

TU DELFT

MASTER THESIS

Developing an Pattern Artefact for
implementing Digital Technologies that
Improve Coordination between Material
and Information Flow in Supply Chains
Sangamesh Balaji Ganesh



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Developing an Pattern Artefact for implementing Digital Technologies that Improve Coordination between Material and Information Flow in Supply Chains

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Sangamesh Balaji, October 2021

Summary

The international trade sector is projected to undergo a significant shift in the next years, with transparency and trust being the most pressing concerns to be resolved as part of the Industry 4.0 revolution (PwC, 2019). International trade consists of several complex process involving several intermediaries (actors). Due to the complexity in international trade, the amount of errors in manual paperwork, delayed order deliveries and the deterioration in quality of products throughout its shipment may arise. As the industry tries to deliver precise and real-time information that can be transmitted to many parties, the volume of data increases.

The sheer volume of data arises from capturing the movement of materials, the associated paperwork and other process data such as customs procedure and other regulations. These different movements of people, materials and money are categorised as flows in supply chain. The three different flows are material, information and financial flow. The errors in manual paperwork and delays in delivery are seen to occur due to lack of coordination between material and associated information flow. The researcher starts this graduation project with the premise: *"Delayed deliveries are caused due to ineffective actions undertaken by different departments such as quality control, procurement, manufacturing and assembly. This causes mis-matched flow of material and information resulting in delay of delivery impacting their quality and timeliness."*

To tackle this problem of mis-matched flow, poor quality, delayed deliveries the emergence of digital technologies are evaluated. Based on the researchers understanding from the evaluation, three technologies namely Enterprise Resource Planning (ERP), Advanced Planning and Scheduling (APS) system, and Blockchain technology seems promising. The capabilities of these different technologies such as *"integral planning"*, *"smart contracts"* and *"hierarchical planning"* are seen to be suitable for improving the coordination between material and associated information flow ((Tavana, Hajipour, & Oveisi, 2020), (de Santa-Eulalia, DAmours, Frayret, Cesar, & Cambiaghi, 2011), (Dutta, Choi, Somani, & Butala, 2020)). Integral and hierarchical planning are methods incorporated by the disruptive technologies to process large volumes of data. Smart contracts are a type of computerised transaction protocol that allows a contract's conditions to be carried out.

Reviewing existing literature regarding material, information and digital technologies showed the integration on the three streams through conceptual models. First, the conceptual models

lacked the presence of detailed process taking place between a buyer and seller in supply chains. Second, the models depicted by researchers failed to mention the "factors" involved in supply chains. Here, the factors are defined as the various activities or actions a firm should undertake in order to improve coordination between the flows.

Next, the influence of these factors in each process of the supply chain were also not found in previous literature. These factors and their associated influence on the different activities or processes in supply chain is seen as building blocks to develop an effective system design (Offermann, Blom, Schönherr, & Bub, 2010). This thesis project aims to fill these gaps by generating a pattern artefact in the form of a technology roadmap which aims to provide generalised elements that are useful for developing future system designs (Kuechler & Vaishnavi, 2008).

The Design Science Research (DSR) has been used to guide the design process since it supports the construction and assessment of such designs in a rigorous and complete manner. The five steps or phases of this DSR approach are *problem awareness*, *suggestion*, *development* and *evaluation*. The thesis project is structured and presented in accordance with these steps.

During the problem awareness step, a rounded view of the problem is described through the lens of Airbus. The different actors, departments and tiers at Airbus were identified. The result indicated that these actors, departments and tiers contribute to the complexity in supply chain. Further, A350XWB is identified as a model aircraft with the lowest delivery and highest demand at Airbus. The movement of materials and associated information flow is explored to identify if it truly is the cause for delayed deliveries.

Next, during suggestion phase the chosen part of the supply chain is studied and analysed further in detail. This is done through the use of Supply Chain Operations Reference (SCOR) model for material flow and Unified Modelling Language (UML) for associated information flow. Through this process, the different steps such as "*order placement*", "*quality inspection*", "*transporting*", "*verification of information*", and "*receiving*" were identified. The analysis of this process showed the existence of various non-value add activities that decrease the rate of delivery. These various activities or actions are which the firm should undertake in order to improve coordination between the flows and improve order-fulfilment rate is termed as "factors". Three digital technologies (ERP/APS/Blockchain) were shortlisted through literature study to enhance these factors and convert non-value add activities to value add activities.

In the development step, the identified factors and digital technologies were integrated into a single stream by the researcher to arrive at a pattern artefact. The initial pattern artefact is presented in the form of a wheel diagram indicating the different elements required to integrate a digital technology into a large firm to increase order fulfilment rate. This generated artefact is seen to assist companies in selecting a suitable technology before integrating it into the companies supply chain processes. This new design created by the author is presented as a technology roadmap and compiled through interviews with supply chain experts, the gaps in information is filled through academic research.

In the final phase, the pattern artefact was evaluated and further developed to understand the influence of each technology on the factors through the Best-Worst Method (BWM). This scientific method is chosen over other ways such as simple brainstorming and data analysis for evaluation, as it enables the researcher to arrive at a generic output through the usage of weights on the response provided by the interviewees.

Interviews were conducted to obtain the level of influence each technology has on the identified factors to improve material and associated information flow. Improving the coordination between the two flows is seen to improve order-fulfilment rate. During this evaluation it is identified that each of the three selected technologies, influences different factors the most. The total number of factors identified by the researcher in this thesis project were thirteen. The factors are "supplier involvement in new product development", "supply partnership", "supplier timeliness", "transaction method", "frequency of quality checks", "level of information shared", "origin, process, routing", "product ID", "reliability", "responsiveness", "agility", "costs", "asset management". The final recommendation on the most suited technology is arrived based on the highest number of factors each of the shortlisted technologies could influence.

The ERP technology is seen to increase "product ID", "level of information shared", and "asset management" the most provided, the organisation issues contracts or certifications that allows these different actors to share required information. The type of certification provided is in the form of a non-disclosure agreement to prevent leakage of information to third parties. The second technology APS is seen to increase "level of integration of factors", "product ID" and "level of information shared" the most provided a preliminary production plan using optimisation models are used. The use of these models are seen by decision makers to provide more integration and information sharing. The third technology Blockchain is seen to increase

"level of information shared", "agility", and "information shared (invoices, documents)" the most. The blockchain technology is still considered not to be market ready and decision makers suggests to develop prototypes focusing on the three mentioned factors.

Out of the three shortlisted technologies, APS is identified to influence most of the thirteen factors and is seen to be the most suitable technology to improve coordination between material and associated information flow and in turn improve order-fulfilment rate. Additionally, the factor "responsiveness" scores high in APS and is seen by the decision makers and the researcher to increase the final order-fulfilment rate. Responsiveness is a direct measure of order-fulfilment rate (Schulze, 2017).

Recommendations for Airbus are made, and the final pattern artefact or the technology roadmap is created for future implementation. When planning for adoption, it is advised to take a comprehensive approach and incremental measures to guarantee that the rest of the supply chain ecosystem can follow.

The last section of this report details on what further research needs to be explored in this topic in order to improve the generated pattern artefact to a system design or to a algorithm. In order to arrive at the system design, it is suggested to map the process of material and associated information flow for other aircrafts at Airbus and also to explore the same at different large aviation firms.

The contribution of this thesis project is described from three viewpoints. First, from a practical standpoint, the mapping and analysis aided in the knowledge of inadequacies in present inter-organisational processes, where the process was mapped for the first time using the SCOR and UML in this study. Next, the suggested category of digital technology implementations, which may aid practitioners in understanding the many applications of these technologies in the supply chain domain. Third, from a design standpoint, the generated pattern artefact extends knowledge of required elements in the domain of digital technologies systems where: i) relevant factors are identified, ii) the expected benefits are quantified, iii) an artefact leveraging opportunities provided by digital technologies is created, and iv) a spherical view of these technologies is provided.

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1 Introduction

The international trade sector across various industries is set to undergo a change in the coming years (PwC, 2019). This revolution is popularly known as Industry 4.0 or I4.0 in short. The international trade sector comprises of several processes. They include procurement, production, transformation and distribution through a chain of actors (suppliers, producers, transporters). Each of these actors are involved in a variety of activities, including contract management, payments, traceability, labelling, sealing, anti-fraud, and anti-counterfeiting.

Because of the process's complexity, it demands the use of many intermediates for services such as goods transportation, quality inspection, original document distribution, and bank payments. All of which incur substantial transaction costs. During this trade process, errors in manual paperwork may occur and degradation of products quality throughout transportation may arise. This scenario of error (in-effective communication) in paperwork can result in significant delays in delivery at the right time and at the right place. As organisations grow and provide accurate real-time tracking, the volume of collected data also rises. Specifically while trading physical materials (eg. aircraft parts) different independent actors have to collaborate. The different actors may be freight forwarders, banks, seller and buyers. To successfully facilitate transfer of material, each of them must be given the required set of information. The situation is such that key issues such as trust, traceability and transparency are to be solved. Achieving this would mean to continually develop or re-invent supply chain strategies. This becomes key to success in supply chain and more so in highly competitive environments such as the aviation sector where major players are present.

Organisations in this sector have started realising that their ability to continually reinvent competitive advantage is dependent on their ability to look outwards to their supply chain partners, as much as it is on their need to leverage internal capabilities. As markets expand or demand grows, the number of actors in a network also increase to satisfy the demand (Aelker, Bauernhansl, & Ehm, 2013). For example, companies such as Airbus have high levels of demand all over the globe. Their actors range from 15,000 to 18,000 (Airbus, 2020a). Channel partnership makes the process of coordinating and communicating with such huge diverse actors easier. They come up with creative solutions and also put together the best mix of skills that can align not only with their own organisations but also with the desires and needs of target markets.

While Customer service satisfaction, innovation growth, financial performance, channel partnership are some of the key metrics seen by organisations for managing supply chain needs, the COVID -19 pandemic has posed significant challenges globally. Multiple lock downs or barriers continue to slow or even stop the flow of raw materials and goods. The substantial negative effects on supply chain motivated me to choose this topic for my thesis. While these challenges may not be completely new it has helped to magnify and show the already existed challenges in SCM. Though there are several general academic and professional solutions proposed to tackle the growing requirements, focus of my research will zoom into certain challenges within Airbus and recommend possible solutions.

Academic papers from google scholar and science direct articulate that existing technologies used by organisations in their supply chain systems has posed problems in maintaining records of products, enabling coordination and thereby reducing the order fulfilment rate (([Ken Briodagh, 2019](#)), ([Ramadhan, Koutaini, & Ali, 2019](#)), ([Berman, 2012](#))). This problem of delayed order deliveries to the respective customers has been an issue for Airbus as well ([Airbus, 2021](#)). To strengthen collaborative relationships in the modern competitive world and to improve capability of tracking different components or parts, efficient material and information flow becomes the key. Integrating them will result in significant improvements of supply chain performance measured in terms of flexibility, responsiveness and reliability ([Capaldo & Giannoccaro, 2015](#)).

Airbus also called as Original Equipment Manufacturers (OEM's) seeks to focus on the product's core functions while leveraging suppliers' additional capital, expertise, and skills to create lower-cost, higher-quality goods. ([Madenas, Tiwari, Turner, & Woodward, 2014](#)) describes that SCM in the modern world has become reliant on information flow because it serves as a catalyst for communication and development. The advantage to developing a better communication medium or integrating the different flows might provide OEMs the opportunity to focus on the product's core functions while leveraging suppliers' additional capital, expertise, and skills to create lower-cost, higher-quality goods.

Given the current challenge and earlier research findings as stated above, this thesis paper is started with a premise: "Delayed deliveries are caused due to ineffective actions undertaken by different departments such as quality control, procurement, manufacturing and assembly. This causes mis-matched flow of material and information resulting in delay of delivery and impacting their quality and timeliness".

This premise will be evaluated in section 3. Due to the time constraint of the graduation project, the focus of this research is to analyse the material and associated information flow for one single aircraft at Airbus.

1.1 Scope

The scope of this research is to examine material flows, information flows and arrive at a suitable digital transformation map that improves communication and coordination between the two resulting in improved order-fulfilment rate. Digital technologies for better communication and coordination has been in existence since the 1990's. In the recent times, there has been a plethora of technologies have been an interest of study. Industry 4.0 plays a major role in driving these different technologies from design to prototyping. The fourth industrial revolution is known as Industry 4.0. It is being pushed by technical advancements to create a digital manufacturing organisation that is not only integrated, but also communicates, analyses, and uses data to drive more intelligent action in the real world ([Deloitte, 2020](#)).

The scope of this research is to assess which technology advancement(s) can benefit Airbus to improve their communication & co-ordination across the actors. To leverage Airbus supplier's capability, Airbus has also announced on their site that their organisation will develop a prototype for a blockchain system. This system, if found successful will be used for communication of designs between different actors in their supply chain ([Airbus, 2020c](#)).

This research as an extension aims to compare different technologies and arrive at which technologies are best suited for Airbus considering the key KPI's as highlighted by supply chain experts/decision makers. To achieve this, this research is divided into three streams. First is to identify, the factors that influence performance of supply chain through a combination of literature study and remote interviews. Second, to identify the technologies that assist in boosting these factors again through a literature study. Third, is to narrow down on a specific or combination of the said technologies through individual interviews and applying the best worst method on the responses received from the individual interviewees. The three streams are discussed in section 2.3 in detail.

Due to the ongoing pandemic, the scope of the thesis is focused through the lens of Airbus, A350XWB aircraft. This was chosen as there were public materials available to understand the suppliers of Airbus and the related material and information flow. Also, the validation of the key factors and the technologies are arrived through remote interviews with available supply

chain experts and decision makers. The figure 1 depicts the scope of this thesis project.

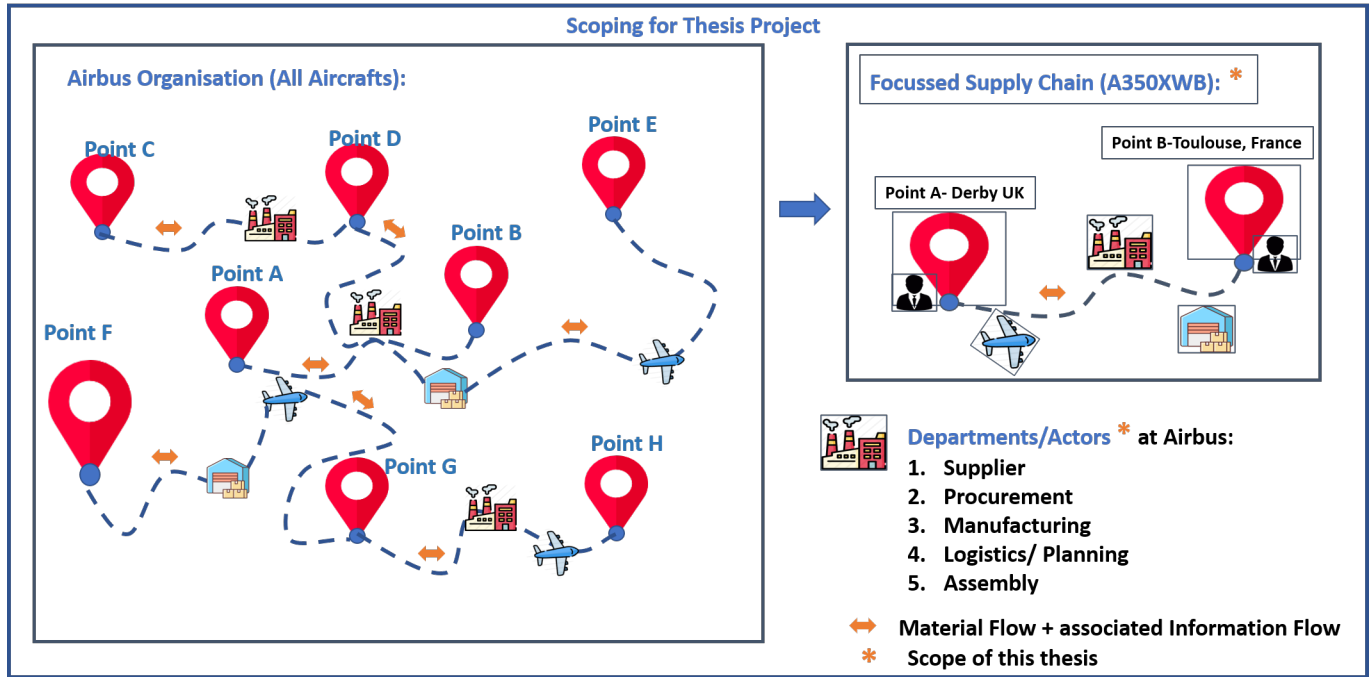


Figure 1: Scoping

Airbus consists of a variety of aircrafts (discussed in table 6) which includes the movement of a million parts between a range of sellers to buyers. Due to the time constraint and information availability, one of the supply chain network of Airbus is studied for this thesis project as depicted in figure 1.

The chosen supply chain network involves that of the A350XWB aircraft at Airbus. The assembly parts such as the wings, hull, fuselage, and engine travels through a variety of different actors such as Airbus and Rolls-Royce. The sub-actors who are considered as intermediaries between the two actors are the various departments within Airbus and Rolls-Royce. These sub-actors are suppliers, procurement, manufacturing, planning and assembly departments. It is seen that the different assembly parts move through the different actors and sub-actors. In order to maintain a consistent order-fulfilment rate, it is necessary to study the functions of the different actors and sub-actors. Studying their functions are seen to give rise to factors that can help improve the order-fulfilment rate from its current state of 42.917% (Airbus, 2021).

1.2 Thesis Objective

The intent of this chapter is to provide clarity on the end goals for this graduation project. The end goals provides the definition and clarity on factors, the key actors, key activities and

key resources that are important for large aviation firms during digital transformation of their supply chain. The objectives defined assist in identifying the level of influence the technologies have on the identified key factors.

In general, all departments undertake certain processes ranging from procuring raw materials, manufacturing, assembling, communicating and transferring the product or a specific part from a particular seller to a buyer. Some digital technologies are seen to improve these processes as described by both professional and research scholars. It will be beneficial to identify these different processes, categorise them as factors and select suitable digital technologies to improve the factors and hence facilitate a smooth flow of materials and associated information. This improved coordination is seen to improve the final delivery of the finished aircraft to the respective customer. In simpler terms, improve the final order-fulfilment rate. The main objective or goal of this research is *to identify, formulate evaluate the different factors and identify suitable technologies that could enhance these factors and provide improved order fulfilment rates at Airbus for the A350 XWB*. The main objective of this paper is achieved through the three different sub-objectives stated below:

1. Understand the information flow and material routes used by the members (Airbus and Rolls-Royce) of the organisation during the inbound and outbound logistics operations.
2. Define and measure the factors based on the researchers understanding, that determine the success of coordination between material and associated information flow in order to ensure customers, the right products at the right time.
3. To identify a solution through comparison of digital technology capabilities that enhances the factors pertaining to both the material and information flow, which can increase the coordination between the two flows and hence increase the final order-fulfilment rate.

The three objectives are separated into three streams of research in this thesis project. The three streams include the analysis of material flow, associated information flow and digital technologies. This is detailed in section 2.4.

In order to define and evaluate the level of influence each technology has over the factors, the communication channels, and the materials that flow, an analysis has to be carried out regarding their current and possible states. This is achieved through a combination of literature study, remote interviews and researchers understanding. The outcome is applied on a set of

different tools such as Supply Chain Operations Reference Model (SCOR), Unified Modelling Language (UML) and Best-Worst Method (BWM). The Design Science Research (DSR) is used to structure this graduation project and achieve the above mentioned objectives. The outcome obtained using this DSR approach is a pattern artefact that provides generalised elements for future design. This outcome is further depicted and described in the form of a supply chain wheel in section 9.

These different tools will be explained in the later sections of the report.

1.3 Research Questions

The research is theoretical, partly qualitative and partly quantitative in nature. Even though researchers and consultant companies have stated the different elements of Digital Supply Chains (DSC) at Airbus, it is critical to do a scientific analysis of the influence on factors by the suitable technologies. Research Questions are framed to serve as input for the objective presented in the previous section. The main research question is: *What percentage of improvement on different processes will digital technologies such as APS/ERP/Blockchain provide to improve coordination between material & information flow and order-fulfilment rate?*

The sub-questions to answer the research question are listed below; it is intended to aid in the research's development. These sub-research questions will be answered in the following chapters. The sub-questions are as follows:

- **RQ1:** How does a material, flow between a seller and a buyer in the A350XWB Supply Chain?
- **RQ2:** How does an information, flow between a seller and a buyer in the A350XWB Supply Chain?
- **RQ3:** How coordinated are the material and associated information flow of the A350XWB aircraft at Airbus?
- **RQ4:** How can firm's improve coordination between material and information flow using the capabilities of digital technologies such as APS/ERP/Blockchain?

Figure 2 on the following page depicts a schematic illustration of the logical sequencing of the sub-research questions. The four sub-research questions are further examined in section 2.4.

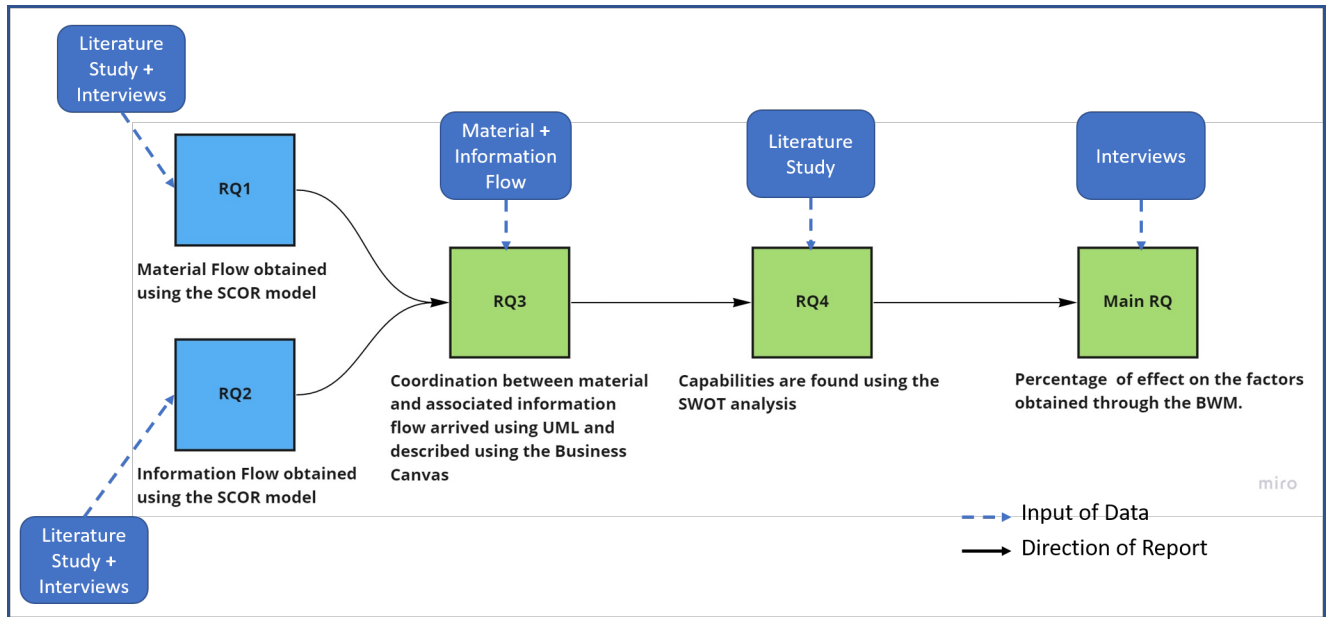


Figure 2: Source of data and Research Questions in a logical Order

Figure 2 depicts the source of data and the logical sequencing for studying the different themes such as material flow, information flow, and digital technologies. The study comprises of different techniques such as literature study and interviews. The processes undertaken during the interview process is explained in section 2.4. The literature study is conducted for three reasons. One, to identify the generic terms for processes carried out by the actors in a large firm. Second, to identify the generic problems experienced by large aviation firms and solutions provided by previous researchers. Third, is to identify existing technologies that exist in the market that is seen to have the capability for improving the identified problems and the premise stated in section 1.

