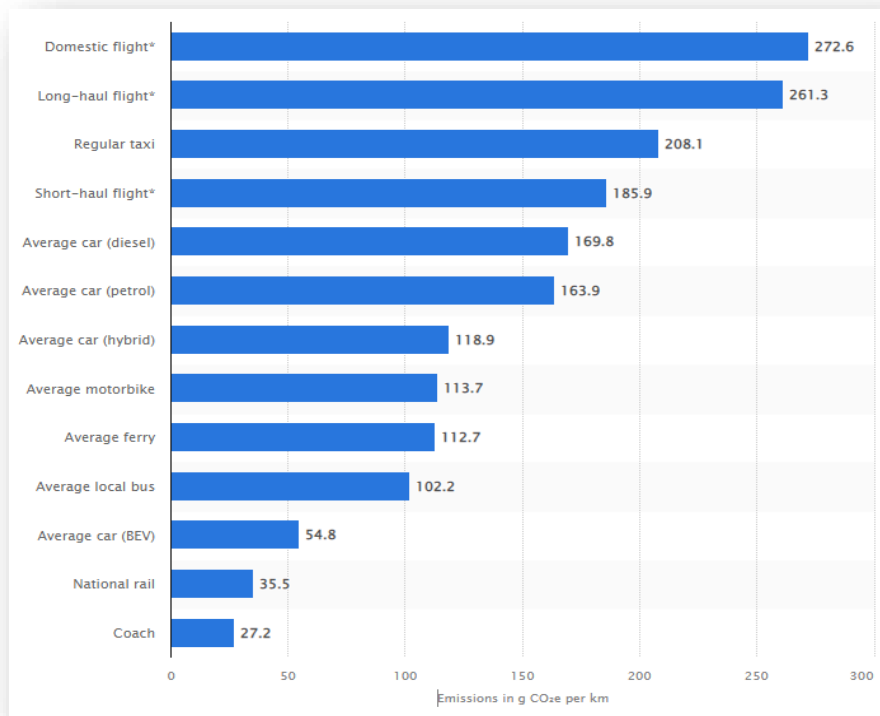


Fig 23: Carbon footprint travel per Km
Source : (Ian Tiseo, 2023)

15.2 : Interview questions

Below are the list of generic question asked during qualitative research. This was conducted to have get knowledge for the different department people about there thinking and capturing the same for analysis, to add some value to study.

1. Self introduction and purpose of this question and answer session ?
2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.
3. Can you please introduce yourself and your position in this organization?
4. Have you heard this term "Circular Economy" ?
5. Doing an research on CE concept. What do you think about this idea ?
6. If implemented , what problems do you see in recyclable materials?
7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?
8. Noticed that Safran is into decarbonisation. Is the organisation moving towards CE & How ?_
9. What do you think about Rail industry & Automotive industry for CE ?
10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?
11. What do you think about the problematic material in cabin interiors?
12. What do you think about the Advance industry 4.0 application in CE ?
13. Would you like to add any suggestion or recommendation towards CE?

15.2.1 : Transcription of Interview - Engineering project lead

This session was with Engineering Project lead , experience in Aero products and technically expert with Aftermarket department. The below transcript is captured form the recorded session.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained. The Interview process was defined and allowed the person to speak in a friendly manner to get a nice output.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, I am perfectly fine to share my experience and current position within the organisation.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, Engineering project lead , with 17 years of experience in aerospace design and development.*

4. Have you heard this term "Circular Economy" ?

Response : *Yes somewhat in recycling point of view.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Yes, it's a good idea, he was eager to know the research on different seating products.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Costing might be a problem, we need to approach specific industries accordingly at the end of product life.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *Think part material should be decided at the very first stage of designing any component & the main barrier I think would be material availability which can be easily recycled. Quality & meeting customer expectation.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : There are many project going on sustainability which you can find on company website. Moving toward Circular economy part like : recycling the seating parts mainly foam and cushions. But research like this will definitely help organisation to think on it.

9. What do you think about Rail industry & Automotive industry for CE ?

Response : Not much idea about Rail Industry as its different platform in terms of regulations. But it's nice you are thinking in that way.

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : I feel the rail industry has different std. there is a luxurious train which has the same class of seating as a plane but simple design.

11. What do you think about the problematic material in cabin interiors?

Response : Composites may not be recycled easily & leathers are used for cushions. Also, any toxic material used to design components will be an issue.

12. What do you think about the Advance industry 4.0 application in CE ?

Response : This industry 4.0 application is leading the product toward more circular. In our organization, 3D printing has played an excellent way in reducing the weight of the component and minimizing tool costs for other manufacturing processes.

13. Would you like to add any suggestion or recommendation towards CE?

Response : This kind of research should be done. The comparison study will help to lead towards sustainable product. Organisation should start thinking on this.