The figure 2 also states the direction of the report. The first and the second sub-research question is used to identify the material and associated information flow using the Supply Chain Operations Reference (SCOR) model to arrive at a business canvas as depicted in section 2.4. The study is conducted in section 5 and 6. The two sub-research questions are then streamlined into the third sub-research question. The third question is aimed towards studying the flow of material and associated information together and is represented using the Unified Modelling Language (UML) in section 6 and the outcome being a business canvas as stated in section 2.4. This is performed in order to identify the activities that slow down the two flows and contribute to low order-fulfilment rate. Once identified, corrective actions are suggested by the researcher through a business canvas in section 6.2. Finally, digital technologies are studied in section 8

further to influence the suggested actions and improve the coordination between the two flows. This improves the order-fulfilment rate. The data for the digital technology is obtained through literature study, described in section 3.4. The outcome of this study indicates the steps to take in order to achieve the research objectives and is depicted in figure 5.

1.4 Relevance

The intent of this chapter is to convey the Academic, Management Of Technology (MOT) and Practical relevance of this thesis project. The academic relevance describes the use of this project in the research field. The MOT relevance describes the relationship and importance of this thesis with respect to the course. The practical relevance describes the use of the end goals in real-life scenarios. This is further elaborated in the below sub-sections.

1.4.1 Academic Relevance

This research focuses on theoretically showing the influence digital technologies have on the processes/ actions (factors) undertaken by the different departments for the aviation industry in supply chain management. The aviation industry is aimed to be identified through the lens of Airbus. To show this the final deliverable will be to quantify the effects or level of influence by certain digital technologies. The selected solution (technology) aims to improve supply chain operations by utilising the selected factors. This statement holds true according to (Kim, 2006). The author states *"in large firms, the close interrelationship between the level of SCM practices and competition capability may have more significant effect on performance improvement"*. The author also concludes that supply chain (SC) integration may be more vital to large firms to improve performance. This integration in SC is taken as the premise to this research and provides the basis for academic relevance. It is to identify these SC best practices and quantify the level of influence to improve the process at the inbound stage¹ of the network.

1.4.2 Management Of Technology Relevance

From the Management of Technology point (MOT) of view, the relevance lies in understanding the required factors for integrating disruptive technologies in an large aviation company. The concepts learnt from MOT such as SCOR model, UML diagram and Best-Worst Method are used to obtain these factors and quantify them. This will be displayed in the form of weights obtained from research, displaying the different levels of influence the factors have over the

¹The part of supply chain involving the movement of materials from suppliers to business

disruptive technologies. The topic of implementation is present and scattered, but its significance in improving supply chain operations has only lately been recognised and addressed ((McKinsey, 2020), (Delloite, 2020)). This paper aims to quantify the influence of certain technologies on certain factors.

1.4.3 Practical Relevance

This thesis focuses on identifying, describing and analysing the various factors present in real-life that could improve order-fulfilment rate. Order-fulfilment rate at Airbus has decreased in the past years. The pandemic situation has further decreased the capability of Airbus to deliver the right product at the right time. There have been some effective attempts under the Industry 4.0 (I4.0) revolution by Airbus, PwC and McKinsey. The attempts undertaken aim to integrate various concepts of I4.0 to facilitate effective information flow between different actors. This graduation project aims to identify the different elements present in real-life that could help facilitate integration of different available concepts into supply chain. The practical relevance of this thesis project comes from this.

1.5 Thesis Flow and Report Outline

This section summarises how the researcher has conducted this thesis project to answer the research question using a flow diagram. Figure 3 depicts the flow of this thesis project.

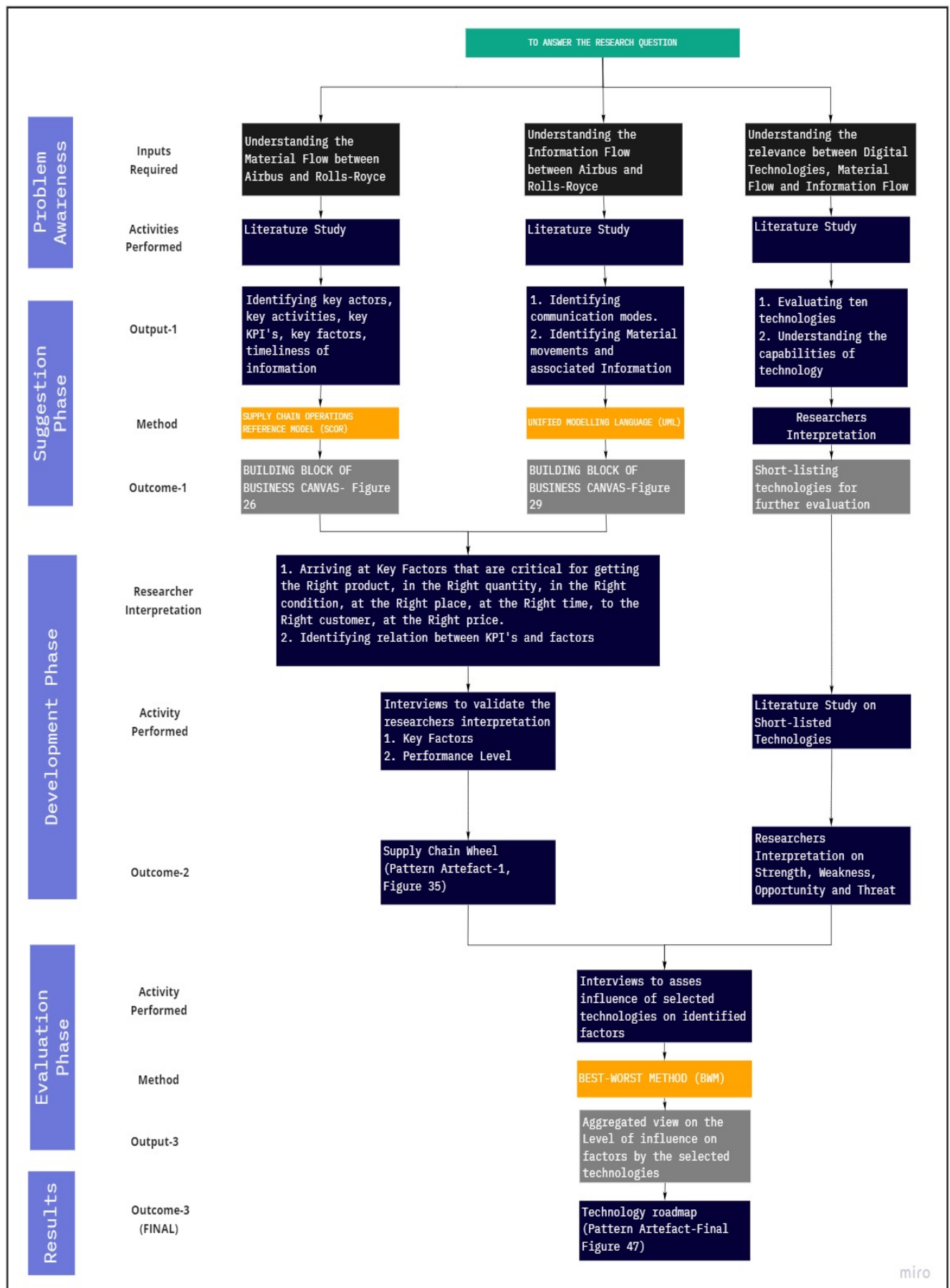


Figure 3: Flow of this thesis project

As represented in figure 3 this research is divided into three streams as mentioned in section 1.1 and are explained below:

1. **Material Flow:** The key actors, key activities, key KPI's, key factors, and the timeliness of information are identified through the use of the SCOR model in section 5 to arrive at a building block of business canvas in section 5.8. The input for the SCOR model is obtained through a combination of literature study and interviews as described in section 2.3.
2. **Information Flow:** The type of information, the modes of communication such as e-mail, manual paperwork are identified and mapped with the information flow using the UML diagram in section 6. The outcome of this study on information flow contributes as the second building block of the business canvas described in the same section. The input for the UML diagram is obtained through two activities performed namely, data gathered in material flow in section 5 and through a literature study as described in section 2.3.
3. **Digital Technologies:** The technologies suitable for improving the coordination between material and information flow that results in high order-fulfilment rate are studied. The suitability of a technology is determined by conducting a SWOT analysis. The input for the SWOT is obtained through a combination of literature study and interviews as described in section 2.3.

The above three streams as indicated in figure 3 are further divided into logical sections, each of which answers the research questions in section 1.3 pertaining to the research topic. This study is exploratory in nature, with a strong focus on the combination of qualitative and quantitative data. It includes both empirical and theoretical findings. The overview of the section in which the thesis paper is arranged is shown in table 1 below.

Table 1: Report outline

Section	Title	Description
1	Introduction	Background study, Scope, Research Question and Research Objective
2	Thesis Project Methodology	Structure of research, Flow of research and sub-research questions
3	Understanding Material Flow, Information Flow and Dig-ital Technologies	Themes such as material flow, information flow and digital technologies are explained in this chapter of the report
4	Practical relevance of Problem at Airbus	Process happening within the company, portfolio of products, Introduction to transportation of A350 XWb aircraft
5	Material Flow and Decision-Making at Airbus	This section explains the roles of different actors, the different departments and their roles
6	Information Flow between Airbus, Rolls-Royce and Suppliers	This chapter explains how movement of different products or parts are being communicated between the different actors,the type of systems used through a business canvas.
7	Proposed Factors and KPI's	The factors obtained from studying the trade flows, information flows, technology and people are combined together in this section to identify how they affect supply chain performance
8	Digital Technologies	This section identifies the different digital communication systems such as ERP, APS and blockchain systems. It identifies the best-fit technology for the identified problem and provides a conceptual model
9	Supply Chain Wheel:Pattern Artefact Development	The process of developing the pattern artefact is described and the section concludes with the development of initial structure of pattern artefact
10	Pattern Artefact Evaluation and Results	The pattern artefact is evaluated through interviews and the Best-Worst Method. The final results are displayed in the form of a technology roadmap, also called as the final pattern artefact.
11	Conclusions,Reflections, Challenges and Limitations	The section describes how the different factors that affect the supply chain performance has to be incorporated into the conceptual blockchain system. Further, the research questions are re-visited and answered

The research organisation and research technique for each topic are discussed in the next chapter.

2 Thesis Project Methodology

The intent of this chapter is to provide an overview of the approach used in this research. The Design Science Research (DSR) technique is followed in establishing the research flow. DSR is a study where researchers gather information in view of what is seen and heard and construe in view of the information gathered.

This method originated from the Information Systems (IS) field to create a pragmatic research paradigm that encourages the creation of artefacts to tackle real-world problems (Offermann et al., 2010). It appears in a variety of fields, including computer science, management, system theory, sociology, finance, economics, and anthropology. This approach is considered suitable due to the ongoing pandemic.

Using the two processes, construction and evaluation of the DSR approach a researcher can generate eight types of artefacts. These artefacts are "system design", "method", "language/notion", "algorithm", "guideline", "requirements", "pattern", and "metric".

From the researchers understanding of the article written by (Offermann et al., 2010), the pattern artefact is arrived through the generation of artefacts such as "method", "language/notion", "guideline", and "requirements". The explanation of these different artefacts and the process are provided below:

1. The "method" artefact is a set of definitions for the activities performed by the actors involved in an organisation. These definitions of activities are already established by the organisation in the case of this thesis project, for example, the procurement department sources raw materials and other required parts for the aircraft.
2. The second artefact "language/notion" is defined as a system to formulate statements that represents the parts of reality. This is excluded as the concepts involving the implementation of the technology are not analysed in this thesis project.
3. The "guideline" artefact is defined as the behaviour of a system in a particular situation. During technology assessment in a dynamic environment such as Airbus, there are a number of possible scenarios to consider. These different scenarios are composed into the Best-Worst Method (BWM) in this thesis project. This makes the study of one particular scenario irrelevant for this study.

4. The "pattern" artefact provides generalised system design elements that can be used for many different kinds of application. The objective of this study is to identify the capabilities of digital technologies to improve the set of identified factors and in-turn improve order-fulfilment rate. Factors are defined as the various activities or actions a firm should undertake in order to improve coordination between the flows. This is called as the pattern artefact and is one of the main outcome of this project.
5. The other two artefacts namely "system design" and "algorithm" involve knowledge in designing and computer programming. This is considered as out of scope for this thesis project.

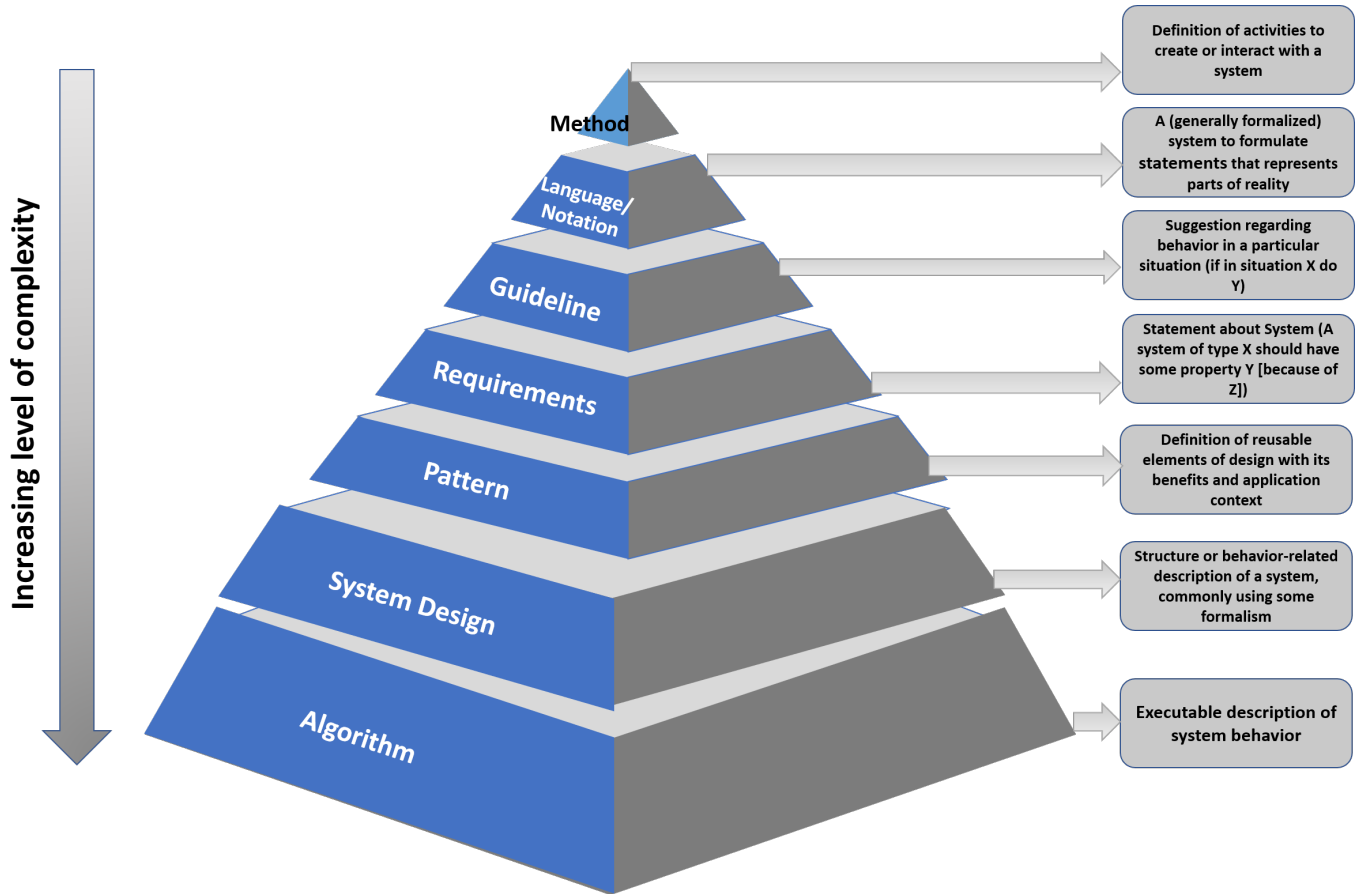


Figure 4: Types of artefacts arranged in ascending order of complexity, Developed by researcher from (Offerman(2010))

(Offermann et al., 2010) provides the definitions of the artefacts and explains the level of complexity of each artefact. This depiction of complexity is shown in figure 4.

2.1 Incentive for employing DSR

In essence, this strategy is employed when digital artefacts must be generated and evaluated in a cyclical manner and are appropriate for resolving organisational issues (Offermann et al., 2010). DSR is widely used in information systems research and digital innovation. An information system (IS) is a collection of interconnected components that work together to gather, organise, store, and communicate data. Information systems are critical in an inter-organisational supply chain, and they include the complementary networks that individuals and organisations use to collect, store, process, and distribute data.

This strategy was chosen due to the exploratory stage of technology development and the prospects for establishing inter-organisational information systems in international physical material trade. Information systems are extremely important in international trading, as companies can use them to execute and track their processes (Kuechler & Vaishnavi, 2008). Communicating and sharing information in real time with partners or consumers might help businesses acquire a competitive advantage in the market.

For the purposes of this study, it is proposed that a design science method be used, with the goal of pushing the boundaries of an organisation's current capabilities by creating novel artefacts. This technique will provide a clear conceptualisation that will aid in the understanding, execution, and evaluation for further research.

2.2 Generating a Pattern Artefact

The intent of this section is to elaborate the five stages to arrive at a pattern artefact. The DSR approach consists of five phases. They are "problem awareness", "suggestion", "development", "evaluation" and "results". This approach is based on the framework presented by (Kuechler & Vaishnavi, 2008) and the respective mapping is depicted in figure 5.

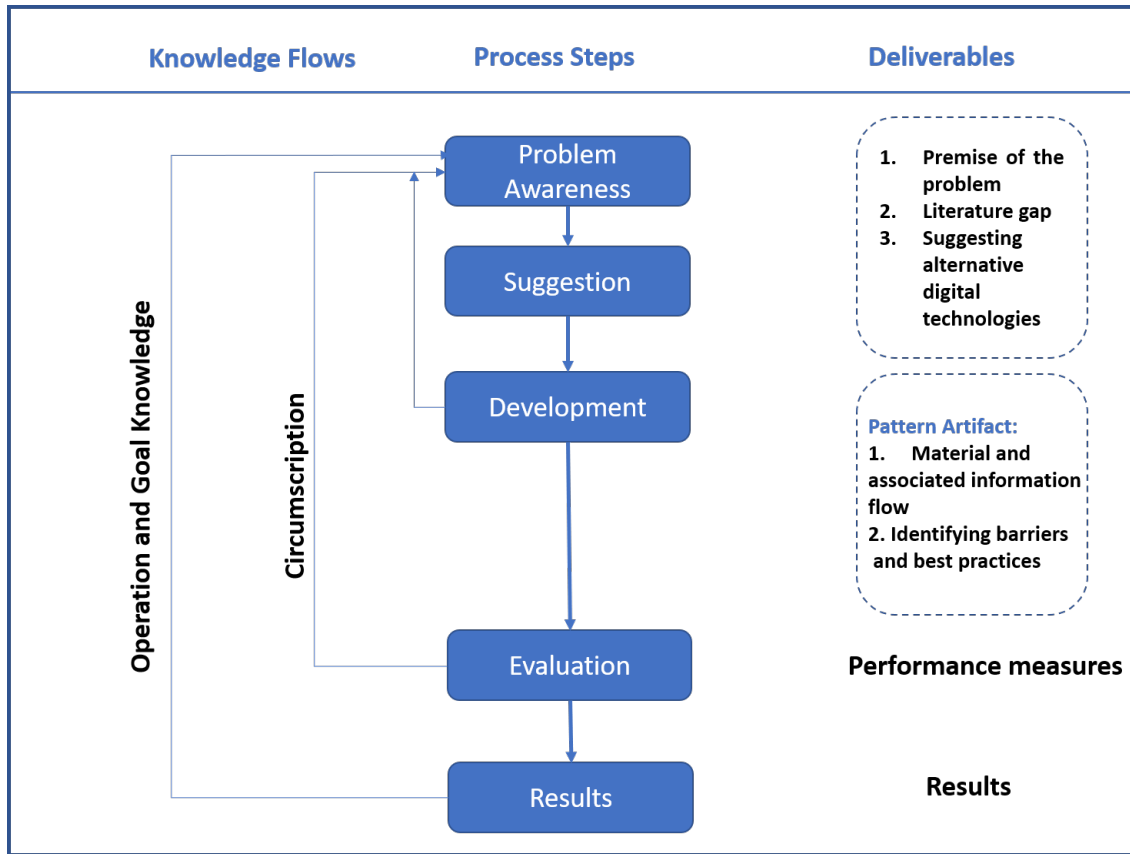


Figure 5: Mapping of DSR phases to deliverable
(Kuechler & Vaishnavi, 2008)

The explanation for each of the five phases are provided below:

1. **Problem awareness:** The problem was confirmed through the means of a premise for improving order-fulfilment rate through technology implementation. Here, a proposal for a new research occurs. In this step, resources such as literature research and expert interviews were employed to help understand the problem at hand. This step is concluded by identifying the different flows and shortlisting the different technologies.
2. **Suggestion:** The different digital technologies presumed to improve coordination between the two flows are analysed through literature review. Next, the different activities that contribute to delayed order-fulfilment are identified. This step is concluded by suggesting a set of actions to convert these non-value add activities to value add activities.
3. **Development:** The different process associated with the material and information flows are analysed using the SCOR model in section 5 and the UML in section 6. The explanation of these tools used are provided later in this section. This step is concluded by

generating a **pattern artefact**. A pattern artefact provides generalised system design elements that are useful for future implementation of digital technologies. In this step, the researchers findings on the material and information flow, as well as the capabilities of the chosen digital technologies, are all combined together in single solution space called as pattern artefact.

4. **Evaluation:** After the artefact has been created, it will be assessed against the criteria that arose from the problem and solution objectives. At this point, the premise can be compared to the artefact to see if the technologies chosen will improve those factors. This is further presented to decision makers and evaluated using the BWM. This step concludes by stating the usage of the generated pattern artefact.

The evaluation is done using the BWM, the process through which BWM is incorporated is described later in this section.

5. **Result:** All the factors are compiled in a tool to identify suitable technology that could improve the coordination between material and associated information flow resulting in improved order-fulfilment rate.

Further to the overview of the research elaborated above, the thesis report moves to describe the tools that are used to gather, organise and arrive at a suitable digital technology that improves the coordination between the materials and associated information flow resulting in improved order-fulfilment rate.

Now that the overview of the research is presented, the tools used to gather data and a summary of each chapter is further explained below.

2.3 Thesis Flow Elaboration

The above chapters covered the research objective, main research question and sub-questions. The objective is to generate a pattern artefact that highlights key factors to improve information flow and material flow, resulting in improved order-fulfilment rate. The graduation project identifies the factors that contribute to the success of communication channels and the technologies that achieves it the most. The technical details of implementation and the detailed implementation process have been neglected as information pertaining to them are not readily available.

The intent of this section is to provide a short description of contents written in this report. The

section aims to provide clarity on relevant topics and on the manner this research is structured. The main research question mentioned in section 1.3 is answered in following steps:

1. The thesis project is divided into three streams namely, material flow, information flow and digital technologies. The data for the three streams are collected through a combination literature study as described in section 3 and remote interviews.

Through this study, the problem that causes the delayed deliveries, mis-matched flow of information becomes clear. This concludes the problem awareness phase as described in DSR in section 2.2.

2. From the first stream "material flow" the actors, activities and relation between the actors and activities are studied using the SCOR model in section 5. This method is used to arrive at a building block of business canvas in section 6.2. Throughout this process the actions that contribute to delayed order-deliveries are identified and corrective steps are suggested in the form of factors.

These factors are also represented as a part of the business canvas to provide clarity to the reader on the various findings obtained.

3. From the second stream "information flow" the modes of communication between the actors to perform activities are identified. This is represented through the use of UML in section 6. Further corrective set of actions are suggested to increase mis-matched flow, order-fulfilment rate.

Both of the streams are integrated together and presented in a final business canvas in section 6.2. This concludes the suggestion phase of this thesis project.

4. The third stream of study which is "digital technology" is studied to understand the capabilities of the technologies that assist in improving order-fulfilment rate. This is done through the use of a literature study in section 3.4.

This third stream of study is integrated with the material and information flow to generate the pattern artefact in section 9. This concludes the development phase of this thesis project.

5. The pattern artefact is further evaluated using the BWM in section 10. The outcome of this phase is an improved pattern artefact that is seen to assist companies in identifying

a suitable digital technology. This concludes the evaluation phase of this thesis project.

Currently Airbus and Rolls-Royce uses a combination of tools to communicate associated information for transporting different components. They are done using manual paperwork and Enterprise Resource Planning (ERP) system. Airbus hasn't yet implemented any of its applications into their supply chain networks as it is conceptual at the moment. Exploration of blockchain integration to their supply chain system has been underway for the past two years. "ADAM" is the open source blockchain network, which aims to develop an digital asset management platform for multiple applications (Airbus, 2020c). The cost allocated and the pilot year for the program have not been released publicly. Other information regarding the area of application, the type blockchain used are discussed elaborately in section C. To determine if the selected technology is truly effective for the organisation and to identify what factors helps in making this determination valid, the research is made exploratory in nature.

The entire research flow / direction has been depicted in figure 6 followed by short descriptions & relevant sub-research question.

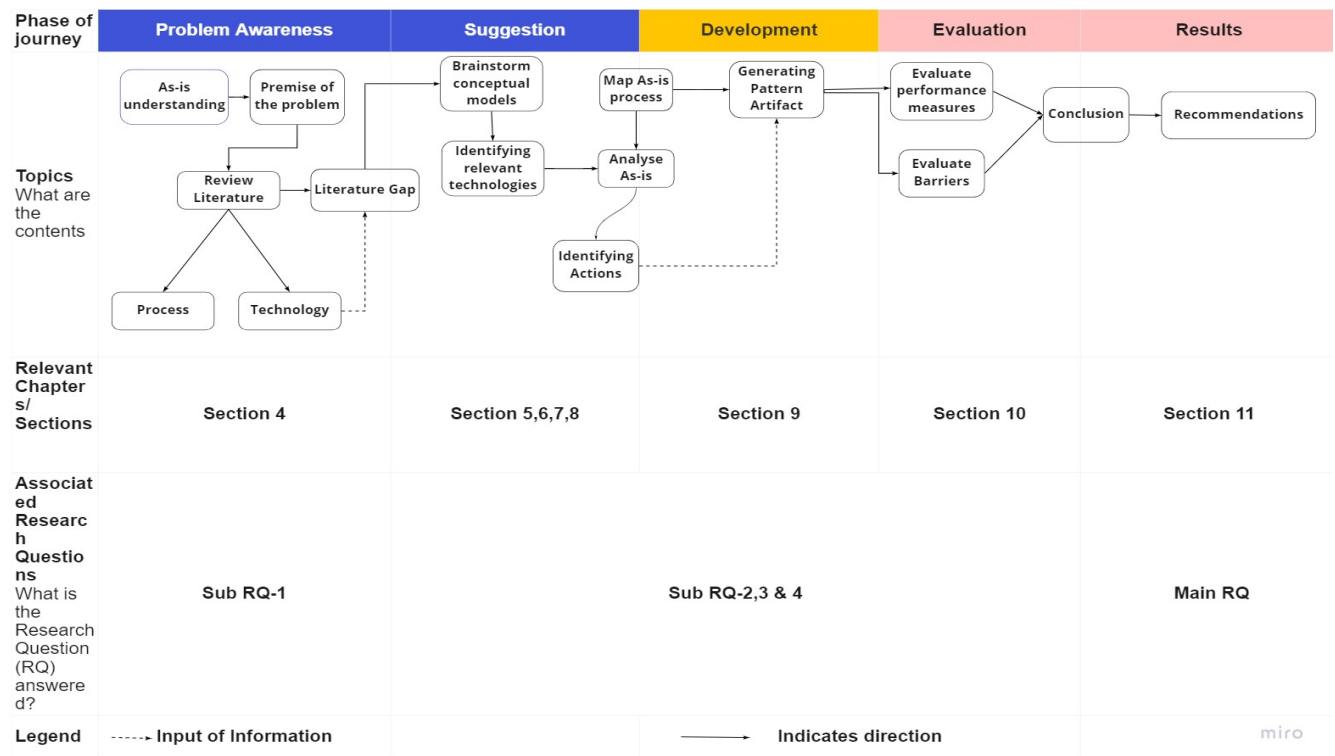


Figure 6: Research flow according to DSR

Practical Relevance of problem at Airbus

The aim of this section is to explain the orientation of different actors or departments at Airbus with respect to their A350 XWB aircraft. It identifies the different raw material supplier, part suppliers, their locations, the type of facility they have and the relation with Airbus. The section also introduces the system in which Airbus classify their suppliers. The information required for this section is compiled using various academic literature, interviews conducted and publicly released documents by Airbus.

The section would provide clarity on the different parts, the actors roles and the complexity of the supply chain. It would introduce the several drawbacks in this complex supply chain network and elaborates more on the premise. Thus guiding us to the focal point of this research paper.

Material Flow and Decision-Making at Airbus

The intent of this chapter is to introduce the various material flows withing Airbus. The section describes the several processes such as procuring raw materials, production of different aircraft parts, assembly of parts and delivery of parts to the respective customer for the A350XWb aircraft. This section also matches the several process with associated departments within Airbus facility. Here some of the best practices to improve coordination and order-fulfilment rate for respective departments are obtained through literature study and interviews.

1. Procurement department
2. Production and service
3. Assembly department
4. Product transfer department

The section provides clarity on the inbound logistics involved and introduces the reader to another major player Rolls-Royce to the picture. This section partly addresses the first research gap and begins to answer the following sub-research questions:

1. *How does a material, flow between a seller and a buyer in the A350XWB Supply Chain?*

Material Flow from Rolls-Royce to Airbus

The section explains the importance of the actor Rolls-Royce, their suppliers for the parts required to manufacture the engine Trent 1000 for the A350 XWB aircraft. Secondly, it describes

the type of communication that takes place while the parts are being transferred from one point to another. The data is collected majorly through interviews and articles available online. It is then categorised by using the certain elements of the Supply Chain Operations Reference (SCOR) model. Level 1 and Level 2 are analysed using the SCOR model. This section further extends the answer to the following research questions.

1. *How does a material flow between a seller and a buyer in the A350XWB Supply Chain?*
2. *How does a information flow between a seller and a buyer in the A350XWB Supply Chain?*

Coordination of Material and associated Information Flow

This section details the flow of information happening while products or parts are being moved. It also describes the type of technology used to communicate the required information and the type of access the several actors have in these systems. This section compiles the several factors that have been observed through interviews and how they are related to constructs (trust and traceability) in academic literature. The Level 1 of the SCOR model is used to indicate the current supply chain performance at Airbus and confirming the premise stated earlier. The current coordination between information and trade flow are indicated using the UML diagram. The section describes how Airbus plans to integrate the two flows using the blockchain technology and the value proposition of Airbus. The sub-research questions answered in this section are,

1. *How coordinated are the material and associated information flow of the A350XWB aircraft at Airbus?*
2. *How can firm's improve coordination between material and information flow using the capabilities of digital technologies such as APS/ERP/Blockchain?*

Digital Technologies

This section lists and compares the different technologies from literature study in section 3.4 that is identified to improve the integration between information and material flow. Ten digital technologies were chosen for evaluation and three systems were shortlisted based on the four criteria "features", "security level", "interoperability", and "ecosystem". The shortlisted technologies are Enterprise Resource Planning (ERP), Advanced Planning System (APS) and blockchain technology. The general advantages and dis-advantages of the chosen technologies are discussed first. The sub-research question answered by this section is, *How can the dif-*

ferent processes pertaining to material and information flow be coordinated better, using the capabilities of digital technologies such as APS/ERP/Blockchain?

Analysis of selected Digital Technologies

The final chapter of this report explains the factors derived in detail and explains their relationship with the constructs trust, traceability and performance within organisations. The factors identified in section 6.2 that are related to the constructs and is presented to supply chain professionals to select the "improved" and "yet to improve factors" by the respective technologies. The interviewees responses are applied using the Best Worst Method (BWM) to find the level of influence each technology has on the identified factors. The outcome of this answers the sub-research question:

1. *How can firm's improve coordination between material and information flow using the capabilities of digital technologies such as APS/ERP/Blockchain?*

This approach helps us to understand the problem at hand in a subjective manner for a single organisation. Also, presenting this solution after the analysis will help Airbus to frame strategies for future development projects and will inform them the important factors or elements that should be included as a part of their strategy for good supply chain performance. The steps taken to achieve this objective are discussed briefly below in 2.4.

Best-Worst Method (BWM)

The DSR is used to generate a pattern artefact (the objective) as mentioned in section 2. This artefact provides system design elements (factors) that are generic and can be employed in a variety of situations. The factors obtained from this artefact are applied onto the Best-Worst Method. This method scientifically helps to quantify and determine the influence of the factors onto each of the disruptive technologies.

BWM is precisely used to resolve a Multi-Criteria Decision Making (MCDM) problem situation, so the factors obtained here are treated as multiple criteria. In a MCDM problem, a number of possibilities are weighed against a set of criteria (s) in order to select the possibility (Rezaei, 2015). Decision making frequently involves imprecision and ambiguity, which fuzzy sets and fuzzy decision making procedures can efficiently handle. Solving an MCDM problem entails a subjective appraisal of the decision maker's preference system as well as an objective analysis of the impact of alternatives on selected attributes.

There are a number of subjective appraisals are possible during technology implementation in a large firm. This BWM provides quantitative measures by encompassing some of the subjective appraisals provided by experts in respective fields. The final result will be indicated with a tree chart that provides a comparison between the chosen technologies.

2.4 Data Collection Approach

This thesis project is divided into three streams which are, material flow, information flow and digital technologies. The data for the material flow in section 5 and information flow in section 6 is collected through a combination of literature study and remote interviews. Due to the ongoing pandemic, the availability of decision makers were less, so the researcher also used a literature study to collect necessary data. For instance, the key actors and activities were identified through the publicly available documents and the movement of material through these actors were identified through interviews. There were instances where the decision makers themselves directed the researcher to their sites for relevant data.

The third stream digital technology is one such instance, where one of the interviewees directed the researcher to the official site. This official site consisted information of Airbus' current approach to improve coordination between material and information flow that could result in improving order-fulfilment rate as described in section C. The data for the digital technologies, their capabilities and the suitable criteria were obtained entirely through a literature study. This literature approach is used as the decision makers themselves were not aware of potential technologies to improve coordination and improve order-fulfilment rate.

The outcomes through the literature study and the remote interviews were used to map the SCOR model in section 5, map the UML diagram in section 6 and perform the SWOT analysis for identifying capabilities of digital technologies. Further interviews were conducted to identify a suitable technology for improving the coordination between material and associated information flow that results in improved order-fulfilment rate through the use of BWM in section 10.

Data collection from Literature

A search for scholarly articles / journals on the usage of blockchain technology in supply chain management yields a variety of results and is more generic in nature. While the articles/ journals used in this study were found on Google Scholar, the substance of these articles/ journals

are not relevant much to the study itself. The journals reviewed describes the progress of blockchain technology in terms of it's maturity. They also provide different applications for the different technologies in several fields. Majority of the articles reviewed states the advantages and disadvantages of blockchain, ERP and APS in supply chain management separately, which is, different when compared to the scope of the study. The relevant search terms for identifying literature were "asset management", "IoT", "trust", "traceability", "blockchain at Airbus", "digitisation in supply chains", "supply chain performance" and "digital supply chains". Some of the information for analysis using the SCOR model in section 5 were also obtained from publicly available documents published by Airbus and Rolls-Royce. The relevant information were identified with terms such as "Make-to-order", "Production", "transportation" and "warehouses".

The search terms assisted in identifying the processes within the company and provided a theoretical understanding of Blockchain, ERP, APS and factors affecting performance of supply chain in organisations. It is also to note that the parameters for performance might differ from one organisation to another.

Data collection through interviews

Interviews of six experts were conducted at the start of this research to obtain information on the location of facilities, roles of managers in the supply chain sector, the mode of transportation of assembly parts to different facilities of Airbus. Also, this approach was taken to understand the different concepts used if any at Airbus. The interview processes were conducted to understand the broad problem perspective and to partly answer the first and third sub-research question. The process of interviews involved professionals from Airbus and related to Airbus. Furthermore, it was discovered that in certain situations, professionals were uninformed of the existence or even the potential of a blockchain integration process, showing that decision-makers themselves had knowledge gaps. This opened up the possibility of studying the different factors that affect not only blockchain integration but also the other systems with the current procedure with these groups.

The interview questions were first unstructured and deductive. This was done in order to grasp the scope of the problem. The questions are all open-ended. This was mostly done in order to comprehend the problem and determine the research's objective. Some of the questions put-forth were:

1. *"The customer airline conducts a thorough inspection before accepting delivery of an aircraft and signing the title transfer. It is represented by a group of experts whose task it is to inspect the aircraft for compliance with the contract requirements"-> To what extent do you agree with this statement?*
2. *How does Airbus receive requirements from the customer?*
3. *How often does the communication happen between the customers and Airbus?*
4. *If the assembly parts are made-to-order, how does the request for required parts processed?*

These questions are designed to gather basic information about Airbus' supply chain management and asset tracking capabilities. The responses gave insight into Airbus' supply chain system, different partners, their location and type of communication system used. Professionals with both technical and management background are chosen for the interview. The Professionals are located in United Kingdom and India. The answers obtained through these questions are briefly discussed in section 5 through the use of SCOR model.

The analysis of the material flow, mode of communication and communication channels lead to identify the factors that influence the supply chain performance. To identify the level of influence in these factors, a second set of interviews were conducted and interpreted using the Best-Worst Method (BWM) as described in section 2.3. The interview consisted questions such as:

1. *Which technology increases the "level information shared"?*
2. *Which technology improves "product ID"?*

Level of information shared and Product ID are two of the factors that helps in increasing effectiveness of material flow through communication channels. Detailed descriptions of these factors are provided in sections 5,6 & 9.

2.5 Research Type: Exploratory

(Uma Sekaran & Roger Bougie, 2016) define exploratory research as "A research where a very little knowledge or information is available on the subject under investigation". This type of study is chosen for this research due to the fact that limited information on technology implementation was available. Secondly, the concept of smart supply chain is fairly new to both the professional and academic world. Lastly, the research demanded data collection from

interviews, surveys and literature study.

2.5.1 Step by Step Research Approach

This section describes the research strategy for structuring each section (4 to 10). It is described more below.

Section 4: Practical relevance of Problem at Airbus

The main aim of this chapter is to describe the practical challenges in large aviation firms. This is understood through the lens of Airbus where the researcher has highlighted the different departments, various tiers of suppliers within Airbus. In addition, the researcher has also adopted literature study and unstructured interviews to understand their practical challenges. Face-to-face interviews were not possible because to COVID-19 constraints, but telephonic interviews provided valuable information.

Section 5: Material Flow and Decision-Making at Airbus

The main aim of this chapter is to identify the routes of the various components present in the A350 XWB aircraft. The different departments through which these components are identified. This helped in understanding the different factors influencing the performance of supply chain. Structured interviews were conducted with managers in the supply chain department to identify routes. Additionally, academic literature was used to attach factors to the respective departments.

Section 6: Information FLOW between Airbus, Rolls-Royce and Suppliers

The chapter focuses on describing the different documents required for transporting the part or component. Additionally, it describes the various digital technologies used to communicate between the actors. The research approach for this chapter is a combination of interviews and literature study. Knowledge gaps identified in interviews were filled with literature study. This helped in identifying the level of coordination between the two flows.

Section 7: Proposed Factors and KPI's

This section focuses on explaining the obtained constructs, factors and KPI's from the study of material and associated information flow. A mapping of these different constructs, factors and KPI's to the different activities at Airbus is done in order to make the reader better understand the influence the constructs, factors and KPI's have at different stages of the process. Further this section captures the current level of influence these factors have on the respective processes

and introduces the topic of digital technologies.

Section 8-9: Digital Technologies and Pattern Artefact Development

The section focuses on identifying the different technologies available to improve the coordination between the two flows. The section also introduces the strategy using the strengths and opportunities of these technologies. Finally, the factors are explained, presented (through interviews) and recorded using the Best-Worst Method (BWM). The best suited technology to solve the above stated issue is identified and the pattern artefact is generated. The pattern artefact aims to provide necessary elements for digital transformation² in the future.

Section 10: Pattern Artefact Evaluation and Results

The obtained results through the BWM is depicted graphically, compared and evaluated. The level of influence each technology has on the identified factors are described individually. The final pattern artefact is evaluated and enhanced further.

²Implementing digital technologies or solutions to transform existing processes

3 Understanding Material and Information Flow, Digital Technologies

The intent of this section is to describe the three streams as in the flow diagram in section 2 of this thesis project which are, "material flow", "information flow" and "digital technologies". Airbus is an international organisation that comprises of various suppliers and actors across the globe. This makes it essential to understand terminologies associated to material and information flow, standardisation process adopted by the different actors in the aviation domain. Also, this thesis is focused on identifying a suitable digital technology and it makes it essential to study different digital technologies that increase coordination between the two flows that results in improved order-fulfilment rate. Hence this thesis project is divided into three streams to focus on studying material flow, information flow and digital technologies. The three streams and their purpose are stated below:

1. The first stream is regarding the review of international trade. The review is funnelling towards one single supply chain network.
2. The second stream is regarding the review of information flow. The review is funnelling towards the above indicated single network.
3. The third stream explores different digital technologies and integrates the first two streams. The review funnels towards further study of set technologies.

These streams of literature reviews were conducted in order to:

1. Define the thesis's fundamental concepts such as "material flow", "information flow" and "digital technologies"
2. Understand the existing state of affairs such as different standards followed, types of digital technologies and terminologies in material flow.
3. Understand the different solutions proposed by academic researchers to enhance the coordination between material and information flow for large firms.

A preliminary search was conducted utilising multiple databases, including IEEE Xplore, Science Direct Search, and Google Scholar, in order to identify the core topics of this thesis. Examples of key words used are "inter-organisational trading", "complexity in supply chains",

"international trade law", "materials trading contracts", "strengths and weaknesses of international trade", "Digital technologies in supply chain", "blockchain eco-systems", "ERP for supply chains", "APS for supply chains", "Smart contracts", "prototypes of digital technologies in supply chain", "smart contracts", and "applications of digital systems in supply chains".

The research began with the gathering and examination of relevant material, which assisted the researcher in developing a broad understanding of the subject. Due to the novelty of integrating digital technologies in supply chains, there were limited articles and use cases available. A few research articles were examined in order to gain an understanding of the status of the different technologies, as well as concepts and challenges that are currently being addressed. Additionally, professionals in the field of supply chain were interviewed and journals were carefully read to assist in theory building.

For the three literature streams, the snowballing method was utilised to conduct a systematic literature review. Snowballing is a way of identifying further publications by using "the reference index of an academic paper or the citations to the paper" (Jalali, Wohlin, & Angelis, 2014). In certain cases such as the digital technologies, the method of reverse snowballing was utilised. This involves tracing research papers from the latest year to the past years. Utilising this method provided insights into basics of the different technologies.

When the credibility of new and less sophisticated sources (e.g. conference proceedings or references from presentations, periodicals, or blogs) was questioned, backward snowballing was applied. Forward snowballing (i.e. looking for citations to a helpful work) was used to assess suggested hypotheses, confirm their acceptability by the scientific community, and find feedback and criticisms on papers.

It is worth noting that the researcher was obligated to search for certain keywords on a frequent basis owing to the topic's uniqueness and the fact that multiple angles were available.

3.1 Common Problems in International Trade

International trade in the modern world depends on the coordination of several modules or entities. The different entities include procurement, production, assembly, transportation, payment and transfer of ownership across the globe as stated by an employee at Airbus. One of the key problems in a global scale or otherwise known as international trade according to (Ross & Ross, 2015), is the development of a network that allows collaboration across organisational

boundaries in an adaptable, flexible, and dynamic environment that is both dependable and secure.

It is also stated that a lack of coordination develops as a result of information asymmetry, and in this situation, the supply chain's performance is affected. Furthermore, it is identified that trade expenses in international commerce are significant and include transportation costs, border-related trade obstacles, and distribution costs. The actual cost of international trades ranges in the amount of trillions and that around 4 billion dollars are lost due to the above mentioned problems (IOTA, 2020).

3.2 Material Flow in International Trade

Material in this context can be defined as a basic good, that has partial but substantial flexibility. In layman's terms, a material is a "good" that may be exchanged for other materials of the same sort (Chatani, 2002). While the quality of a particular product may vary slightly from producer to producer, it is basically uniform. For example, a raw material such as Ti or Cu is the same as an component such as Blades and Fuselage regardless of the manufacturer or producer.

Materials may go through numerous transformations from their raw condition to a form that may be used, and they generally include risk owing to the uncertainty of future market prices. Material trading organisations may offer expertise on both risk management and material trading between different entities. Materials may undergo different types of transformation, some of which are ((Chevallier & Ielpo, 2013)):

1. **Spatial:** The transportation of materials from one location to another is known as spatial transformation.
2. **Inventory:** This transformation of material is defined as the storage of a material and transporting it at a later time.
3. **Form:** This transformation includes processing such as manufacturing of materials. For example, Ti alloy to Ti blades for engines.

Materials traded on exchanges must fulfil specific requirements established by exchange rules. Product trading is often done through futures contracts (Digital or through manual paperwork), which specify the quantity and minimum quality of the material being traded. When trading, the cost of shipping, storage, and spoiling must be included in. As a result, most materials are

traded on futures exchanges. In simpler terms, they are made-to-order.

The standardisation of material quantity and quality is an essential aspect of exchange traded material futures contracts. Specifications may vary by material, but the uniform contract is used for all deals. The majority of Airbus parts are traded under the First Article Inspection (FAI) ([Airbus, 2020a](#)). The FAI is a formal technique of giving a reported measurement for each produced feature of a component or assembly, as well as a design verification and design history file. Typically, the FAI is performed by the supplier, and the report is reviewed or approved by the customer. The quantity of the same materials are documented using the First Article Inspection Report (FAIR). The standards and document records all necessary information and makes the supply chain more efficient.

First Article Inspection is a needed document for approval of material. It is part of AS9145, which is a requirement standard for Advanced Product Quality Planning and Production Part Approval Process (APQP/PPAP), Phase 4. Many significant aerospace businesses, including Airbus, Boeing, and Spirit AeroSystems, have lately implemented upgraded FAI's. This is done in order to keep track of the various first articles received by different companies along the company's supply chain ([Pennella, 2006](#)).

3.3 Supply chain in Aviation Industry

The generic overview of key supply chain considerations of the aviation industry are depicted in Table 3. The related activities from design to consumer use includes planning procurement, standardisation processes, manufacturing and delivery. Among these key considerations the three forms of transformation takes place. They include an array of players such as engineers, technicians and logistics planners.

Table 2: The aviation supply chain
([Ernst & Young, 2018](#))

	Design and Engineering	Planning	Procurement	Product Manufacturing	Delivery	Aftermarket
Who	Engineers	Supply chain professionals	Suppliers	Manufacturers	Aviation organisation	Manufacturing, Repair and Overhaul
What	FAA	EAQG, AOCM	FAI	FAI	FAA	IAQG
Where	Toulouse, Spain	Germany, Toulouse	Eg. Redditch, Japan	Germany, France, USA	Germany, France, USA	India, China

Table 3: Caption

The "what" in Table 3 indicates the different standards followed by different actors or entities in the supply chain. Wherein FAA stands for Federal Aviation Administration, AOCM stands for Aircraft Out Of Standard Parts. These different standards are incorporated into a single document, which is described in section 6. Currently, this document is transferred through a digital platform at Airbus. This digital platform is an Enterprise Resource Planning (ERP) system known as "Net-Inspect". This digital technology like all others consists of certain capabilities to improve coordination between material and associated information flow, thereby improving order-fulfilment rate. To identify these capabilities, alternative technologies and their capabilities the literature study on "digital technologies" is conducted in the upcoming section.

3.4 Digital Technology Literature Study

The concept of digital technologies were introduced in the field of supply chain by the Industry 4.0 revolution. A plethora of technologies are available (as in Table 4) in the market to enhance supply chain performance. This study is further elaborated in section 8 by identifying capabilities of the narrowed down technologies.

This section identifies ten different technologies that are potential to improve coordination between material and information flow. Further assessment assisted to shortlist three technologies largely based on four criteria which are, "features", "security level", "interoperability", and "ecosystem". The existing solutions provided by the academic researchers in the form of conceptual model further helped to arrive at the pattern artefact.