15.2.2 : Transcription of Interview - CSE Department

This session was with Senior Customer support lead , experience in Aero products and technically expert with Customer and support department.

1. Self introduction and purpose of this question and answer session ?

Response: *The introduction to the dissertation topic and purpose was explained. The Interview process was defined and allowed the person to speak in a friendly manner to get a nice output.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Happy to share my experience and present role.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, I am working in customer support department & mainly involved in ISI (in-service issues) after aircraft is in service.*

4. Have you heard this term "Circular Economy" ?

Response : *Have heard during economy road show. Interested to know more in deep.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Great Idea. we face too many issues with component failure and quick solution to replace the part on wings.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Availability of recycling units.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response: *Material properties are important. Should have trials before implementing on manufacturing drawings.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response: *A lot of things going on with decarbonisation. France unit has developed a unit for plastic parts manufacturing through 3D printing.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *Railways are good for travel. Seating in railways is simple without much mechanism.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *Seats on trains are in different configurations. material properties are different as per their application and environmental conditions. Need to study & feel some techniques can be adopted.*

11. What do you think about the problematic material in cabin interiors?

Response : *The expensive materials and customer requirements in terms of aesthetic and all.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *3D printing is already implemented. Many cost-saving projected has been done. It's an up growing technology and companies should adopt it for manufacturing their product.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *Need to explore more on this topic. Need to study successful examples.*

15.2.3 : Transcription of Interview - Manufacturing

This session was with Additive manufacturing expert , experience in Aero products and technically expert with Development department.

1. Self introduction and purpose of this question and answer session ?

Responses : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to transcript this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript from the discussion and was happy to share his industrial experience .*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, working as Sr. design and technical expert in design and development area for Additive manufacturing.*

4. Have you heard this term "Circular Economy" ?

Response : *Yes familiar with the term , lots of things related to AM.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Yes, excellent approach to think and implement in present scenarios.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Composite material recycling may be an issue ..*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *Material spec definition is important. Many materials are concerned about toxicity, density recyclability, and safety. These points need to be considered. Also in seating, specifically trims, leather, cushions & non biodegradable covers.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : *The company is working toward low carbon aircraft & multiple in-house activities in process to reduce Co2 emissions.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : Rail industry is really low carbon mode & different from aerospace due to its regulation.

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : Nice way of thinking. In terms of design, rail industry is a bit simpler in structure & limited mechanisms. But few European trains have excellent interiors nowadays for expensive journeys.

11. What do you think about the problematic material in cabin interiors?

Response : Electrical items , harnesses, medium-density parts like brackets, and PVC material parts seem to be a concern in cabin interiors.

12. What do you think about the Advance industry 4.0 application in CE ?

Response : AM is the one that every manufacturing industry is looking into. Even our company has invested in such processes. Many cost-saving projects are done with AM parts in-house which saves project cost. These technologies also helped to maintain CSE with customers by developing instant prototypes for review.

13. Would you like to add any suggestion or recommendation towards CE?

Response : Standardization should be implemented. Knowledge sharing about this topic will definitely help. More case studies should be done.

15.2.4 : Transcription of Interview - Design and development

This session was with mechanical engineer , experience in designing seating system for business and first class aircraft seats.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript from the discussion.*

3. Can you please introduce yourself and your position in this organization?

Response : *Working as design engineer & role to design the seating component and creating manufacturing drawing.*

4. Have you heard this term "Circular Economy" ?

Response : *Heard about it , but having limited knowledge.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Its good way of thinking about company product and growth towards sustainability.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Available units & procedure may be expensive. Many material are based on customer demands, so need to consider this requirement.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *As a designer, the material specification needs to be addressed in the design review. Need to check its implementation in previous projects. Check for lessons learned from another program. If any specific customer requirement, then need to find alternative material with the supplier.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : Many programs going on. For example: The concept of hybrid aircraft as per our company website can be seen for more information.

9. What do you think about Rail industry & Automotive industry for CE ?

Response : No design idea about the Railway industry. Rail seating providers should be studied for any particular methodology they have implemented in their products.

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : It's different, but it's a good approach to see their product. Even though they have diff standards and regulations. The material properties should be studied and compared.

11. What do you think about the problematic material in cabin interiors?

Response : Seating materials are mainly cushions, leathers, and materials which are toxic. IFE units used in entrainment may be an issue.

12. What do you think about the Advance industry 4.0 application in CE ?

Response : This technology is used in every were now. we are using AM a lot for replacing the vacuum forming parts & to reduce the cycle time with tooling cost.

13. Would you like to add any suggestion or recommendation towards CE?

Response : The design should be simpler and limited mechanism. This kind of comparison with similar products should be noted. Brain storming session will be a good idea.