Table 4: Comparison of Technologies, developed by the researcher based on:
(Varma, Management, & undefined 2014, n.d.)

Technologies	Features What are the advantages of the technology?	Security Level Level of Trust and safety provided by Technology	Interoperability How well does it integrate with existing equipment?	Ecosystem Strength of connectivity between partners
Cloud Computing	Integration of modules	High	Medium	Low-medium
Big Data Analytics	Predicts Demand	Medium-High	Low	NA
Augmented Reality	Prototyping	NA	NA	NA
Electronic Data Exchange	Information Sharing	Medium	Low	Medium
Digital Twin Model	Asset tracking	Medium-High	Medium-High	High
Blockchain	Immutable, records transactions	High	Medium	High
Autonomous trucking	Compliance, asset tracking	Medium	Medium-High	NA
ERP	Integration of modules	High	High	Low-medium
APS	Integral Planning, Demand Management	High	High	NA
ML/ AI	Demand Management	Medium-High	Medium	Medium

In the industry 4.0 domain, there are different communication technologies. Each of them have their own features and disadvantages when applied to organisations. (Varma et al., n.d.) lists, describes and compares these different technologies for supply chains at large firms. The technologies such as "augmented reality", "electronic data exchange", and "big-data analytics" have been neglected for this thesis project. The reason being, these different technologies have low or medium interoperability, which means they have less capability to work with existing equipment. The second reason being, the features such as demand prediction and information sharing for big data analytics and electronic data exchange are not fully available. This is due to the lack of standardisation within the system.

The three criteria "security level", "interoperability" and "ecosystem" on which the technologies are selected poses business benefits. Ecosystem streamlines the actors journey in the system,

that is, a relationship between all business actors will become more interconnected. Higher the security level of the digital technology, the better prevention of sensitive documents from leakage to third parties. Higher levels of interoperability in a digital technology reduces the costs endured by the organisation. APS, ERP and Blockchain is seen to have high or medium level of the three criteria and is implicitly understood to be better when compared to the other technologies.

Some of the readily available ones are described below ((Atos, 2018), (IOTA, 2020), (Deskera, 2020), (de Santa-Eulalia et al., 2011)):

- **Digital twin model builders:** In traditional SCP systems, the model has to be configured step by step, such as the bill of materials for a product, the routing, and the setup time for a manufacturing machine. However, DT is a solution in which an AI system develops and builds the graph database and links, as well as picks and applies important business rules, allowing people to draw out their value chain more quickly.
- **Blockchain:** Blockchain is a Distributed Ledger Technology (DLT) that is shared, immutable and facilitate the tracking of assets. Additionally, it has the capability to record transactions. There are three generations of blockchain present, they are :
 - Blockchain 1.0: This is the first generation of blockchain which only contained a currency.
 - Blockchain 2.0: This generation of blockchain expands from the concept of currency to tracking assets in real time.
 - Blockchain 3.0: Decentralised applications (Daaps) have been developed into other domains that are deemed more general purpose industries including government, health, and science, in the third generation.
- **Autonomous trucking:** Autonomous and connected vehicles (collectively referred to as "automated vehicles" or "AVs") have the potential to have a significant impact on almost all aspects of today's most pressing trucking issues, including hours-of-service regulations, compliance, safety, driver retention, truck parking, driver health and wellness, congestion, and driver distraction.
- **Enterprise Resource Planning (ERP):** This is a software that businesses use to manage and integrate activities such as procurement, project and risk management. It

helps organisations to plan their next activities in an efficient manner.

- **Advance Planning and Scheduling Systems (APS):** APS is a tool that assists companies in planning the entire supply chain network through development of mathematical models. These models help companies to align their supply chain activities to demand fluctuations.
- **Machine learning (ML)/ Artificial Intelligence platforms (AI):** These platforms enable businesses to absorb vast volumes of historical and real-time streaming data, analyse and process it. Post processing the data the software evaluates if applying machine learning or AI algorithms and approaches to the data would yield reliable prediction for supply chain operations.

Out of the six different technologies, ERP systems, APS and blockchain have end-to-end capability such as data storing, interpretation and analysis. The other three namely, digital twin, AI/ML platform and autonomous trucking depend on a central or distributed database for communication of information. Hence, the research focuses on only three technologies, namely ERP, APS and blockchain. These technologies are analysed in length later in section 8. Further to identify research gaps in technology implementation, conceptual models for the three selected systems (ERP, APS, Blockchain) are studied below.

3.4.1 ERP For Supply Chain Management

When different enterprises come across a number of independent information systems across organisations, they usually consist of large amounts of accumulated, non-standard information in various departments, functions, and business processes throughout the company. This lack of standardisation poses a problem of communication through the digital system due to the heterogeneous formats ((Tsai, Fan, Leu, Chou, & Yang, 2007), (Häkkinen & Hilmola, 2008)). A ERP system is seen as a viable solution to standardise several modules for connecting data from various parts of the company. Each module (for example, finance, logistics, order fulfilment, and production) denotes a distinct organisational function. As a result of connecting these modules, data from various functions is integrated, providing managers with the necessary knowledge to capture a larger picture of the firm's activities and make more educated real-time choices.

To achieve this ideal state, there are certain measures that should be undertaken. The first measure include implementation of RFID devices in warehouses or during transportation. The

second measure is deciding the level of integration between different actors present in the supply chain. (Oghazi, Fakhrai Rad, Karlsson, & Haftor, 2018) establishes four different levels of integration, they are depicted in the below figure 7.

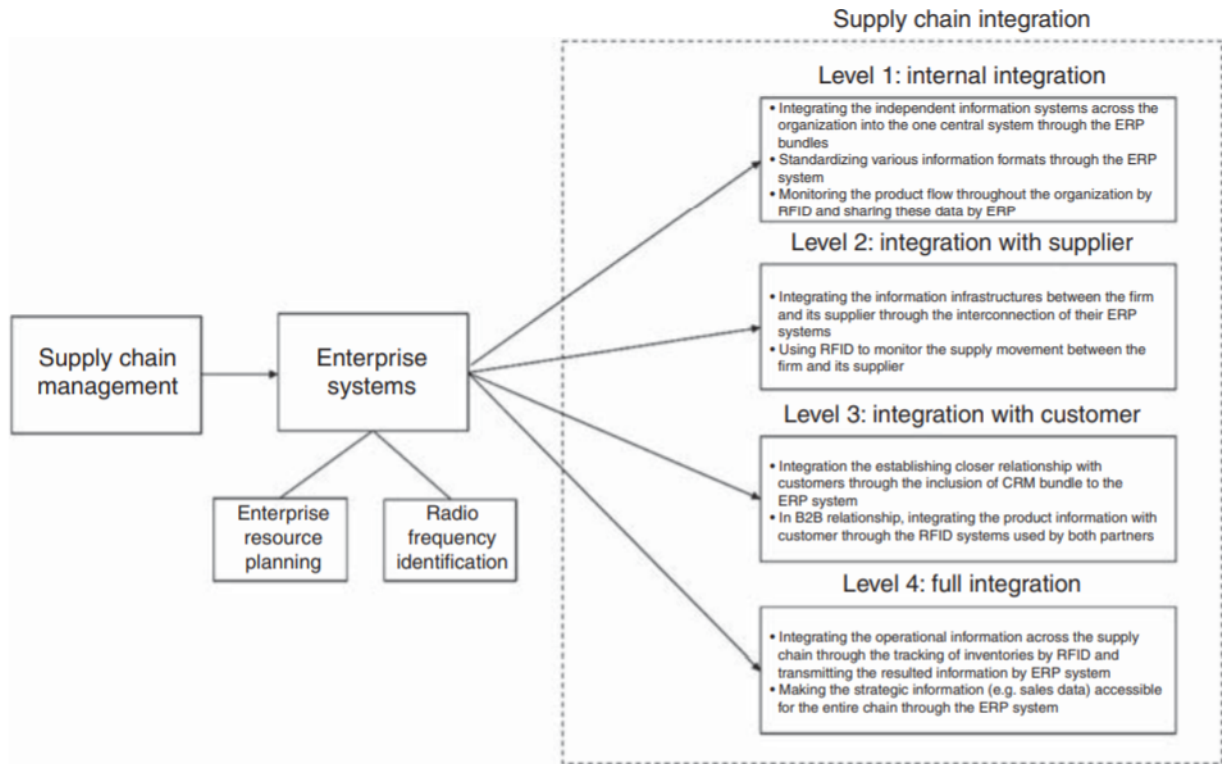


Figure 7: Levels of integration in ERP systems

(Oghazi et al., 2018)

This conceptual model provides direction for the technologies implementation from it's initial stages to full integration. However, the effect or the influence this technology could have on the companies performance is not indicated in this paper. The framework is established without the consideration of everyday processes in supply chain. This is an important aspect to consider as it changes with respective to the organisations. Despite the missing aspects in this conceptual model, it is considered as a basis for ERP implementation.

Another research paper written by (Zeng & Pathak, 2003) depicted a conceptual model for ERP systems is the form of electronic hubs or e-hubs. The author categorised each department of the aviation supply chain in the form of hubs and identified missing links in them. The final model of this process was depicted the type of integration that could result in increased performance. The conceptual model is depicted in figure 8.

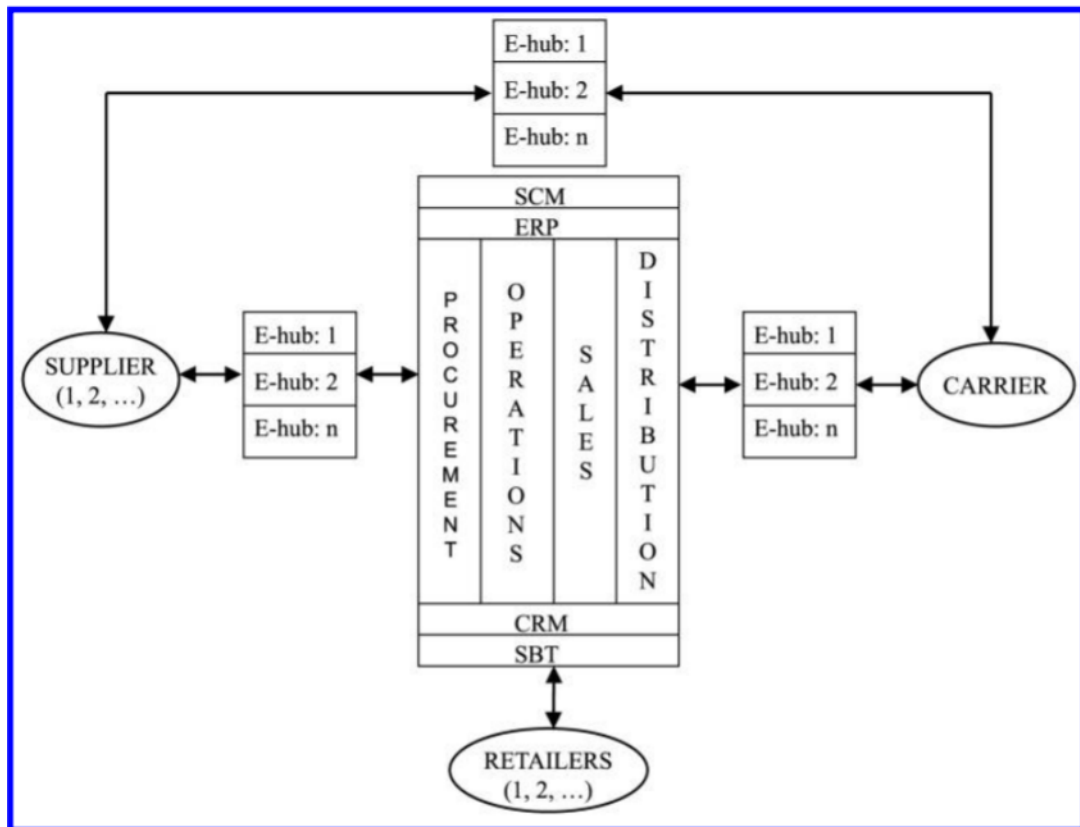


Figure 8: Conceptual model of ERP system indicating the type of information flow
(Zeng & Pathak, 2003)

The above depicted model explains the integration between different suppliers, departments and retailers through ERP systems. The similarity between figure 8 and 7 is seen by the list of actors. The latter ignores "level of integration" and "supporting technologies" in their study. Regardless, the overarching theme of the two remain the same.

3.4.2 APS For Supply Chain Management

Advanced planning and scheduling (APS) is a sort of cost-tracking system that is based on the activities that generate costs in the manufacturing, production & assembly of materials (Rudberg & Thulin, 2009). An APS balances demand and plant capacity by allocating raw resources and production capacity appropriately. Such a system could be suitable for large firms to improve order-fulfilment rate. This is the reason for this technology to be selected.

APS offers reliable planning aims to take into consideration the finite nature of resource capacity and other restrictions (Rudberg & Thulin, 2009). APS does not presume that capacities are unlimited, that all customers, goods, and materials are of equal value. Some characteristics (such as lead times) can be set, just as in a typical ERP systems. Furthermore, APS are not

restricted to the planning and scheduling of a single plant. Rather, they are applicable to supply chains including numerous locations and transportation linkages. The same author (as above) also proposed a conceptual model for APS at large firms. The same is depicted in figure 9.

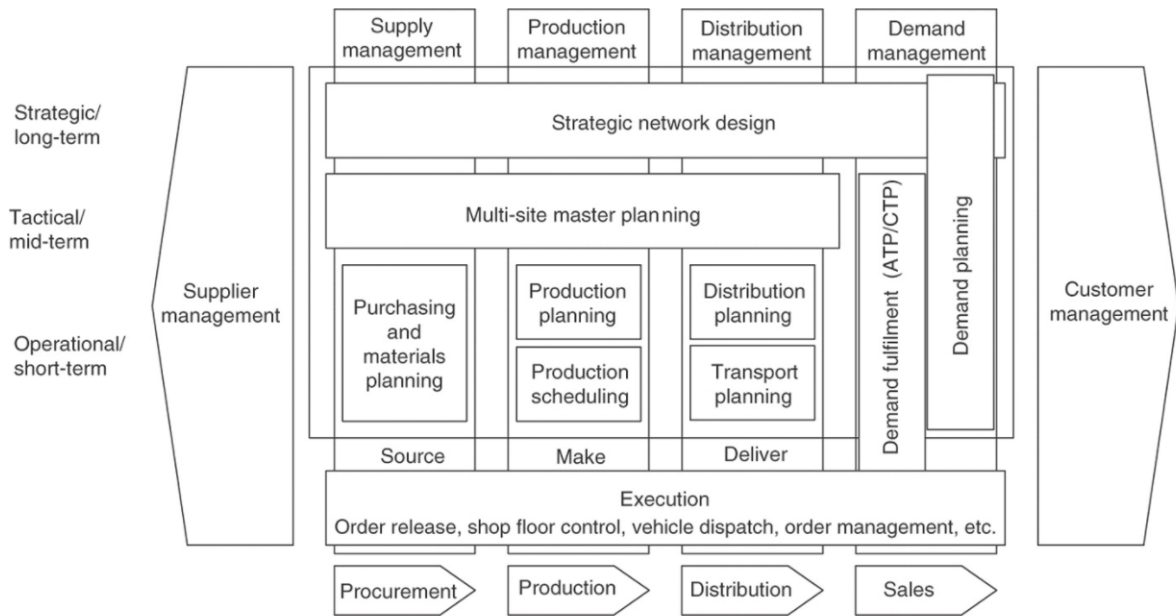


Figure 9: Conceptual model for APS technology at large firms
(Rudberg & Thulin, 2009)

Yearly budgets, weekly forecasts, access to raw materials and customer order serves as input to the different modules indicated. The algorithm designed by the particular company calculates the lead times for manufacturing. This could be particularly helpful for companies (aviation sector) seeking to optimise supply chain process. Majority of academic papers identifies the opportunities, weaknesses and capabilities of APS ((de Santa-Eulalia et al., 2011), (Stadtler, Kilger, & Meyr, 2015)). The inclusion of different departments and complexity of day-to-day processes seems to be excluded.

3.4.3 Blockchain system for Supply Chain Management

A common definition of blockchain is that *it is simply a digital record of transactions that is replicated and distributed throughout the blockchain's complete network of computer systems*. Each block on the chain comprises a number of transactions, and whenever a new transaction happens on the blockchain, a record of that transaction is added to the ledger of each participant.

Over the years this technology has evolved from being a currency to a platform on which different subject matters are exchanged. Blockchain has undergone changes, which can be categorised in generations. The first generation blockchain consists of currencies. The second generation consists of tracking capability of assets. The third and the ongoing generation consists of decentralised applications or Daaps that allow industry level applications. To get better equipped with the concept of blockchain, the "internet" analogy is depicted in figure 10.

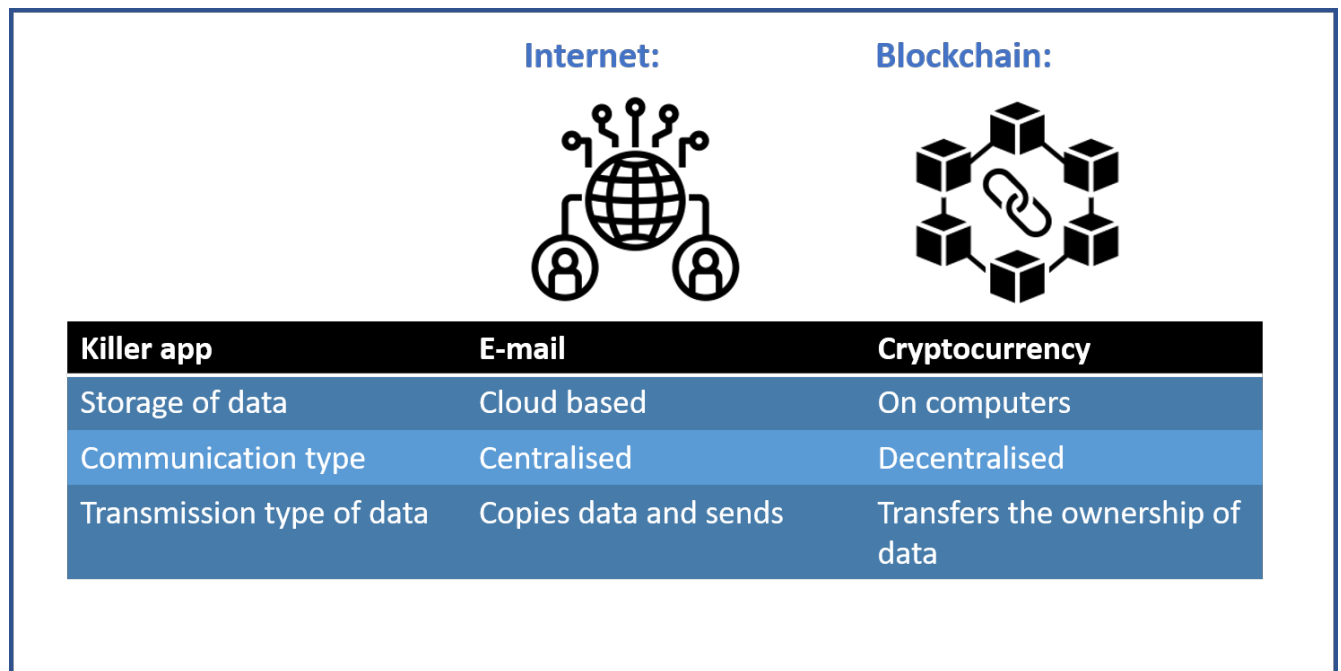


Figure 10: The Blockchain and Internet Metaphor (Developed by the researcher from understanding of literature)

Due to the novelty of the topic, the conceptual models available were few. One such model was framed by the academic researcher (Wasim Ahmad et al., 2021). This conceptual model is depicted in figure 11. As seen from the figure, the model integrated stakeholders such as Original Equipment Manufacturers (OEM), Inventory manager, Engineer and Component Shipper. It provides the types of information to communicate between these different stakeholders.

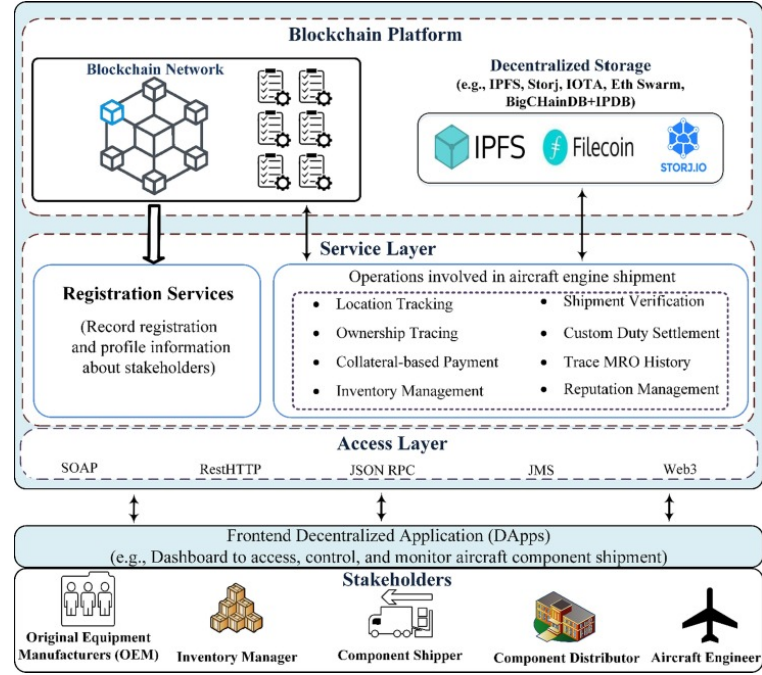


Figure 11: Conceptual model for blockchain system in supply chain management
(Wasim Ahmad et al., 2021)

The identified downside of this model is that, it ignores issues such as certifications of suppliers and level of involvement of suppliers. These issues hinder the full potential of blockchain and the model in its day-to-day use. The second model studied was framed by a blockchain company IOTA (in figure 12).

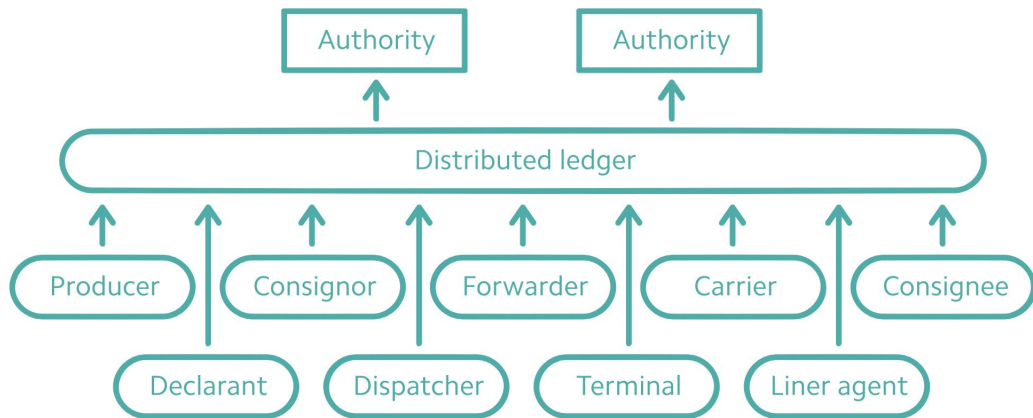


Figure 12: Conceptual model for blockchain system
(IOTA, 2020)

This model in the above figure depicts the direction of information flow in an large organisation. It is a broad model presented by the company IOTA to indicate the future scenario of blockchain systems. This scenario encompasses an ideal world of different modules integrated. However, in the real world, there are certain boundary conditions present under the category of business, regulation, supply chain and traceability (Behnke & Janssen, 2020).

3.5 Sub-conclusions

The literature study is divided into three streams they were, material flow, information flow and digital technologies. Material flow is defined as the movement of commodities between a seller and a buyer. When materials flow between a buyer and a seller, it undergoes different types of "transformation". The types of transformation are "spatial", "inventory", "form". During the transformation process in an aviation industry there are certain "common problems" such as development of a network that allows collaboration across their supply chain network (Ross & Ross, 2015). This lack of coordination might result in information asymmetry and impacts order-fulfilment rate.

To tackle this problem of low collaboration, Airbus developed an ERP system to reduce information asymmetry called as "net-inspect". The incorporation of this ERP and a document known as the FAIR document following certain standards managed to improve order-fulfilment rate. The literature study is used here as per the directions of one of the interviewees.

To further improve this problem of low order-fulfilment rate other digital technologies were shortlisted based on four criterias "security-level", "features", "ecosystem", and "interoperability". The shortlisted three technologies were ERP, APS and Blockchain. Different conceptual models of the shortlisted technologies were studied to identify potential improvements to the existing design. It is identified that the conceptual models did not recommend a set of actions to achieve their end goal that is to improve coordination between the flows that results in improved order-fulfilment rate. The reasons for lack of this data and steps taken by the researcher to develop a pattern artefact that describes the set of actions for Airbus to achieve this end goal is explained below:

1. Absence of clear understanding on the precise movement of materials from a buyer to a seller and the associated communications between inter-organisational network.

Researcher, using SCOR model has described the movement of materials and associated

information flow in section 5.

2. Scarcity of literature that consists of set of actions to overcome complexities and other barriers in supply chain management.

A set of actions are recommended for the organisation Airbus and it presented in the form of factors in section 9

3. Lack of literature that quantifies level of influence each of these technologies provide to better equip best practices within the organisation.

The impact each technology has on the identified factors are evaluated using the Best-Worst Method (BWM) and presented in section 10.

The above indicated steps are performed in order to generate the pattern artefact. Each of the steps indicated above are used to answer at-most two sub-research questions explained in section 1.3. The relation between these steps and the sub-research are indicated in table 5.

Table 5: Mapping of steps to take and sub-research question

Sub-Research Question (Reference: section 1.3)	Missing parameters and approach taken
1. How does a material, flow between a seller and a buyer in the A350XWB Supply Chain? 2. How does an information, flow between a seller and a buyer in the A350XWB Supply Chain?	Absence of clear understanding on the precise movement of materials from a buyer to a seller and the associated communications between inter-organisational network. Approach: Supply Chain Operations Reference Model (SCOR) and Unified Modelling Language (UML)
1. How coordinated are the material and associated information flow of the A350XWB aircraft at Airbus? 2. How can the different processes pertaining to material and information flow be coordinated better using the capabilities of digital technologies such as APS/ER-P/Blockchain?	Scarcity of literature that consists of set of actions to overcome complexities and other barriers in supply chain management. Approach: Recommending set of actions based on researchers understanding
1. How can the different processes pertaining to material and information flow be coordinated better using the capabilities of digital technologies such as APS/ER-P/Blockchain?	Lack of literature that quantifies level of influence each of these technologies provide to better equip best practices within the organisation. Approach: Best-Worst Method (BWM)

The literature gap has been established through this review of several academic literature. Following the DSR approach, the literature gaps (in table 5) are addressed and the research questions are answered in the upcoming sections.

4 Practical relevance of problem at Airbus

The goal of this chapter is to gather all relevant data about the material flow of A350XWB aircraft parts. The research aims to find a solution to the research question RQ1 in section 1.3 using the DSR approach. The flow of this approach is explained in section 2. Figure 13 overlays the sections and sub-research question on the DSR approach.

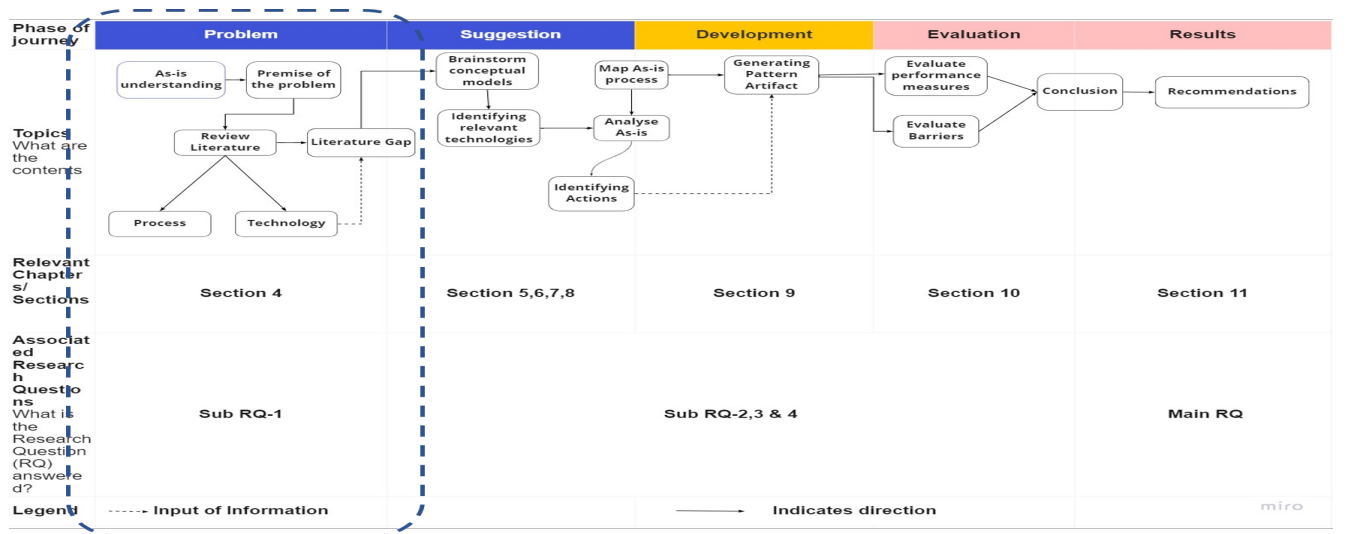


Figure 13: Problem phase in accordance to DSR approach

A rounded view of the current situation is necessary to identify relevant factors, literature analysis, practitioner involvement, and the application of suitable modelling approaches. This section will elaborate the same. First, the environment in which these processes take place will be presented. Following that, the actual day-to-day process will be mapped out, which will include all of the steps required for an international trade of aircraft parts. At the end of this section, the mapped process and respective stakeholders within the scope of analysis will be described and analysed further.

4.1 Case of Airbus

The company chosen for this graduation project is Airbus, as market leaders in the aviation industry and with the assumption that implementing the right technology will be one of their key drivers towards their future strategy.

In the aerospace industry, Airbus is a global leader. They design, produce, and supply industry-leading commercial aircraft, helicopters, military transports, satellites, and launch vehicles for customers all over the world, as well as providing data services, navigation, safe communications,

urban mobility, and other solutions. They are located in several parts of Europe such as France, Germany, Spain, Russia and Turkey. The different locations or facilities of Airbus have specific functions with respect to material flow ranging from procurement, manufacturing, assembly and delivery. The functions of the different facilities differ with respect to the type of aircraft. They are also situated throughout the globe in parts of Asia, Americas and Africa, with different functions in commercial aviation, defence and Space programs ([Airbus, 2020f](#)).

Focus for the research papers is limited to commercial sector of Airbus and to improve their supply chain performance. The focus aircraft would be the A350 XWB, which is an aircraft with one of the highest operational efficiency and the most used aircraft. This is one particular aircraft which also has less order intakes and most outstanding orders at the moment, according to the information published on Airbus's site the total order intake is 3100 and the total delivery made is 2305 ([Airbus, 2021](#)).

A representative business process that would demonstrate how physical trade of materials was required and is now implemented in this part of the report. This business process would serve as a foundation for obtaining the accompanying information flow, which is needed to generate the pattern artefact.

The actual transfer of aircraft parts is normally governed via standardised contracts issued by the FAA, FAI, and IAQG trade associations, as described by literature study conducted in section 3. These identified standards are applied to the case of Airbus and elaborated using the SCOR model as indicated in section 2.4.

The standards to be followed, as well as the descriptions of aircraft parts, are standardised and defined in those contracts, and they have an impact on how the business process is carried out. One such contract named First Article Inspection Report (FAIR) was found to be standardised by Airbus ([Airbus, 2020a](#)). However, the routes, structure of organisation and steps taken in order to execute material flow was not found in literature. Hence, the process is recorded for the first time in this report.

Much of the information regarding the actors, their process and trade routes were available publicly. However, certain experts were interviewed in order to provide input for studying the key activities, key actors and relationships between activities and actors. The question asked to these experts are described in section 2.

4.2 Description of Process and Actors within Airbus

The intent of this section is to describe the different actors, the activities performed by them and the direction of material and information flow in the A350XWB supply chain. The spatial transformation of aircraft parts between buyers and sellers is part of the process to further trace and expand in. In the case of Airbus, the buyer and the seller may be from the same or different organisation. This depends on the respective aircraft part undergoing spatial transformation. It is identified that irrespective of the aircraft part, they are transported using the FAIR document and under the same organisation rules (Airbus, 2020a).

There are several actors spread across the globe at Airbus. Some of these actors are in direct relation with Airbus while others have to contact Airbus through a mediator. For this purpose, Airbus has segregated their suppliers into different classes and tiers. Classes are actors who have a specified role such as production unit, logistics department and procurement department as indicated in figure 14.

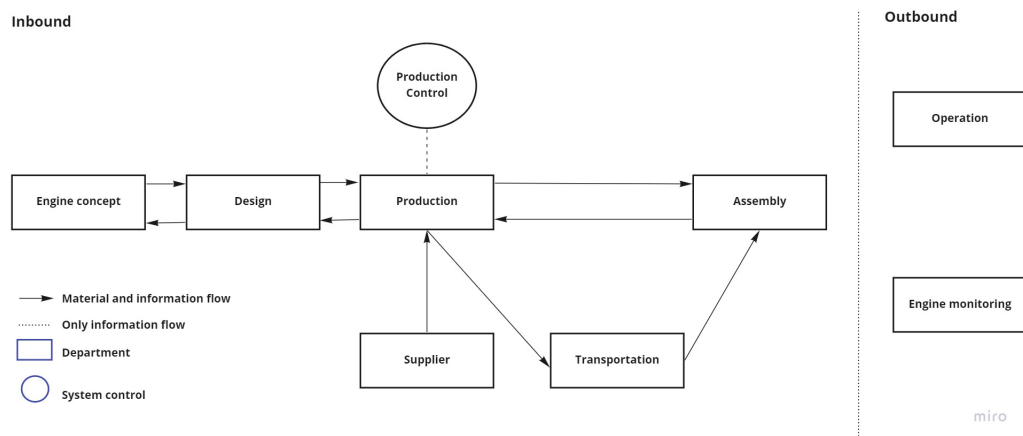


Figure 14: Outlook of different classes

(Gary Wills & Richard Michael Crowder, 2007)

The main focus is "on-time" production, therefore all the information starting from concept to final delivery has to be coordinated properly in order to maintain their competitive advantage (Airbus, 2020b). Communications between these different classes are two-way in order to revise any faults that may occur during the entire process. The departments indicated in figure 14 are situated at different parts of Europe and the world. Secondly, tiers are established in the supply chain network to establish a vertical form of communication as indicated in figure 15. These divisions are structured to maintain records on the different raw material suppliers that are not in direct contact to Airbus but are in direct connection to their main player Rolls-Royce

(Airbus, 2020a).

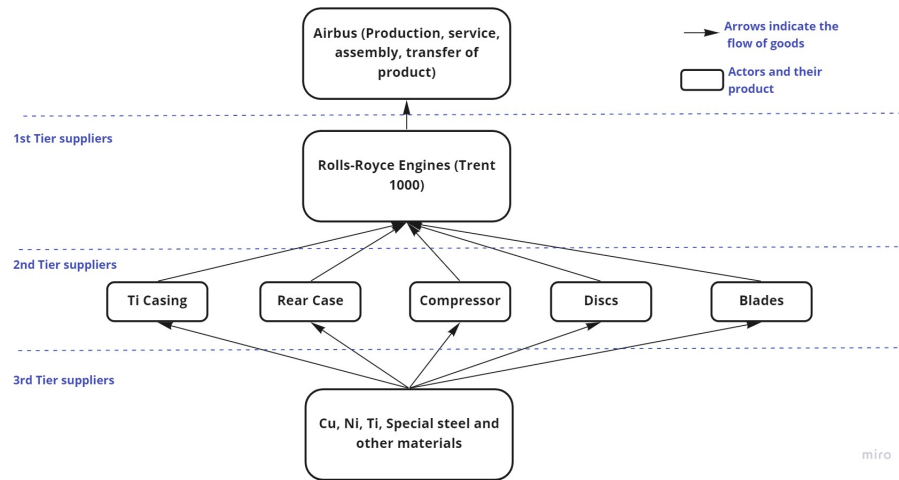


Figure 15: Outlook of different tiers (adapted from the interviews conducted at Airbus)

Figure 14 and 15 depicts the process between the several departments (actors) at the highest degree of abstraction. It is presumed here that an agreement for a specific aircraft part or product has been reached between a buyer (e.g. Rolls-Royce) and a seller (e.g. Airbus), and that a binding contract has been signed. The seller is responsible for delivering the product to the buyer at the right place at the right time. The buyer's responsibility would be to present a schedule or a date in which he/she is willing to receive it. As a result, there is a flow of materials from the seller to the buyer, as well as a constant flow of data (information) between the two parties.

The seller might run into delays in their respective processes and might not deliver the material at the right time. The buyer might also experience in delays of production or other uncertainties, which restricts them to supply a concise schedule. Due to this lack of traceability within the organisation, a streamlined, consistent and simultaneous flow of information and material does not occur.

Due to limited availability of public materials on this, the above figures 14 and 15 are described taking into consideration Rolls-Royce, as Rolls-Royce is one of the largest and key actors for Airbus.

4.3 Types of Aircraft at Airbus

There are different families of aircrafts present at Airbus. The most common families of aircraft are the A350, A220, A320 and A330 (Airbus, 2020f). The chosen aircraft for this study

A350Xwb falls under the family of A350 and has the highest operational efficiency and the most popular flight of Airbus. The biggest challenge is, it has a major order backlog. The other aircraft that falls under this family is the A350-900, the comparison in their performance is shown in table 6 below.

Table 6: Portfolio Comparison based on:
(Airbus, 2020f)

S.No	Performance metric	A350 Xwb	A350-900
1	Range	16,100	15000 Km
2	Mmo	M0.89	M0.89
3	Max Ramp weight	319.9 tonnes	280.9 tonnes
4	Max take-off weight	319 tonnes	280 tonnes
5	Max fuel capacity	159000 L	141 000 L

In the A350 aircraft supply chain there are different type of flows such as material, technology, people, information and financial flows. Following the direction of premise and literature study, the researcher will analyse material and information flow in the following sections.

4.4 Sub-Conclusions for Practical Relevance

In this section on practical relevance the researcher described various actors within Airbus and their respective locations. The researcher also outlined the standards that are followed within the company for movement of materials. This is further elaborated by defining the inbound and outbound part of the A350XWB supply chain. The literature study conducted by the researcher also indicates the different tiers in the supply chain network and their vertical form of communication. An outline of multiple types of aircrafts is highlighted. This section provides the basis of material flow between the different actors involved in the A350XWB supply chain. Also, the understanding of the key actors, process and the type of aircraft aids in the understanding of the material and information flow described in sections 5 and 6.

5 Material Flow and Decision-Making at Airbus

The abstract view of the types of actors, processes and their structure in the A350XWB supply chain were described in the section 4. The intent of this section is to describe the roles, responsibilities and decision process of the actors to facilitate material flow. Additionally, the best practices are also gathered using academic papers. This makes the research partly shifts from the problem awareness phase to the suggestion phase as indicated in flow diagram 3. Figure 16 also indicates the sections where the suggestion to the research question is elaborated.

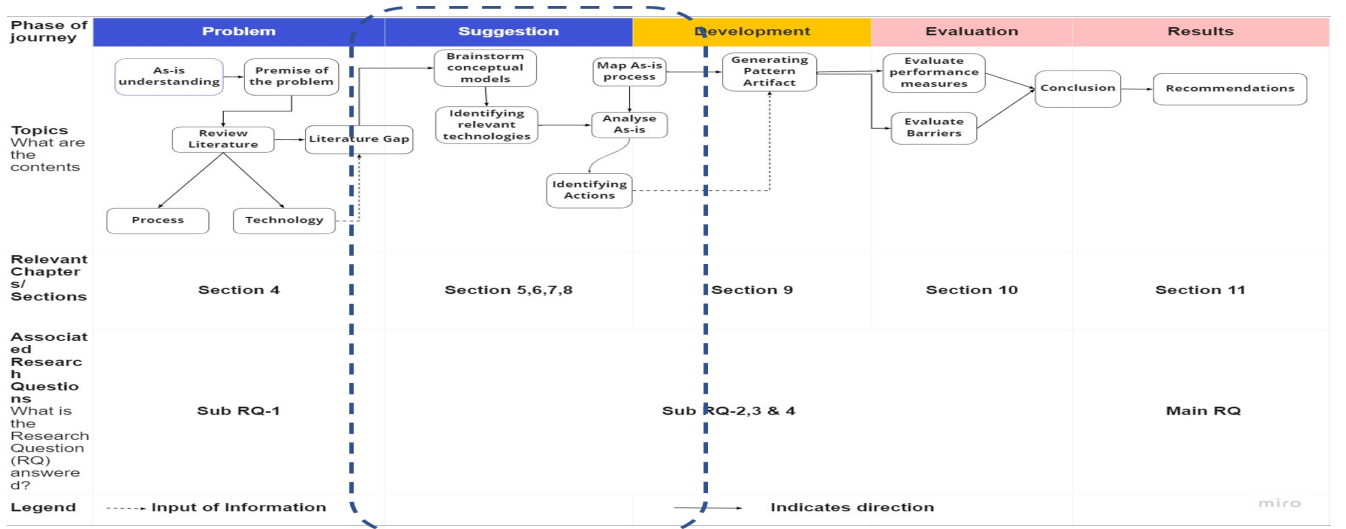


Figure 16: Suggestion Phase according to DSR approach

The material flows between actors such as Airbus, Rolls-Royce, first and second tier suppliers are studied in this section. This section aims to study how different aircraft parts move about the different tiers indicated in figure 15. An aircraft such as the A350 XWB consists of the following parts as depicted in figure 17. These different parts require raw materials to be submitted by several suppliers and manufactured by different manufacturers. Raw material suppliers and manufacturers are located at different parts of Europe. Most of the manufacturers are under Airbus itself, except for the engines as it is produced by Rolls-Royce. These parts travel through these suppliers and manufacturers before taking shape and delivered to the respective customers. *These different classes and processes are studied in order to obtain factors that affect or have a certain effect on the adoption of a digital technology at Airbus.* The methodology is such that, the practical functions are studied, followed by a theoretical evaluation of the functions. These evaluations are conducted using academic papers, which aims to provide certain factors considered important for the particular class.

This section focuses on identifying the issues that cause delay in delivery by analysing the actors such as Airbus, Rolls-Royce, 2nd and 3rd tier suppliers. The research starts with the main actor, Airbus in this section, then proceed to Rolls-Royce in section 5.6. The first and the second tier suppliers are studied for the two main actors Airbus and Rolls-Royce.

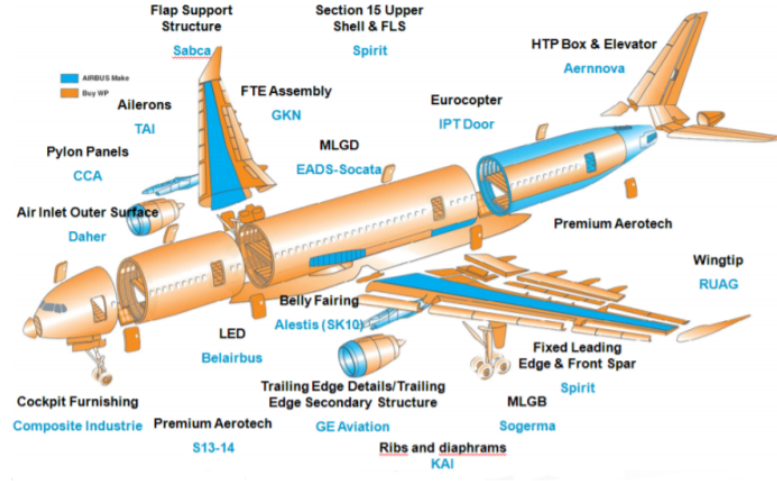


Figure 17: Exploded view

(Plura, 2016)

Airbus are the actors who manufacture, assemble and transfer aircraft with their own suppliers, manufacturers, production facilities, assembly facilities and logistics department. An enlarged view of different stakeholders involved in the A350XWB supply chain is depicted in figure 18. The description of different processes to facilitate material flow of different actors within Airbus are documented below. Additionally, the best practices to be followed by the respective actor are gathered from academic papers and described.

The second key actor Rolls-Royce in the A350XWB supply chain, procure raw materials, manufacture and assemble the associated engine for this aircraft. Planning, manufacturing and assembly are the respective departments to execute these processes. Their day-to-day operations remain the same as Airbus, as it is guided by standards such as FAA and FAI mentioned in section 3.

The associated stakeholders and an abstract view of Rolls-Royce in relation to Airbus is depicted in figure 18.

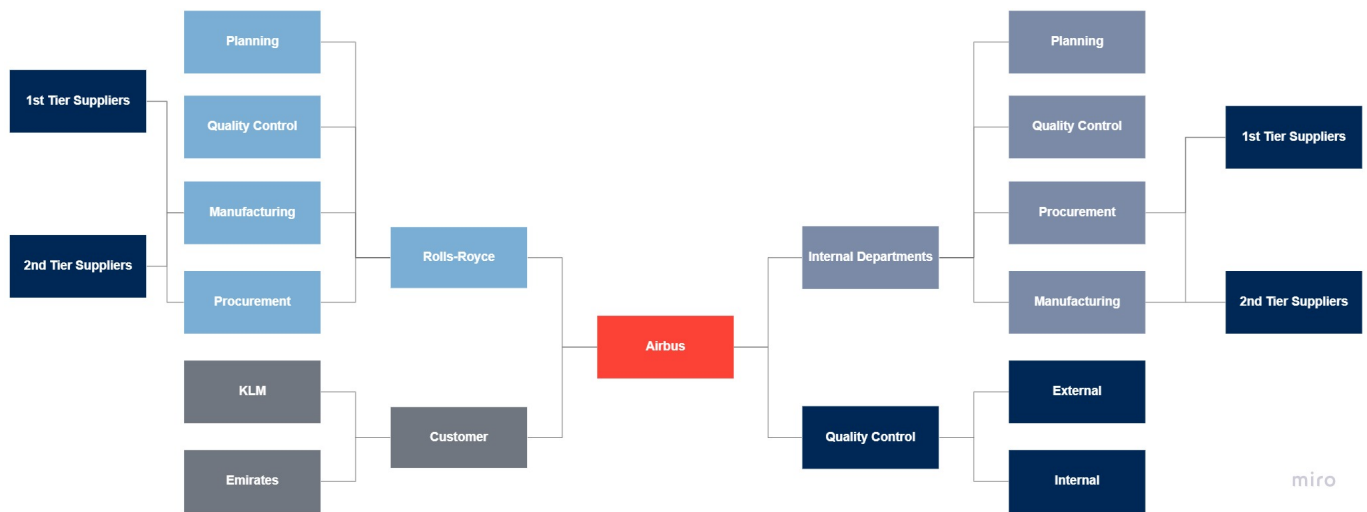


Figure 18: Stakeholder Map of A350XWB Supply Chain, developed by researcher based on:
(Airbus, 2020f)

5.1 Procurement From Suppliers

The first class of actors are the procurement department who are responsible for obtaining special steels, alloys and other materials to produce the hundreds of components ranging from flaps, wings, hull, interior and fuselage (Airbus, 2020a). The different parts are manufactured at different places in Europe. Each of the facilities in Europe have their own procurement departments. As there are hundreds of sub-components present in fuselage, there are third party producers involved who are not in direct contact with Airbus. These different tiers are represented in figure 19. Tier 1 corporations are the supply chain's driving force, responsible for ensuring that the whole system is run effectively and efficiently while adhering to all government regulations (Brintrup, Wang, & Tiwari, 2015). They act as a conduit for all of the supply chain information. Tier 2 bear a great deal of liability and is considered as the heart of the supply chain. They are critical for maintaining the flow of materials and production. They are also the ones who are held the most responsible for part and component requirements, standards, and enforcement. The figure 19 indicates the number of interactions that are being carried out between the tiers. For example, there are 145 interaction possible between tier 4 and tier 3. These interactions are neglected for this study as it would add a great deal of complexity.