15.2.5 : Transcription of Interview - Graduate

This session was with Graduate Trainee , min experience with aero product.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript from the discussion.*

3. Can you please introduce yourself and your position in this organization?

Response : *Graduate trainee , new to Aero products.*

4. Have you heard this term "Circular Economy" ?

Response : *Not heard about this. Need some overview.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *As explained the topic , its interesting to think about after life of product. It should be implemented in all manufacturing areas.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Research on recycling industries to be done. Time consuming task.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *Material properties can be checked by applying to the CAD model. Analysis of the CAD model will help in designing further.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : *Need to refer companies insight portal for more information.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *Railways are good for small journeys and are quite affordable. Aerospace is comparatively more towards comfort.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?
Response : Do not have much idea about their product, but it seems more simple due to its configuration and number of seats. Need to do some case studies.
11. What do you think about the problematic material in cabin interiors?
Response : As recycling is one of the factors, the non-recyclable material would be an issue.
12. What do you think about the Advance industry 4.0 application in CE ?
Response : It seems like a lot of going through Additive manufacturing. Technologies like digital twins would be beneficial to see and analyze the product without physical involvement & might simplify many maintenance processes.
13. Would you like to add any suggestion or recommendation towards CE?
Response : This kind of study needs to be done and identify the processes that other industry follows.

15.2.6 : Transcription of Interview - Technical expert

This session was with Sr. engineer (technical expert) having wide range of experience in both Automotive and Aerospace sector.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript from the discussion.*

3. Can you please introduce yourself and your position in this organization?

Response : *Experience in product development for automotive and aerospace. Technical expert with design approval signatory.*

4. Have you heard this term "Circular Economy" ?

Response : *Yes , I know about the terminology.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Yes, it's a good idea to make our product more sustainable.*

6. If implemented , what problems do you see in recyclable materials?

Response : *The problem with the market as recyclable material is in low demand. Costing and quality will be an issue.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *It's very important to apply material at an early stage of designing. This will help to identify any issues during the prototype review. Further other factors like certification, flammability, and stress concentration can be identified accordingly. Further supply and demand might be an issue.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : *Yes, its true, projects related to low carbon are in the process.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *No idea about locomotive engineering. But in automotive, the seating industry working towards sustainability and making their products from waste material. There are many examples of seat cover manufacturer making their product fully recyclable.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *This is very interesting to know that we should think in this manner. Check with other industries how they are working and get some insight from their product. In general, many design considerations can be learned from another seating manufacturer.*

11. What do you think about the problematic material in cabin interiors?

Response : *Non-recyclable material will be an issue. Also, the toxic material used in the seating industry is something needs to be addressed.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *Every manufacturing company is now working towards weight optimization. Additive manufacturing is the one that is implemented all over. This technology is leading the company towards sustainability. The other I4.0 like AI, digital twins, and AR/VR are used fully in process development.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *Research on this topic and awareness to the people should be spread. Every organization should start thinking about sustainability. The organization should merge their ideas to achieve one goal.*

15.2.7 : Transcription of Interview - Non Technical

This session was with Project engineer , experience in Aero / Auto and This session was with Engineering Project lead ,

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, we will have general discussion as its new for me.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, non engineering dept.*

4. Have you heard this term "Circular Economy" ?

Response : *No, but would like to know more about it.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *Yes, It would be good idea as we are thinking about the environment.*

6. If implemented , what problems do you see in recyclable materials?

Response : *No idea about material specification but it would be better if nothing is wasted.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *No idea about the design processes.*

8. What do you think about decarbonisation ?

Response : *Heard about the concept. Companies are working towards. Avoid travelling by automobile. Also, the transportation of goods for repair should be controlled by developing in-house repair stations. so that less fuel is used.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *Railways travel is more eco-friendly as compared to others. This CE system in railways will be simpler to achieve if any seating area is concerned due to its simpler design.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *No idea as such but we should look around us to know what other industries are following and should think about what we can adopt from them.*

11. What do you think about the problematic material in cabin interiors?

Response : *Non Recyclable materials.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *Should go more digital & limit the physical appearance at places where travel is required.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *looking at the topic, recycling is the main factor. So, companies should think about the recycling process of their product. Would prefer Rail for max travel.*

15.2.8 : Transcription of Interview - Repair (Part 145)

This session was with System engineer Part 145 repair , experience with repair and solving customer issue for aero industry.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript from the discussion and interested to be part of this discussion.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, experience in part 145 dept and customer problem solving. Knowledge of supply chain and on-wings aircraft inspection.*

4. Have you heard this term "Circular Economy" ?

Response : *No, need some information. Might be familiar about similar process.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *As explained . It's an good ideas thinking about sustainability.*