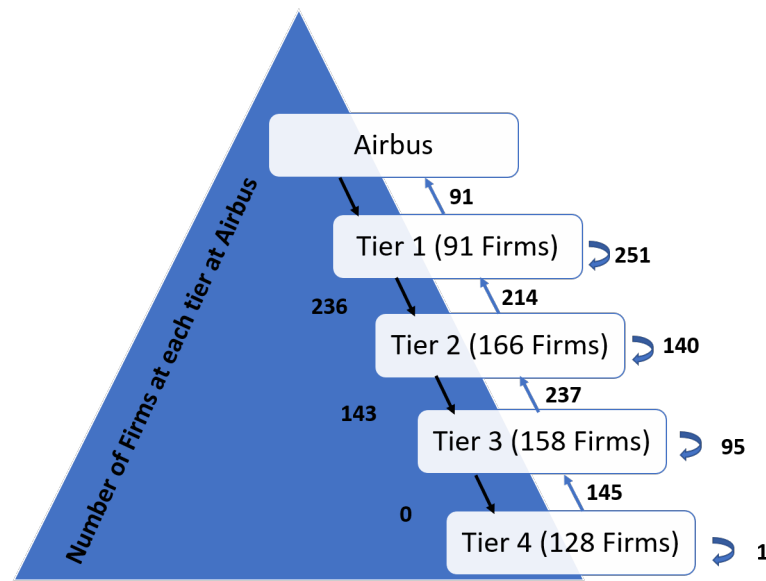


Figure 19: Tiers at Airbus
(Brintrup et al., 2015)

(Flanckegård, Granlund, & Johansson, 2021) state that continuous interaction between the customer and the supplier increases the amount of trust between the two. This trust can be facilitated by different types of interaction, for example, repeated interaction. However, there are challenges present when attempting to establish these repeated interaction, they are due to ((Flanckegård et al., 2021)):

- **Absence of a product development model:** The lack of a defined and visual model for the product development process may result in a lack of knowledge of the roles and responsibilities of various activities, as well as a lack of information interchange. Interdependencies exist between difficulties relating to internal supplier capabilities and customer interface. This is case with Airbus as well. The minimal contact with the 2nd and 3rd tier suppliers prevents the amount of information shared between them.
- **Lack of involvement:** Suppliers are advised to be customer-centric and build trust through long-term relationships with customers. This is dependent on how well-structured and visible the product development process is, how roles and responsibilities are defined, how planning techniques are used, and so on.

5.2 Production and Service

The second class of actor are the production and service department. They are responsible for manufacturing the different parts of the Aircraft. The different production facilities are located

in Germany, Spain, France and the UK. The roles of the different departments are shown below ((Airbus, 2020d)):

1. **Germany:** The structural assembly and outfitting of fuselage portions are overseen by Airbus' Hamburg facility. The company's Bremen facility is in charge of designing and producing high-lift systems for all Airbus aircraft's wings. Wings for the A350 XWB are supplied to Bremen from Airbus' Broughton, United Kingdom, facility, where they are completely fitted with all required equipment. This site is also responsible for producing the upper wing shell, CFRP fuselage shells, electronic communications and cabin management systems.
2. **Spain:** Getafe, in central Spain, specialises in the engineering, design, manufacture, and assembly of aviation components. The factory serves as a delivery hub for Toulouse and Hamburg's final assembly lines. Getafe manufactures fuselage for all Airbus aircraft using metallic and advanced composite materials, and specialises in final assembly, systems testing, and testing of all horizontal tail planes for all Airbus aircraft; rear fuselage of the A350 XWB. The Illescas plant of Airbus is a world leader in the production of composite aeronautical components, mostly large-scale or complex-shaped elements like the wing lower cover of the A350 XWB. Sections of the rear fuselage and the inside skin of the wing for the Airbus A350 XWB are among the components made at Illescas for Airbus models.
3. **France:** Engineering (general design, systems and integration tests, structure definition, and more), structure testing and a materials processes development center, systems organization, flight tests, the Beluga hangar, and one of Airbus' three delivery centers are among Toulouse's duties. For the whole A350 family, the Saint-Nazaire facility specialises in structural assembly, outfitting, and testing of front and centre fuselage parts. It receives sub-assemblies for the A350 XWB's nose fuselage assembly. The site in Nantes, France is a pioneer in the creation of Carbon Fibre Reinforced Plastic structural elements, such as the A350 XWB keel beam, and specialises in the fabrication and assembly of centre wing boxes for all Airbus aircraft.
4. **United Kingdom:** The Broughton plant, located in North Wales, assembles wings for the complete Airbus commercial aircraft family, producing approximately 1,000 wings each year. Wing skin milling, stringer manufacturing, full wing outfitting, and wing box

assembly are among its services. Filton is Airbus's other UK-based plant, comprising engineering and research technology units in charge of wing design, landing gear and fuel system design and testing, as well as component manufacture.

The sites outside of Europe are in USA and Quebec in Canada. They are mainly responsible for manufacturing and transporting parts for the A320 aircraft. Once the materials are procured, manufactured and tested, they are transported to the final assembly line before they get transferred to the respective airline company.

The different products stated above have a unique ID in form of digits attached to them (Airbus, 2020d). Logistics of these different components entails certain challenges such as maintaining the records for each of them during transportation. These unique ID has to be cross referenced with the document after the package has been received. With the increase in production capacity and increasing orders, manual tracking of the several components will cause a delay in the succeeding operations (Shamsuzzoha, Ehlers, Addo-Tenkorang, Nguyen, & Helo, 2013). Shamsuzzoha also states that there is a requirement for enhanced demand and up-to-date tools to monitor and handle the corporate environment's ever-increasing complications. This is achieved through real-time monitoring and traceability in logistics chains and the development of auto-ID technology may address some of these issues. This makes the use of an appropriate *Product ID*, important in the supply chain.

5.3 Quality Checks

After every part is being manufactured, there are quality checks conducted periodically. The department responsible for monitoring and maintaining these quality checks is called "Quality control". Quality control is an internal department at Airbus. Employees in this department visit the respective sites to check the quality of products received from its own Airbus and Rolls-Royce facilities. The 2nd and 3rd tier suppliers' quality checks are managed by the first tier. If there is an issue with any of the parts manufactured by the manufacturer, they are responsible to rectify the issue and manage the delays caused. The functions performed in case of a delay are depicted in figure 20.

Management of delays The Supplier shall: (a) collect internal and external delays in an integrated or linked database, establish correlation between the delays found during industrialization, production (including tests) and after delivery to the Purchaser, (b) manage significant/recurrent delays with complete root Cause analysis and problem solving (c) inform the Purchaser in case of forecasted delays.

Figure 20: Quality check management process

(Airbus, 2020a)

In this upstream section³ of the supply chain the quality control strategy is influenced by 13 factors as indicated in figure 21. More importantly, companies such as Airbus dealing with highly specific business requirements such as quality, standards, delivery time, and customer satisfaction must be more connected to other chain members and enable their managers to follow the QC's lead; otherwise, they may not be able to survive intense market competition or improve overall chain performance. As seen from section 5.1, the different tiers are not connected directly which affects some of the 13 factors such as *communication*, *commitment* and *satisfaction*.



Figure 21: Quality check factors

(Jraisat & Sawalha, 2013)

5.4 Assembly Process

The various parts manufactured as mentioned above are transported to the Toulouse factory in France. This facility is responsible for cabin furnishing, painting and the the final assembly line for the A350 XWB aircraft. Most of them are transported by water and road to the Toulouse factory. The different parts and their location are indicated below in figure 22.

³The section of supply chain that involves the procurement department, suppliers, and manufacturers

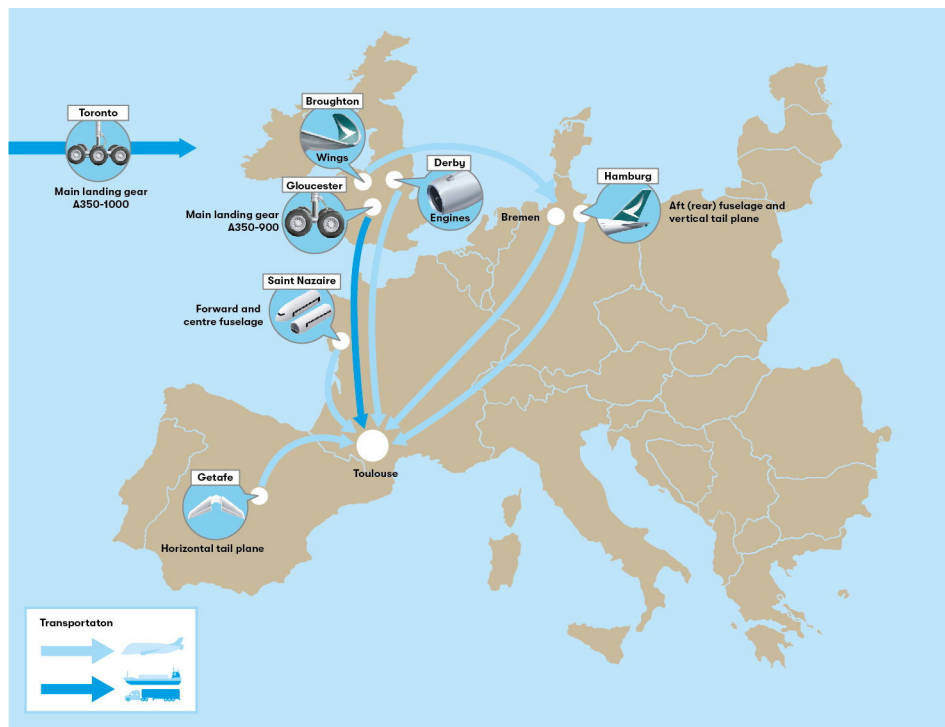


Figure 22: Components of Airbus

(Phil Heard, 2019)

Once the aircrafts are assembled and tested, the ownership of the aircrafts are transferred to the respective airline company such as Emirates, Air France and KLM. The transfer of ownership has certain process, which are explained below.

While the assembly process looks straightforward there are various challenges present that offset the regular assembly process. The challenges stated by (Airbus, 2020e), they are: Missing components, late out-of-hangar issues, or routine replenishment: day-to-day operations generate a variety of levels of urgency and order priority, each with its own set of supply chain requirements. As a result, transportation and logistics have a significant impact on the supply chain, particularly on the on-time availability of components in the aviation business. (Fransoo & Udenio, 2021) state that the delays in these infrastructure of supply chain cause the "bullwhip effect". The bullwhip effect is a supply chain phenomena that causes demand variability to be amplified from a downstream to an upstream location (Fransoo & Udenio, 2021). This problem comes under the category of *Asset management* (Dai, Li, & Peng, 2017). This makes the factor "asset management" important to this study.

5.5 Product Transfer

The transfer of an aircraft from one actor to another is a five day process. This five day process involves different sub-actors who perform different functions, which involves paperwork, physical inspections and technical checks. The five day process in details is:

1. **Day 1:** The first day includes visual inspection of exterior surfaces, bays, and cabins, static aircraft system and cockpit checks, and engine tests.
2. **Day 2:** Acceptance flight: all aircraft systems (including cabin systems) and aircraft behaviour in the entire flight envelope are checked during flight.
3. **Day 3:** Physical rework or provision of solutions for all delivery-related technical and quality problems.
4. **Day 4:** This is when the technical approval is completed. Technical closure of the aircraft and all related documents attesting to the aircraft's conformity with the type of certificate are checked.
5. **Day 5:** The aircraft's title deeds are transferred to the customer airline on the fifth day, and the aircraft's owner changes. The plane is being prepared for its ferry flight back to its home base.

The fourth day during the process of transferring aircraft requires professionals to visit the site and sign the documents, which increases the time and also the cost by the company. To avoid this problem, a solution have to provided and it can as well be digitising the supply chain of Airbus.

Recently, due to COVID-19, there have been issues with Airbus in delivering the products at it's desired (at the right time and right place) quality ([Reuters, 2021](#)). Due to this reason, the aircraft's are being returned back to the respective facility to be reworked on. Airbus has taken this issue into consideration by strictly monitoring it's supplier network. Reuters also state, Airbus has given suppliers "maximum 72 hours" to contain any newly detected quality flaws. Although there is no evidence that such complications have jeopardised aviation safety, analysts believe they can result in costly manufacturing delays. This reduces the *reliability* of the supply chain at Airbus. The degree to which a supply chain produces consistent results is referred to as supply chain reliability ([ILIM, 2003](#)). Now that the roles of the departments

and an abstract flow of materials (within Airbus) are established, the detailed descriptions are mapped out. This is done from the perspective of Rolls-Royce, where abundant information is available.

5.6 Material Flow from Rolls-Royce to Airbus using SCOR Level-2 Analysis

The intent of this chapter is to help map the precise movements of materials flowing from Rolls-Royce to Airbus. This will help in identifying barriers that restrict digital transformation. Additionally, it will identify complexities that design artefacts should contain in order to integrate digital technologies in the future. Mapping the routes of material flow and identifying barriers and best-practices are one of the literature gaps identified in section 3.

As we have identified and explained the major classes of departments within Airbus, we proceed to study the actor Rolls-Royce who supplies the trent 1000 engine for the A350 XWB aircraft. They are a company comparable to that of Airbus. They are comparable in terms of the number of suppliers (around 10,000) and have specific classes such as procurement, production and service. This makes it important to study Rolls-Royce in detail. The part of supply chain focused for this graduation project originates from Derby, UK and ends at Toulouse, France. This is studied using the SCOR model. SCOR model helps to identify the type of parts being transported and provide clarity on order type. The section 5.7 elaborates more on the model.

The SCOR model describes three things. First, type of information communicated for transporting part. Second, the steps taken by the organisation and third the barriers (factors) involved in the A350XWB supply chain. These different steps and type of information involved in the supply chain are later mapped to the identified factors in section 7.4. The map designed by the researcher helps to identify a suitable technology that improves these processes by facilitating the factors. The mapping of factors and processes are done in section 7.4.

It is identified in section 3 that conceptual models constructed do not involve the complexities of a supply chain process between the buyer and the seller. This gap identified by the researcher, appeals to map the details of movement of products and the associated information flow between the different tiers of suppliers in the A350XWB supply chain. This mapping of detailed material and associated information flow is conducted in order to arrive at a *business canvas*. This tool

utilised by the researcher depicts the different elements, interactions and factors present in the supply chain and serves as a base for further exploring these factors and in determining the associated technology.

SCOR Definition

Supply Chain Operations Reference (SCOR) mapping is used to measure and analyse Airbus' corporate behaviour. SCOR is involved in the end-to-end supply chain process, which includes all suppliers, sources, and final end consumers. The goal is to use the SCOR model to identify the type of material flow in the supply chain network, the factors that affect its performance if any due to material flow. All of SCOR's supply chain procedures are divided into subdivisions or categories, such as Plan, Source, Make, Deliver, and Return, and the result is a complex supply chain with interconnections or numerous combinations of these fundamental activities. The SCOR is divided into three streams they are, "strategic", "tactical" and "operational". The operation level is first studied and is analysed from the strategic and tactical level. There are four levels in the operational stream of SCOR, they are ([ILIM, 2003](#)):

1. **Level 1:** Key performance indicators (KPIs) and SCOR measures are used to evaluate the overall supply chain.
2. **Level 2:** Plan, Source, Make, Deliver, and Return are the five processes that are described and established here.
3. **Level 3:** The processes that can be regarded as a progression from level 2 in order for the company to successfully distribute and compete in the market. Schedule material delivery, receive material, assay material, transfer material, and approve payment are all part of this process ([Schulze, 2017](#)).
4. **Level 4:** The stages are developed from level 3 into specific industrial operations in order for the company to gain a competitive edge.

The first two levels will be assessed in this research project. Level 3 and Level 4 is out of scope as it involves financial flows. Level 2 is illustrated using the physical locations, drawings and material flows. We match the same against location and product using a thread diagram. As we do not know the KPI's or factors directly, they will be derived from the analysis of this SCOR model and the information flow. This means, the Level-2 analysis will be conducted in this section, the KPI's factors will be obtained and compiled in the later sections for the

Level-1 analysis in section 7.

The three major questions are asked to acquire a better understanding of the topic at hand by using the SCOR model: What is the current state of affairs? What are the current situation's complications/bottlenecks? And, more importantly, how many of these issues can be resolved? In terms of the viewpoint needed to answer these issues, a detailed examination of key processes is analysed. The below figure 23, represents the different process happening from the Rolls-Royce perspective. The chain represents several stages starting with procurement from various tiers of suppliers. Then the focus is towards the engine which is manufactured by Rolls-Royce in Derby, UK. There is a sub-assembly process of the engine inside the facility of Rolls-Royce and several data transfers with Airbus and the control room before it is tested and sent out to Airbus for the final assembly in Toulouse.

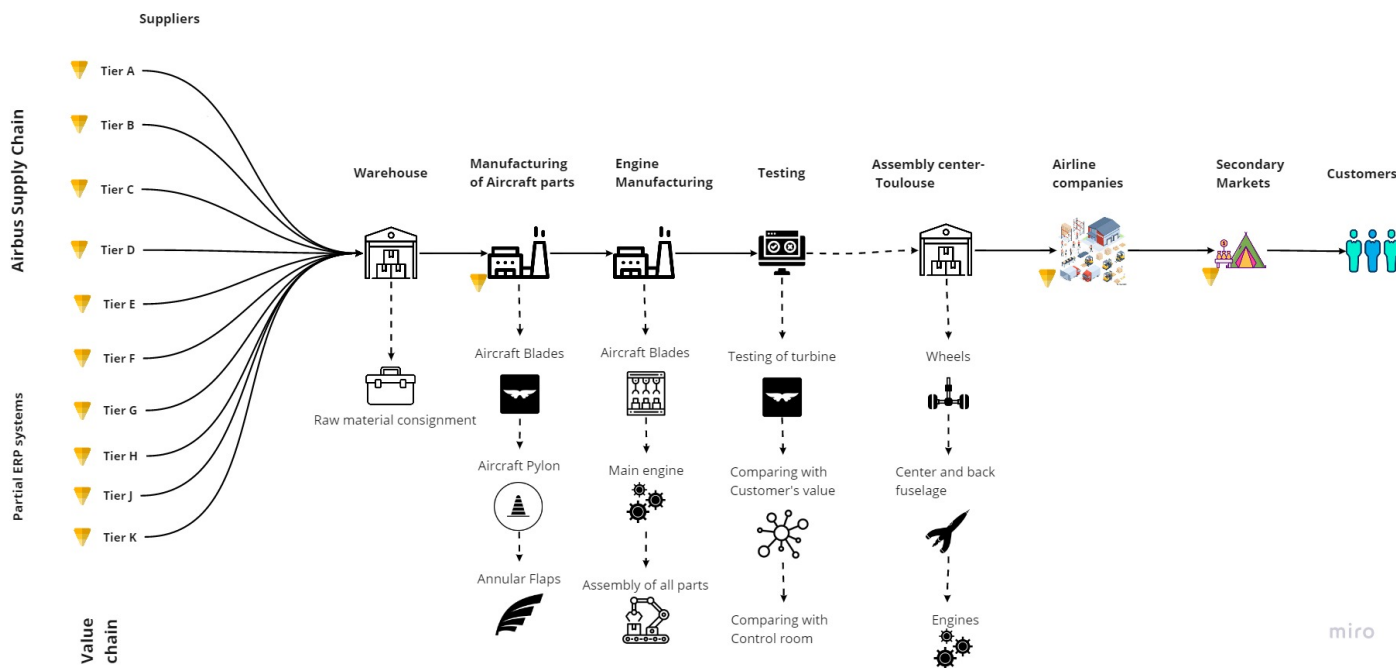


Figure 23: Supply Chain of Rolls-Royce

The overview of supply chain of Rolls-Royce is indicated in the figure 23. Each of the processes are complex in nature. The complexity comes from the 10,000 actors performing different functions. These functions and their respective actors are further elaborated using the Level-2 of the SCOR model below.

SCOR: Level-2

This level is analysed to map the different key actors, key activities and the relation between the actors and activities in a detail. Five primary processes are present in Level 2: Plan, Source,

Make, Deliver, and Return. These are discussed in further detail below:

1. **Plan:** All activities related to gathering and communicating information to the entire supply chain about demand dynamics, quantity and quality of raw materials from suppliers, pallets required for packing, capacity planning for inventory, transportation, distribution, and return of damaged products are included in the planning process.
2. **Source:** Obtaining raw materials from a supplier network, establishing a supplier agreement, making payments, and maintaining inventory by clearing out and refilling stock to meet variable demand are all part of the procurement process.
3. **Make:** To meet market demand, scheduled production methods entail converting raw materials to finished commodities. Whether to make to order, make to stock, or engineer to order is determined. To assure good quality and limit the number of damaged panels returned, high-quality scanning and packaging are a key focus.
4. **Deliver:** A delivery order is placed with the carrier products, and it is an official document that directs the recipient to transfer the products to the named individual ([Airbus, 2020b](#)). To fulfill the order, the goods are validated with the head office after the transfer.
5. **Return:** Return of goods from the respective facilities, which refers to malfunctioning products or damaged parts for which the cause might be delivery or manufacturing fault. The specified return period is not explicitly stated by Airbus. This may be due to the several factors affecting delivery period.

The five processes stated above, which are, plan, source, make and deliver are analysed in SCOR level 2 can be further elaborated into the interaction between the first, second, third tier suppliers and Rolls-Royce itself. The table [24](#) below indicates the corresponding processes to Rolls-Royce activities and the description of the same are provided in the same table.

Process	Code	Description
Plan	P1: Plan Supply Chain	This section describes the decisions made by top management regarding the sourcing of raw materials, manufacturing the Aero engines, the deliveries, returns and replacements.
	P2: Plan Source	
	P3: Plan Make	
	P4: Plan Deliver	
	P5: Plan Return	
Source	S1: Source Stocked Product	Raw materials sourced from different suppliers
	S2: Source Make-to-order Product	
Make	M1: Make Stocked Product	Manufacturing the different components of the Aero engine
	M2: Make-to-order Product	
Deliver	D1: Deliver Stocked Product	Delivery of the manufactured components to different actors
	D2: Deliver Make-To-Order Product	
Return	SR1: Source return of defective product	Return of damaged products and surplus inventory and replacement deliveries for each
	SR2: Source return of excess product	
	DR1: Deliver return of defective product	
	DR2: Deliver return of excess product	

Figure 24: SCOR Level 1 Processes and Level 2 Alternative Sub-processes

(Harmon, 2003)

The material flow between actors such as procurement, manufacturing, quality check and assembly are studied. The steps such as "absence of a product development model" and "lack of involvement of suppliers" are seen to be ineffective from the study of material flow as elaborated in section 5. It is understood from here that due to some of the ineffective steps the order-fulfilment rate might be low. In order to identify any further inefficiencies geographical map between Rolls-Royce and Airbus is studied using the SCOR model referred in figure 24.

5.7 Geographical Map Of Rolls-Royce: Operational Level

The intent of this section is to map the "as-is" state of the supply chain. The tools used to achieve this section were literature study and interviews. Information on data collection approach were presented in section 2. The outcome of these interviews and study is described in this section. The level-1 of SCOR model is used as a means to achieve this output.

From the interviews it is identified that there are five steps involved in the physical trading of materials, they are:

1. **Order Placement:** This task entails informing linked parties about materials acquisition, approval of the trade agreement between associated parties, and the "creation" of

a trading contract (FAIR document). The trade process is first agreed upon between the buyers and sellers, then entered into ERP systems and double-checked by many executives. This process is further elaborated in section 6 .

2. **Quality Inspection:** Before transporting the respective materials to the buyers location, there is a mandatory quality check. This quality check is conducted by the supplier. In some cases, there are random quality checks conducted by Airbus to ensure up to standard of quality of parts.
3. **Transporting:** This step of the process includes, loading of materials, attaching shipping documents, planning routes and executing the process. These transporting plans (routes, type of document attached) are communicated among the respective stakeholders through e-mails, ERP systems and manual paperwork. These different modes of communication depend on the material transported. The type of information communicated is also examined further in section 6.
4. **Verification of Information:** At each step the information communicated to the respective stakeholder is verified by an administrator or an executive. The details of steps involved in verification are not entirely available. This restricts the researcher in exploring further technical details in this process.
5. **Receiving:** The transporting vehicle, the product, and the shore tanks where the material is intended to be stored are all inspected by a surveyor. If the inspection reveals that everything is in order, the buyer's team signs the necessary documentation, and receives the material.

The "receiving part" is excluded as it is out of scope of this research as indicated in figure 1. The material flows, the routes are examined here and the associated information flow are depicted later in sections.

To comprehend Rolls-Royce's supply chain and understand the above indicated steps, it is vital to first comprehend who the primary suppliers and end consumers are. The figure 25 depicts the procedures involved in the company's supply chain, from material procurement to the manufacturing of the trent 1000 engine. This also covers the return policies offered by suppliers and distribution centres in the event of damages or faults. The standard followed to design processes and sub-process is depicted in the above figure 24. Similar, to that of

Airbus, Rolls-Royce also has different classes such as procurement, manufacturing, production and service. They have this distinction to produce and transfer the engines. The functions of these different classes are described below:

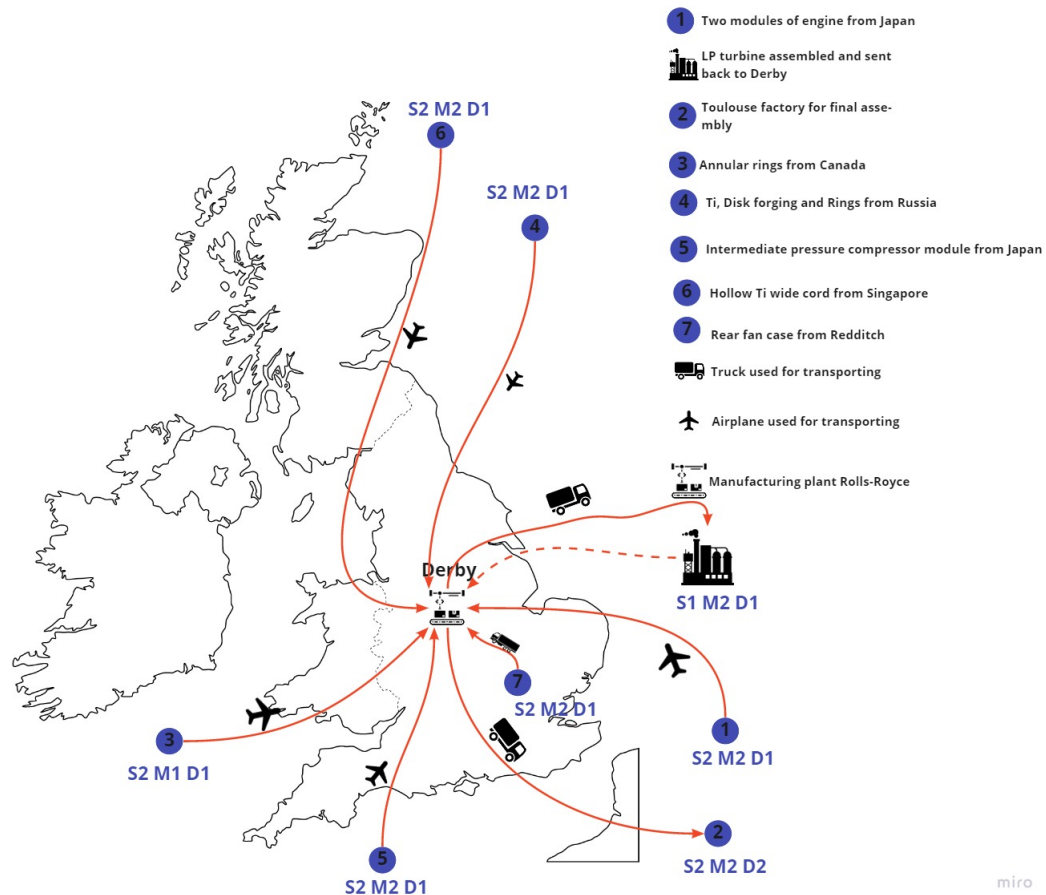


Figure 25: Derby production facility, UK
(Rolls-Royce, 2020)

5.7.1 Raw material and parts required for production(S2, S1, M2, D1):

The raw materials required for production of the trent XWB engine for the A350 XWB comes from around the globe such as Singapore, China, Japan and Russia. These different suppliers supply different parts required for the engine and they are delivered based on order placed by Rolls-Royce. The different parts are ((Airbus, 2020f), (Rolls-Royce, 2020)):

- Engine modules
- Annular rings
- Titanium, disk forging and rings from Russia
- Intermediate pressure compressor module from Japan

- Hollow Titanium wide cord from Singapore
- Rear fan case from Redditch

Most of the parts and raw materials are made-to-order (M2) and delivered to the production factory in Derby, UK. These suppliers are some of the world's largest producers of the raw material in question, and as a result, they also make special orders for other customers (M2).

The annular rings are stocked if they have arrived in excess (S1) and most of the time they are source make-to-order (S2). All of the processes are standardised and in order to reduce inventory they are made to order (M2).

5.7.2 Manufacturing plant(S2, M2, D2):

The manufacturing plant located in Derby, UK manufactures the engines for the Airbus aircraft's ((Airbus, 2020f), (Rolls-Royce, 2020)). The engines are produced, tested and sent to Airbus based on the order they receive from Airbus itself(S2,M2,D2). Some of the parts are stored in warehouses but they are used later for service as a part of Manufacturing, Repair and Overhaul (MRO). This portion of the supply chain is excluded from this research as it is not within the scope described earlier.

5.8 Sub-Conclusion of Material Flow

It is identified that there are different classes and tiers at Airbus and these different actors within the class and tiers form as the stakeholders in the A350XWB supply chain. The different classes or otherwise known as departments perform different functions of transforming materials ranging from spatial to form transformation. It is identified that Rolls-Royce, a large firm in its own is also a major player in this supply chain. Rolls-Royce also performs the different transformations of materials. All of these different functions are categorised as Plan, Source, Make and Return using the SCOR model. The study of these different functions provided insights into the different type of materials being transformed (assembly parts), the type and the mode of communication that happens at each stage of the supply chain process. The identified mode of communication for spatial and form transformation is through electronic means such as e-mails and Enterprise Resource Planning (ERP) systems. Further, it is identified that the document frequently used is the First Article Inspection Report (FAIR). For example, the movement of products into the Derby facility is indicated S2M2D1, meaning that the material is

sourced from the stocked product of the buyer. It is then manufactured immediately when the material has arrived in their facility and delivered to Airbus when there is an order confirmation received. This confirmation of order, their quality and the required number is checked through the FAIR document.

In short, the different actors involved such as the "suppliers", "manufacturers", "logistics providers" and "buyers" communicate with each other to enable transfer of material between them. To enable this spatial transformation, they perform certain activities such as "order placement", "quality control", "verification of information", "transportation", and "receiving process". A single document branches over conveying required information pertaining to the material flow at different locations, complex interactions and segregated functions of actors within the classes and tiers. This process of transferring information breaks down while travelling through the supply chain network. Issues such as loss of knowledge of activities and lack of information during exchange processes arise.

To avoid these issues a set of actions are suggested such as developing a "product development model" and "involvement of suppliers" during all parts of the process. Some of the other suggestions to found through the analysis of material flow are to improve the method of "product ID", update quality inspection processes and to trace products at real-time to improve the flow of materials up-stream and down stream in a supply chain network. These different set of actions are converted into factors such as "product ID", "involvement of suppliers", "Quality Control", and "Asset Management". The identified factors, activities and actors are depicted using a business canvas model in figure 26. This depicts the first building block of the business canvas as described in section 2.4.

The Business Model Canvas

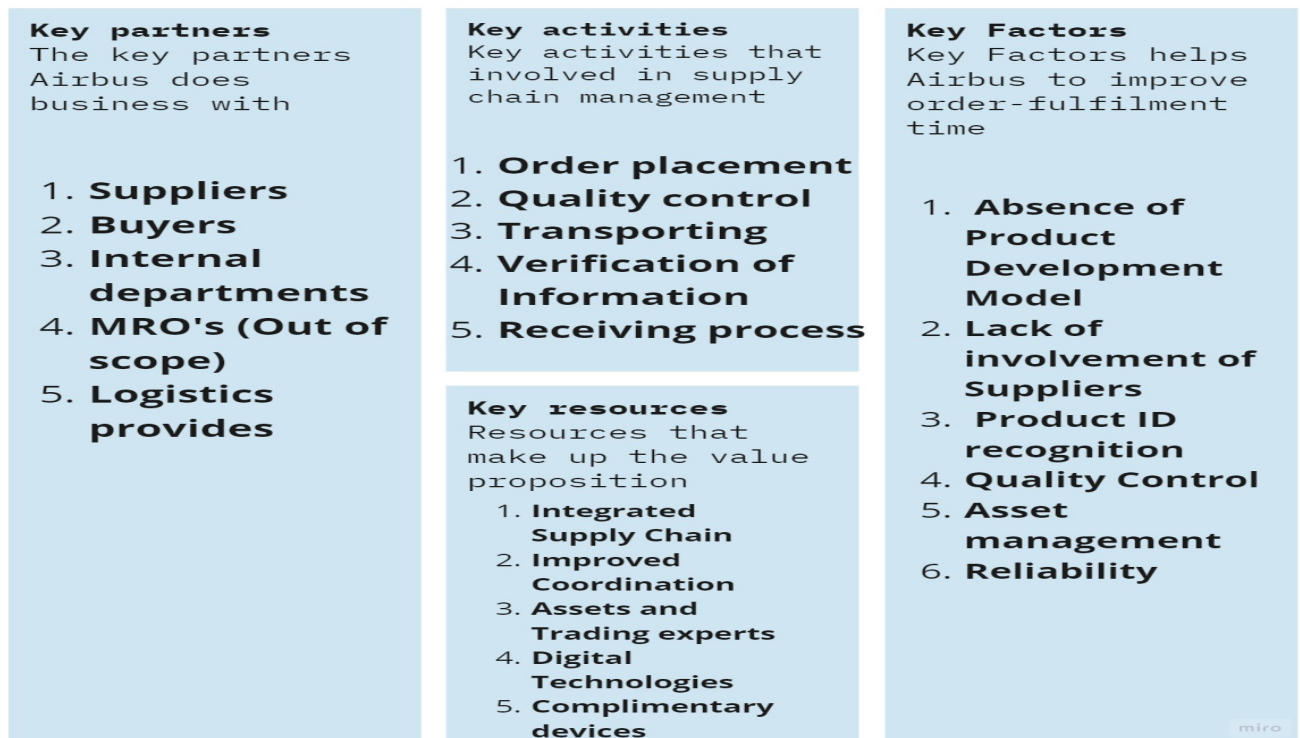


Figure 26: Building Block of Business Canvas (Adapted by the researcher from the study of SCOR model)

The associated information flow is studied to identify more factors associated with this A350XWB supply chain. The long list of factors obtained will be presented in a fully developed business canvas in section 6.2. Further, the detailed description of factors will be tabulated in section 7. The relevant data found through this study will be added in the business canvas and the whole picture of the canvas will be discussed in the upcoming sections.

6 Information Flow between Airbus, Rolls-Royce and Suppliers

The thread diagram (Appendix A) provides an overview of types (S1,M1,D1) of information involved in planning of supply chain. This section aims to list and describe the different communication tools & format for communication used by Airbus, Rolls-Royce and their suppliers to ensure delivery of the respective material. The description of this information communication process will be mapped to the material flows described above and divide into value add & non-value add activities. The overview of all the elements involved, their associated interactions and factors identified from this section will be depicted using a business canvas. This aims to serve as a conclusion for material and associated information flow.

As depicted in the thread diagram in figure 50, there are several processes that have to be communicated on-time in order to maintain order-fulfilment rate. These are critical to avoid delays in the production, assembly and delivery time. The current communication system used by Airbus, Rolls-Royce and the other suppliers mentioned above are ERP systems, paperwork and e-mail. Also, this involves several types of documentations that have to be submitted by the different classes during the entire process. The different documents submitted are depicted below in figure 27 and explained:

Section	Class										
	A	B	C	D	E	F	G	H	J	K	
7.1 Documentation Records Requirements	X	X	X	X	X	X	X		X		
7.2 Supplier Resources Working Within Airbus Canada Facilities	X	X				X					
7.3 Control of Documented Information	X	X	X	X	X	X			X		
8.1 Configuration Management		X				X					
8.2 Control of Work Transfer	X	X	X		X	X					
8.4.1 Sources of Supply	X	X	X	X		X					
8.5.1 First Article Inspection Report (FAIR)	X	X				X					
8.5.2 Source Inspection	X	X	X		X	X					

Figure 27: Documentation rules at Airbus to be followed by different classes

(Airbus, 2020a)

For the above documentations, suppliers must also obtain a contract for supply, testing and perform controlled process of aeronautical products. The suppliers will always be in surveillance (has become more strict due to COVID), where the supplier must take corrective action if anything goes wrong. The detailed explanation for some of the key elements in figure 27 are

given below ([Airbus, 2020a](#)):

1. **Documentation record requirements:** The supplier must keep records of data relating to quality, manufacturing and engineering. Unless stated, the records have to be kept for 10 years.
2. **Control of Documented Information:** Technical updates of the requirements (A2P,A2MS, etc.) must be maintained by the supplier for six months.
3. A record of revision reviews shall be kept, which shall contain the date of revision of the reference document, the date of inclusion in the supplier's management system, and a brief description of the steps taken to indicate the completion of the revision review.
4. **General:** Revised form of documentation and or reference systems are communicated to the supplier via a notice or an electronic means.
5. **Other duties:** The supplier must verify process of compliance with specifications and other related documents. The second miscellaneous duties also include documenting control of engineering processes.

The document titled "First Article Inspection Report (FAIR)" is important for the organisation as well as this research. The reason being this document has to be maintained by all the actors in every tiers. The information contained in this FAIR document are:

1. Actual configuration (kit number)
2. A list of all detail parts and/or sub-assembly part numbers
3. A FAIR, in accordance with AS9102, for each detail part and/or sub-assembly part number and the required quantity;
4. All hardware part numbers including the lot number and the required quantity

The document is required to be uploaded by the respective supplier or manufacturer onto a third party ERP system called as "Net-Inspect", which is accessed by Rolls-Royce and the different suppliers across the world. The different processes mentioned above such as *procurement, production and service, assembly* and *product transfer* have to prepare this document and submit onto the ERP system. This action is performed in order to plan the respective production schedule and transporting schedule. There are two scenarios possible for this document as described below (([Airbus, 2020a](#)), ([Airbus, 2020d](#))):

- **Scenario 1:** The FAIR document is uploaded onto the ERP system 10 days prior to the transporting schedule, which can be accessed by Rolls-Royce and the other suppliers. Two days prior to transporting, there are quality checks conducted and compared to the document. If the lot passes the checks it proceeds to being transported. If not, there is a delay experienced.
- **Scenario 2:** This is the scenario where the document is not ready 10 days prior to the planned transporting schedule. In this case, the supplier has to inform the quality representative who informs the transporting department about the delay. This scenario leads to a significant delay in production and in turn assembly.

The above explained process of both material and information are combined in a Unified Modelling Language (UML) and depicted in figure 28 below. This UML diagram describes the combined flow of both material and information flow. The process starts by Rolls-Royce receiving the order and followed by conveying the message to the suppliers, which is monitored by Airbus. Then the information is communicated to the production facilities and the production department. The raw materials are sourced by both Airbus and Rolls-Royce from their suppliers. Simultaneously, during production the supplier and the manufacturer prepare the FAIR document and upload to the "Net-Inspect" software. Following the upload, the parts or the components gets prepared for quality checks. The quality checks and the transportation happens through one of the scenarios as described above. Finally, the assembly processes are conducted followed by quality checks and transferring the product from Airbus to the respective airline company.

In both the scenarios, there are significant delays experienced due to the delay in preparation of the document. The delays are also due to the difficulty in finding alternative supply chains in sending the required parts. These difficulties are due to the complex process, lack of a unified platform to access information and in general lack of proper technology (Airbus, 2020c). (Danese, 2013) state that the flexibility (a parameter of supply chain performance) can be improved in an organisation by providing information to the respective actors in real-time. This factor is called *supplier timeliness* (de Janeiro et al., n.d.).

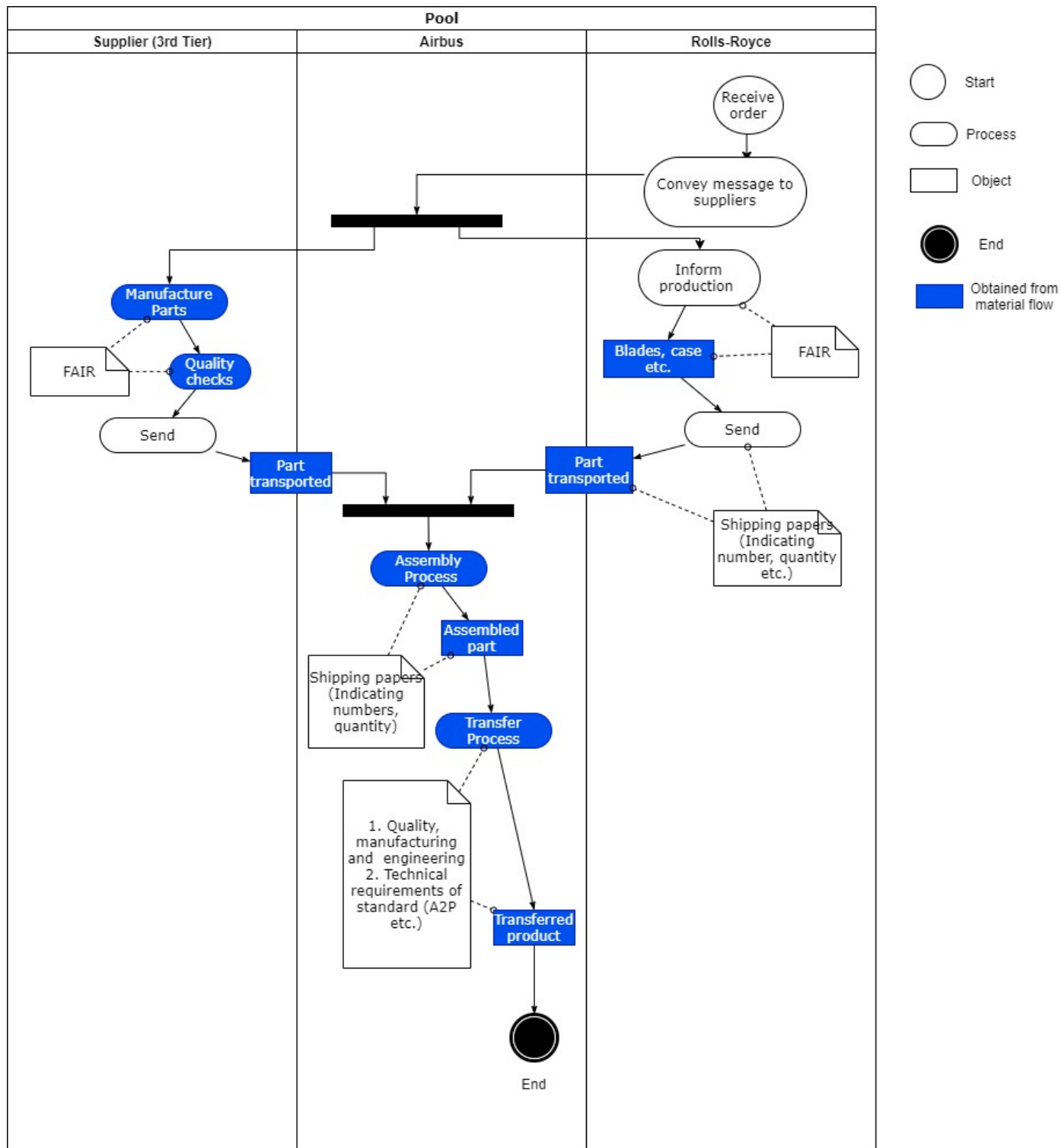


Figure 28: Information and Associated Material Flow, developed by the researcher based on this study

The UML diagram in figure 28 depicts the unified flow of both the material and associated information flow. The SCOR model described the different actors present in the A350XWB supply chain, they are, "procurement", "manufacturing", "assembly", and "logistics" departments. These different departments can be categorised under "Supplier", "Airbus", and "Rolls-Royce".

These different actors perform a variety of activities such as order placement, quality inspection, transporting, verification of information and receiving on a global scale. It is seen that most of these activities are co-dependent of each other and if performed correctly the final delivery would reach the right customer at the right time and at the right quantity.

However, certain activities tend to hinder the smooth flow of these material and associated information such as the loss of knowledge of activities and lack of precise information exchange. The possibilities were discussed in section 6 as "scenario 1" and "scenario 2". It is established that the hindrance in coordinated flow of material and associated information flow arises from a lack of information transferred on time and the restriction in the level of information shared among the different actors during the functioning of supply chain. The set of actions such as "increase level of information shared" and "increase the timeliness of information shared" are suggested by the researcher in order to improve coordination between the two focused flows and to improve order-fulfilment rate. These set of actions are converted in the form of factors such as "Level of information shared" and "Supplier Timeliness".

An interview with an employee at Rolls-Royce stated that "although information sharing is useful, there are certain certifications that the suppliers have to have in order to have clearance". This fact does restrict the firm to allow more access to their suppliers. But, specific capabilities of transformative technologies such as the APS/ERP/Blockchain allow organisations to share more information and prevent possible leakages (([de Santa-Eulalia et al., 2011](#)), ([IOTA, 2020](#))). These technologies allows an organisation to establish "direct contact" with their buyers and increases the "information shared" and the "level of involvement" of the actors in the supply chain. These elements from the information flow and the material flow creates new dimensions on the already developed business canvas in figure 26. The new business canvas with the added dimensions are depicted in figure 29.

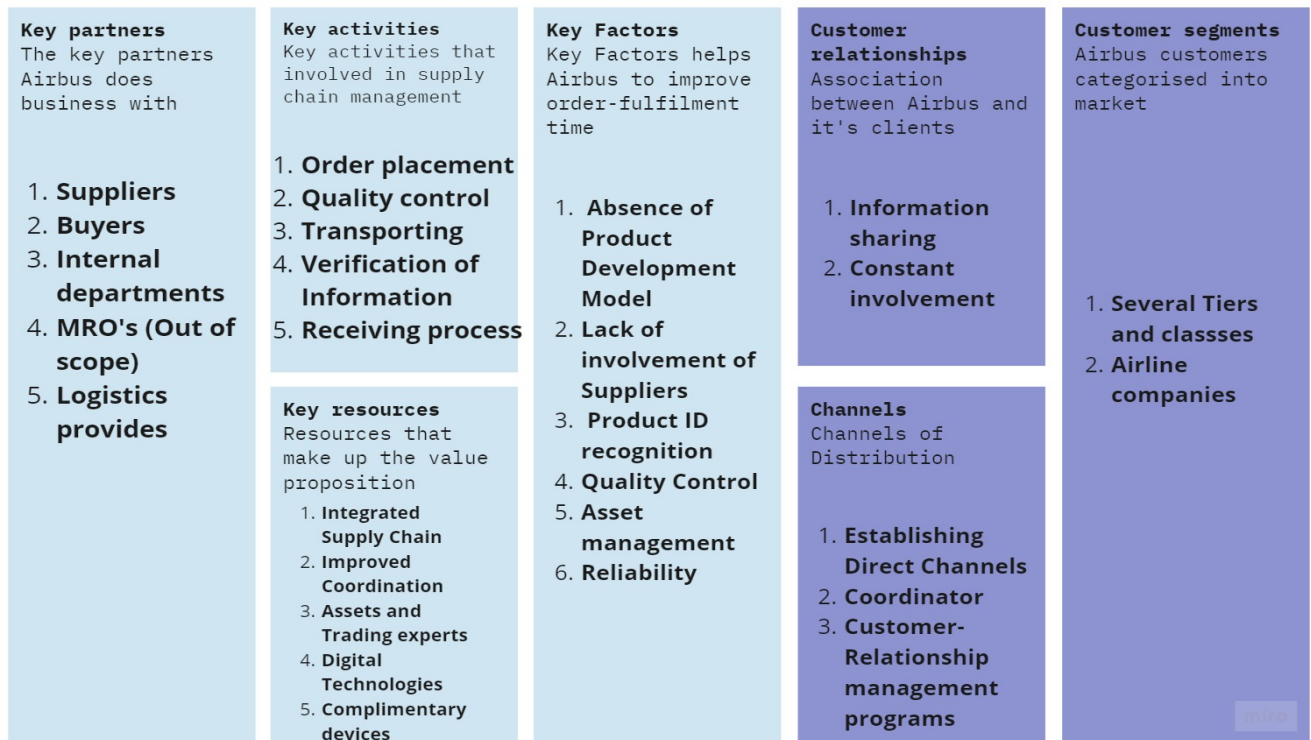
The Business Model Canvas

Figure 29: Building Block of Business Canvas (Adapted by the researcher from the study of SCOR model and UML diagram)

The activities that tend to hinder the coordinated flow of material and associated information and tend to cause the low order fulfilment rate are segregated from the activities that doesn't hinder the flow. These activities are called as non-value add activities and are discussed in section 7.4 below based on the researchers interpretation. This flow of research is depicted in figure 3.