6. If implemented , what problems do you see in recyclable materials?

Response : *Customer approach towards new material cost. Mixed material issues to segregate it during recycling. Reliability of the component. Electrical items recycling.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *Listing out critical material. Electronics device can be calibrated and reuse. Material which can be long last should be consider in design phase. Application of reused the parts.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : *Company polices and general info on sustainability is available on company website.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *It's more comfortable. Aerospace comparatively has lots of boundaries in terms of designing components with light weight as compared to rail. No much experience in the rail industry.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *Can be adopted while considering the other factors like flammability. quality and reliability.*

11. What do you think about the problematic material in cabin interiors?

Response : *Non recycling materials , composite is light weight but is hard to reuse it. More research to be done on synthetic material. Issue with leather material seen on many products.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *Heard about AM new ideas, Preferable but don't have enough knowledge to explore on it. Company is using 3D printing parts to satisfy customer need quickly.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *Good thought, business should proceed towards it. This will save a lot of energy.*

15.2.9 : Transcription of Interview - Other engineering field

This session was with Non technical , experience in electronics and telecommunication engineering. Travelling experience.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, Its new to me so, we will have general discussion.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, experience with the electronics engineering domain & work experience in process management and technical support on electronic devices*

4. Have you heard this term "Circular Economy" ?

Response : *No, need information. Might know in different aspect.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *As explained to topic , it's really good idea to proceed. Interested to know more about this research.*

6. If implemented , what problems do you see in recyclable materials?

Response : *The limited idea about the mechanical material properties but if compared to electronics items used in seating systems should be recyclable Material like cable lining and LCD sub-parts need to be considered.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *No particular idea on this , But may be standardisation should be considered & meeting customer expectations.*

8. Have you heard about decarbonisation ?

Response : *Yes heard about it , every one thinking on Co2 emission.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *As most of my travel is through Railways and Automobile. The seats on the Railway are more comfortable but minimum facilities like NO reclining mechanism and all. But for short travel it's fine. About its circularity, that point needs to be explored with some case studies.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *As not have much experience in first-class seating products in aircraft and never travelled with first class or business class in aeroplanes. But feel Railway travel is more comfortable for small journeys instead of Air economically and environmentally.*

11. What do you think about the problematic material in cabin interiors?

Response : *Non recyclable materials.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *Heard about it. Just go more digital by using technologies like AR/VR and digital twins.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *Need to consider other industry applications and case studies of their product for more information. The knowledge about this topic needs to be spread.*

15.2.10 : Transcription of Interview - Project support manager

This session was with Program / Project Manager , experience in project management in aero industry and expert in process improvements with quality.

1. Self introduction and purpose of this question and answer session ?

Response : *The introduction to the dissertation topic and purpose was explained.*

2. Do you allow me to record this session ? You can hide your personal identity for confidentiality.

Response : *Yes, allowed to transcript and interested in this session.*

3. Can you please introduce yourself and your position in this organization?

Response : *Yes, Engineering project manager with 15 years of experience in product support in aircraft industry.*

4. Have you heard this term "Circular Economy" ?

Response : *Yes familiar with this concept.*

5. Doing an research on CE concept. What do you think about this idea ?

Response : *This is fantastic idea towards company growth and sustainable product.*

6. If implemented , what problems do you see in recyclable materials?

Response : *The issue may be recycling units available. Costing might be a problem in terms of availability of special material in market.*

7. As per OEM perspectives , what do you think in product redesigning and barriers in implementing CE ?

Response : *Barriers like regulations, economic transition, and customer expectations should be addressed. further quality of the product will also play an important role. The designing factors for new material should be satisfied. The approval stages like flammability, stress, and certification should be satisfied to release for manufacturing.*

8. Noticed that safran is into decarbonisation. Is the organisation moving towards CE & How ? [Safran (2024)]

Response : *In-house strategies are in place and many tasks are running like replacement of hazards substances.*

9. What do you think about Rail industry & Automotive industry for CE ?

Response : *Railways has modular infrastructure and based on its different seating configuration design considerations are made. This industries case study will help to understand there process.*

10. Read some article that Rail industry is developing more sustainable product. Do you think Aero industry should incorporate same concept ?

Response : *This is a nice thought, to compare the other industry product and learn from them. The design strategies by the rail seating provider need to be explored for more information.*

11. What do you think about the problematic material in cabin interiors?

Response : *All non-recyclable materials and the ones with toxic properties in seating need to be addressed. Areas like structures al. alloy, steel brackets, and IFE units must be from recyclable material.*

12. What do you think about the Advance industry 4.0 application in CE ?

Response : *This is an important part of CE. Companies are implementing weight optimization projects. Major scope in developing part sustainable. Other technologies related to digitalisation should be incorporated which will improve the process and management activities.*

13. Would you like to add any suggestion or recommendation towards CE?

Response : *This kind of research will help organisations to think towards CE. Other industry design aspects should be studied for new product development.*