6.1 Mapping and evaluating the activities of Material and Information Flow

The intent of this section is to map the activities gathered from material and information flow as Value add and Non-Value add activities to differentiate activities contributing to maintaining order-fulfilment from the ones that do not. This mapping is conducted through a qualitative analysis and is based on the understanding of the researcher from the study of material flow conducted using the SCOR model and the information flow conducted using the UML diagram.

The findings are plotted using a business model canvas to clearly show which factors are key to Airbus to achieve coordination between material, information flow and increase order-fulfilment rate. The company Airbus also put-forth strategies that aligns with the objective of this thesis project and makes it important to discuss them in this section. The strategies discussed in this section are gathered from the company's publicly available information and from McKinsey, as the initial interviewees did not have a complete picture on these strategies.

In 2017, Airbus started to frame strategies for improving order-fulfilment rates through digital transformation. Some of these strategies are ((Fontaine, 2017)):

1. **Utilise digitisation to improve our current operations and develop revolutionary business concepts:** This strategy focuses on four main points:
 - Improve involvement/engagement of suppliers
 - Increasing operational excellence through digitisation
 - Improving business agility
 - Controlling the value chain of our product data and turning data into insight
2. **Strengthening the position of Value chain:** The strategy is aimed towards improving profit and customer satisfaction. Additionally, the strategy includes building a robust supply chain governance framework to maintain partnerships.
3. **Maintaining market leader position in commercial aircraft division:** This strategy is aimed at Airbus being self-sufficient. Given the massive backlog execution difficulty, a focus on right-time, right-cost, and right-quality deliveries is critical (over 7,500 aircraft). Airbus wants to improve its position by focusing on digitisation, innovation, services, a more global strategy, and an improved industrial system.

To understand the alignment of day-to-day processes mentioned in section 5 and 6, the activities are divided into value adding process and non value adding process based on the researchers' understanding through study of material and information flow. This refinement is provided in the form of factors in section 6.2. Value added process contribute to improving the order fulfilment rate. Non value adding process are contributing to the delay in order-fulfilment rate. The table 7 below segregates the different activities into value adding and non-value adding processes.

Table 7: Segregation of Value Adding and Non-Value Adding Process (Developed by the researcher from this study)

Activity	Value-Adding Process	Non-Value Adding Process
Order Placement	✓	
Quality Inspection		X
Transporting	✓	
Verification of information		X
Receiving	✓	

Value Adding Processes

Value Adding Processes are considered to contribute in increasing order-fulfilment rate in this research. The order placement activity generates a contract (FAIR) between the buyer and the seller. This standard contract is also followed during the "receiving" stage. Hence, both these activities are treated as a value add processes.

Transporting activities primary focus is to communicate the routes and the type of document to the buyer. A buyer (Rolls-Royce) places an order for titanium disk forgings from Russia. The seller prepares this FAIR document, which contains all necessary information regarding the material to be transported. This document is sent through the ERP system to the buyer and helps the buyer to track the product and compare their specifications with the received material. To understand this value added process, the scenario obtained from the SCOR model (S2 M2 D1) in section 5 is used.

Non-Value Adding Processes

Non-Value adding processes are considered as bottlenecks, which are considered to increase order fulfilment rate in this research. Here "quality inspections" and "verification of information" are considered as non-value adding activities. It is understood from section 5 that the tiers (figure 15) at Airbus are not connected directly and information passes through several intermediaries. Delay in information sharing through these intermediaries impact production plans and further cause a delay in transporting the material. The cause of this delay is explained as

"scenario 2" in section 6.

These non-value adding processes that involves intermediary actors present make the supply chain network complex. This complexity makes aligning day-to-day activities more difficult with the company's strategy. For instance, improving *"involvement of suppliers"*, *"improving partnerships"* and *"maintaining order fulfilment rates"* will be more difficult in such a complex network.

The above value add and non-value add activities contribute to factors such as involvement, partnerships, order-fulfilment rate, & product ID and they are directly linked to constructs such as trust, traceability and performances of a supply chain within an organisation. Improving these constructs were identified as one of the key issues of Industry 4.0 in section 1.

6.2 Sub-Conclusions for Material and Information Flow

Following the thesis flow diagram in section 2.4, the intent of this chapter is to provide a summary of key findings, the list of stakeholders, and the factors obtained from material flow in section 5 and information flow in section 6. An abstract view of these different elements are depicted in figure 30 through a business canvas. The business model canvas is a useful tool for understanding a business model in a systematic and simple way (BMI, 2020). This can be used to learn more about a company's customers, what factors help which channels, and how organisations can run profitable business.

Although the financial flows are neglected from this research, it is mentioned in the business canvas to provide a better understanding to the reader about the different elements present. The general cost structure and revenue streams were provided by (Dijkman, Sprenkels, Peeters, & Janssen, 2015) for the Internet-Of-Things in large firms. The explanation of the summary using the business canvas is provided below:

1. **Key Partners and Key activities:** The partners or departments within and outside Airbus perform certain key activities. The key activities consists of various process associated with material and information flow towards the goal of maintaining order fulfilment rate.
2. **Key resources and Key Factors:** The key activities are achieved using the key resources such as the "integrated supply chain" and existing "digital technologies". The *key factors* are seen to have an association or influence when determining these key resources

and improving key activities.

The Business Model Canvas



Figure 30: Business Canvas Model developed by the researcher from the above study

3. **Customer relationships and Customer Segments:** As stated above, the supply chain network consists of a buyer and a seller. The buyer is termed as customers. These customers can be departments within Airbus who place orders on aircraft parts and buy them or the airline companies that buy the final aircraft.
4. **Channels:** They are forums or mediums through which the buyer places an order and the mediums through which, the seller provides the material. To maintain effective channels large firms usually have Customer Relationship Management (CRM) programs in place.
5. **Cost Structure and Revenue Streams:** When performing key activities, developing key resources and maintaining channels to improve customer relationships, there are certain costs involved. Although, this part has been neglected in the scope of this graduation project it is included to describe the complete picture to the reader.

The key factors which are seen to have associations with key activities at Airbus are described and mapped to the respective activities in the coming section.

7 Proposed Factors and KPI's

Through literature study and remote interviews, material and associated information flow in sections 5 and 6 are studied. The outcome of this material and information flow helped the researcher to arrive at the factors that impact the Airbus supply chain performance. Some of the key factors are "Lack of involvement from supplier", "Product ID", and "absence of product development model". From this study, the researcher has identified that these factors correlate with some of the key constructs "trust", "traceability" and "performance".

The intent of this section is threefold. First, to group the obtained key factors as shown in figure 30. Next, to map the factors to the activities in figure 8. This could help the firm to have a view on which factor impact what activities. This is achieved based on researchers' understanding. Third step is to measure the current level of these factors through interviews as described in section 2 to indicate it's influence on the order-fulfilment rate.

Explanations for some of the factors identified from the study of material flow in section 5 and information flow in section 6 are provided below:

1. **Lack of involvement from supplier:** Information or knowledge sharing within the organisation positively affect competitive advantage (Azeem, Ahmed, Haider, & Sajjad, 2021). The knowledge management systems should be better integrated to achieve this end result. Improving ERP or developing Blockchain networks can improve information or knowledge sharing in organisations.
2. **Involvement in New Product Development:** Improving communication and Integral planning can increase the level of involvement by providing the right information at the right time.
3. **Supplier timeliness:** Timeliness is an important aspect of velocity (rate in which information travels) because it determines whether data creation, analysis, and associated inferences are available at the appropriate time. As a result, any organisation must be concerned about the accuracy and timeliness of the data utilised in analysis and decision-making (Castka, Searcy, & Mohr, 2020). The blockchain technology has the capability to transfer information to all actors at the same time.

Following the flow of the DSR approach as mentioned in 2.4, this section aims to elaborate the constructs, then map the same to the activities mentioned in section 5. This will help

Airbus to understand the focus area against the listed activities. Further to understand the current performance of the supply chain and its related constructs, a questionnaire is presented to industry experts/ supply chain decision makers as described in section 2. The summary of the interview are further mapped to find which factors needs improvement.

7.1 Trust

Trust has been widely researched by several researchers over the past years. The first study on trust in organisations was done by (Ring, 1996). Different definitions of trust has been provided by different authors in previous studies. One of the recent study describes trust as a multi-dimensional concept. The different dimensions are fairness, loyalty, vulnerability, reliability, non-opportunism, compassion, and partnership (Capaldo & Giannoccaro, 2015).

In the context of supply chain, trust is divided into three categories namely: "contractual", "competence" and "good-will" trust. Contractual trust arises when organisation expect that their partners will adhere to the respective contract. Competence trust develops when organisations believe their partners (suppliers/seller) have the skills required to do specified jobs. Lastly, When organisations establish open-ended pledges to adopt actions for mutual benefit while not taking unfair advantage of their partners, they form goodwill trust. For the purpose of this research, the researchers focuses trust as level of collaboration. This form of trust is seen to come under the first category of trust (Contractual).

When there is trust in the supply chain, the collaborating organisations are more likely to act jointly in the best interests of the outcome, even if it is locally less advantageous. When trust is lacking in the supply chain, partners are less likely to collaborate resulting in a poor outcome.

7.2 Traceability

The capacity to identify and verify the components and chronology of events around products at all stages of the supply chain is referred to as traceability (Kros, Liao, Kirchoff, & Zemanek Jr., 2018a). The term "traceability" refers to the ability to follow items from their basic ingredients to their transformation into consumer goods, and finally to their distribution. Effective supply chain traceability allows organisations to track raw materials, finished items, and services wherever they are in the supply chain in a cost-effective and precise manner.

Traceability does provide a measurement of product and service history, and can be useful

to consumers, manufacturers, auditors, and other parties involved in the supply chain process (Kros et al., 2018a). This increases supply chain transparency, enhances record accuracy, and allows businesses to keep a tight grip on their products. Implementing traceability measures might also boost a company's competitiveness.

7.3 Supply Chain Performance

Supply chain performance is a measure of flexibility, responsiveness and cost reduction. Meeting customer needs such as delivering at the right time, right place with good quality improves trust and thereby supply chain performance. The traceability factor in this chain improves the order-fulfilment (responsiveness) and also leads to better supply chain performance (Warren H. Hausman, 2004).

The benefits of trust and traceability have been studied in a variety of businesses and economic sectors and explained using a variety of theories. In one of theories known as transaction cost economics, it is described as an alternative to control within any organisation (Capaldo & Giannoccaro, 2015). Trust lowers the expenses of searching, contracting, monitoring, and enforcement, as well as the unpredictability of information sharing.

7.4 Mapping activities to Constructs

The intent of this chapter is to establish the relationship between different activities studied in section 5 and 6 along with the key constructs. This mapping is depicted below in table 8. This mapping of activities to constructs is developed by the researcher based on their understanding of material and information flow.

Table 8: Mapping activities to Constructs and Factors obtained (Developed from the researcher's understanding based on this study)

	Activities				
	Order Placement	Quality Inspections	Transporting	Verification of information	Receiving
Trust					
Supplier Involvement in New Product Development					
Supply Partnership	✓	✓	✓	✓	✓
Supplier Timeliness	✓		✓	✓	✓
Transaction Method		✓	✓		✓
Frequency of Quality Checks		✓			
Level of Information Shared			✓	✓	
Traceability					
Information of origin, process, routing	✓		✓		✓
Level of Integration of Suppliers				✓	
Product ID			✓	✓	
Supply Chain Performance					
Reliability					✓
Reponsiveness	✓				✓
Agility					
Costs	✓	✓	✓	✓	
Asset Management	✓	✓	✓	✓	✓

It was established earlier that the constructs such as trust, traceability and performance are multi-dimensional in nature. These different dimensions were obtained through academic papers ((Capaldo & Giannoccaro, 2015), (Kros et al., 2018a), (Warren H. Hausman, 2004)). Each of the dimensions are associated to at-least one of the activities mentioned in section 5.

It is interpreted by the researcher through literature study and interviews that the low order-fulfilment rate at Airbus is due to the poor level of performance of these associated factors. The detailed description on the current performance level of these factors at Airbus are tabulated in tables 9 and 10. The input for categorising the performance level of the factors as "poor", "medium" and "good" is obtained from the interaction with the decision makers.

Table 9: Constructs and Factors-1

Construct	Variables	Performance Level	Reference
Trust	Supplier involvement in New product development	medium	(de Janeiro et al., n.d.)
	Supply partnership	poor	
	Supplier timeliness	medium	
	Transaction method	medium	
	Frequency of quality checks	good	
	Level of information shared	poor	

Table 10: Constructs and Factors-2

Construct	Variables	Performance Level	Reference
Traceability	Level of information shared (origin, process and routing)	medium	(Kros et al., 2018b)
	Level of integration of different suppliers	medium	

Table 9 refers to the trust construct and table 10 refers to the traceability construct. Both of the constructs mostly have their performance as "medium" or "poor". Due to medium and poor performance levels, the order-fulfilment rate is low. This low level of order deliveries made by Airbus is also reflected in their performance as indicated in table 11 obtained through the SCOR model.

The researcher used SCOR level-2 to analyse the material flow and is described in section 5. Further, the associated information flow is mapped using the UML diagram in figure 28. The factors and constructs arrived through the literature study are termed as KPI's by the researcher and are further evaluated for confirmation through interviews with supply chain experts. These KPI's are compared with the different parts of the supply chain using level-1 of the SCOR model to obtain a better picture of Airbus' supply chain performance.

Table 11: Key Performance Indicator Analysis
 ((Harmon, 2003),(Airbus, 2021),(Airbus, 2020d))

	Reliability	Responsiveness	Agility	Costs	Assets
Perfect order fulfilment	poor				
Order fulfilment cycle time		poor			
Upside supply chain flexibility			medium		
Upside supply chain adaptability			medium		
Downside supply chain flexibility			medium		
Supply chain management cost				poor	
Cost of goods sold				Good	
Cash-to-cash cycle time					medium
Return on supply chain fixed assets					medium
Return on working capital					medium

As observed in table 11, the Responsiveness factor is indicated as "poor". This indicates less order-fulfilment rate according to the level-1 of the SCOR model and confirming premise described in section 1 of this graduation project for Airbus. To increase this order-fulfilment rate, Airbus started exploring one of the digital technologies "blockchain" as mentioned in section C. The description and comparison of blockchain technology with ERP and APS are compiled in the later sections. The research is done in this manner, to identify which technology has the most influence of each of the factors.

7.5 Sub-Conclusions for Proposed Factors and KPI's

The SCOR model in section 5 and the UML diagram in section 6 were used to identify key actors, key factors, key activities and the relationships between them. The business canvas is used to represent all the different parameters in section 6.2.

To further group the different factors identified, a series of different academic journals were

read. Through this study, the different factors were identified as variables of trust, traceability and supply chain performance. The identified factors were grouped respectively. All of the three KPI's are identified as multi-dimensional concepts that contribute to increasing supply chain performance. One of the factors for "supply chain performance" is "responsiveness". This factor is a measures order-fulfilment rate of a supply chain.

Based on the researchers understanding as depicted in the flow diagram in section 2.4, the applicability of these identified factors were mapped to the identified activities in section 6.1. Applicability can be defined as the set of actions to take during an activity.

The current level of the different factors were identified through interviews as described in section 7.4. It is concluded that each of the constructs within Airbus has a "medium" or "poor" performance level. The upcoming section describes the identified digital technologies that are seen to improve the various factors and improve order-fulfilment rate.

8 Assessing Digital Technologies

In section 3.4, ten technologies were identified as potential solutions for improving the coordination between material flow and information flow that results in improving the order-fulfilment rate. Three technologies were shortlisted and chosen for further study as it most fitted the two criteria "interoperability" and "ecosystem" from the researchers interpretation. A literature study is conducted for the shortlisted three technologies to arrive at a business model in section 6 that will help to understand how and which technologies can help to improve the order-fulfilment rate. Certain key set of actions were suggested in order to achieve this objective. It is also identified that the suggested actions has an influence on the key activities at Airbus in section 7.4.

This sections aims to identify the resource/capabilities Airbus can use to improve the coordination of material and associated information flow to increase order-fulfilment rate. The identification of the resource is done through the Strength, Weakness, Opportunity and Threat (SWOT) analysis. A SWOT analysis is conducted in order to identify the strong and weak points of the technology, which will be first mapped to the information and material flow. The different parameters of the SWOT analysis are gathered through a literature study as described in section 2.4 and depicted in figure 3.

The outcome of the SWOT analysis is to identify the capabilities of the selected three technologies and describe how these capabilities can be used by Airbus to improve the identified set of factors in section 7. Improving these factors is seen to improve the coordination between material and associated information flow resulting in improved high order-fulfilment rate. Further, the BWM is used to identify the level of influence the respective technology has on the identified factors in section 6.2. The information to conduct the SWOT is gathered from existing literature.

Presently, Airbus is also researching on the capabilities of blockchain at their organisation as described in Appendix C. Currently it is not clear if Airbus research is on the basis of any assessment for choosing blockchain. There are other digital technologies present for unifying segregated platforms or databases to facilitate better information and material flow. Blockchain has certain weakness such as scalability issues, which means registering a massive amount users to the network is not possible at the moment (Ethereum, 2020). These strengths and weakness of the different technologies makes the identification and comparison between them

important.

8.1 ERP

ERP stands for enterprise resource planning, and it is a sort of software that businesses use to handle day-to-day operations like accounting, procurement, project management, risk management and compliance, and supply chain operations (Oracle, 2020). Enterprise performance management, software that helps plan, budget, predict, and report on an organisation's financial results, is also included in a comprehensive ERP suite.

ERP systems connect a variety of company operations and allow data to move between them. ERP solutions avoid data duplication and ensure data integrity with a single source of truth by gathering an organisation's shared transactional data from numerous sources. The strength, weakness, threat and opportunities are explained in figure 31. The several parameters depicted in the same figure are explained below (Tavana et al., 2020):

Strengths

1. **Inexpensive primary investment:** ERP systems involve creating a unified database, which is inexpensive. The devices required to collect relevant data has to be installed, which adds the cost to the initial system.
2. Re-orders, replenishment, out-of-stock stocks, and missed delivery might all be automatically informed by sensors and internet-connected equipment. The systems installed during the lifetime of the ERP system will help with the above mentioned process.

Weakness

1. **Robustness of ERP systems:** The large influx of data from various devices and products is expected to be handled by IoT ERP. As a result, industrial organisations must do a lot of planning ahead of time, taking into account the scale of their present ERP program and if it can link to IoT.
2. **Expensive overtime:** Sensors and other IoT related devices are expensive to install and maintain.
3. **Timely communication:** The planning of the scale of ERP, the availability of sensors have to be properly executed, if not, there might be delays in receiving data. There might be latency issues, that is: In the context of cloud computing, latency, also known

as turnaround time, refers to the period between the computation being offloaded and the results being received from nearby infrastructure or cloud.

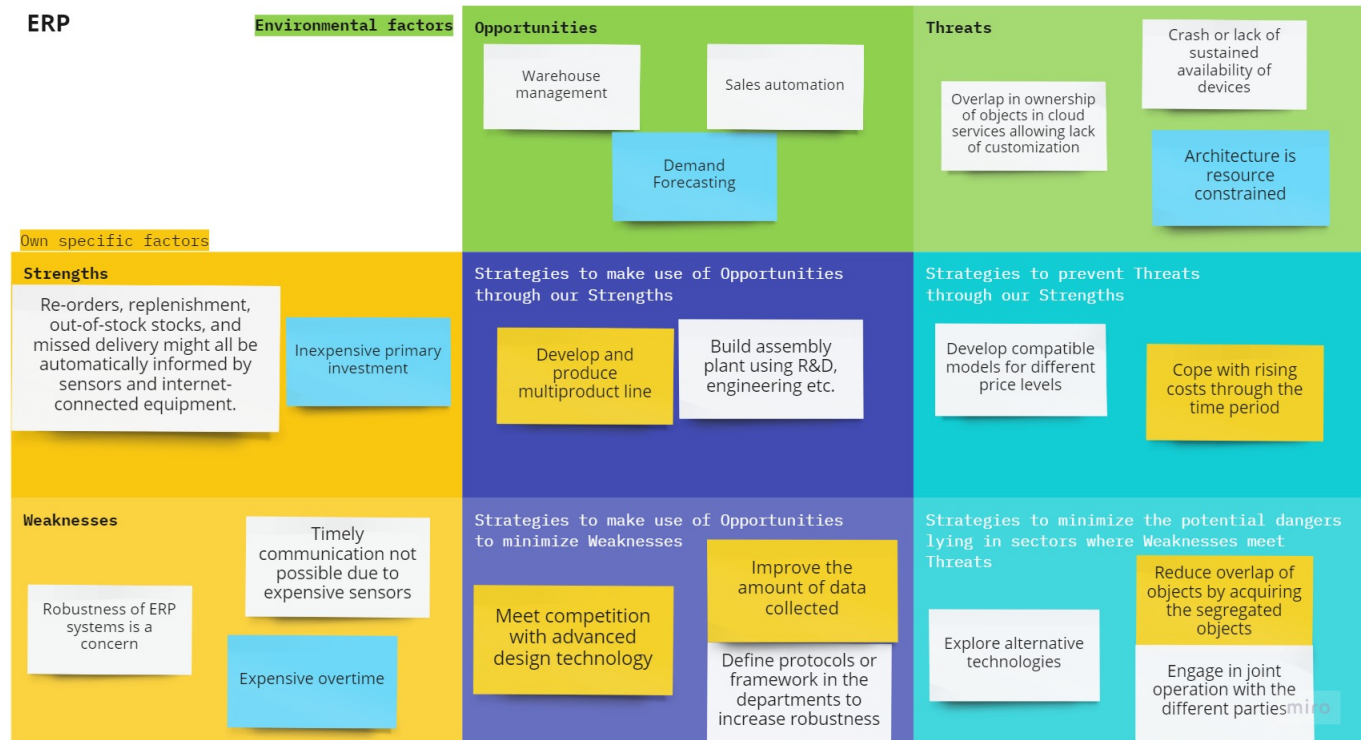


Figure 31: SWOT analysis-ERP (Arrived by the researcher)

Opportunities

1. **Warehouse management:** There are numerous demand forecasting models that may be accurately tested using machine learning and deep learning approaches to adjust to various types of variables such as demand changes, supply chain disruptions, and the introduction of new products.
2. **Sales automation:** AI-powered chatbots assist not only customers, but also the entire sales triangle. Bots can now deal with segmentation and deliver real-time solutions.
3. **Demand Forecasting:** Machine learning and deep learning technologies aid in the development of solutions that can interpret previous data and forecast the future. These strategies aid in the identification of seasonal patterns and provide recommendations for output volume in the commercial environment.

Threats

1. **Overlap in ownership of objects in cloud services allowing lack of customization:** This is the case of segregated third party databases or servers, that prevents

customisation.

2. **Crash or lack of sustained availability of devices :** Cars are normally on the move most of the time in the field of intelligent transportation, and vehicle networking and communications are frequently disrupted or unreliable. When utilising applications in low-resource conditions, there are a few issues with the device crashing or not being available for long periods of time.

8.2 APS

At the strategic, tactical, and operational planning levels, APS are computer-assisted planning systems that bring forward various tasks of Supply Chain Management, such as procurement, production, distribution, and sales (de Santa-Eulalia et al., 2011). These systems represent a quantitative model-driven approach to using IT to support Supply Chain Management, as well as advanced analytical and supply chain optimisation techniques. This quality of combining the various tasks undertaken by the respective departments in the supply chain network, does make APS a suitable technology to be studied to solve the mis-match between the different flows. Like any other technology there are strengths, weakness, opportunities and weakness to APS. The SWOT analysis for this technology in the supply chain domain in conducted in figure 32. The several factors depicted in the same figure are explained below ((de Santa-Eulalia et al., 2011)):

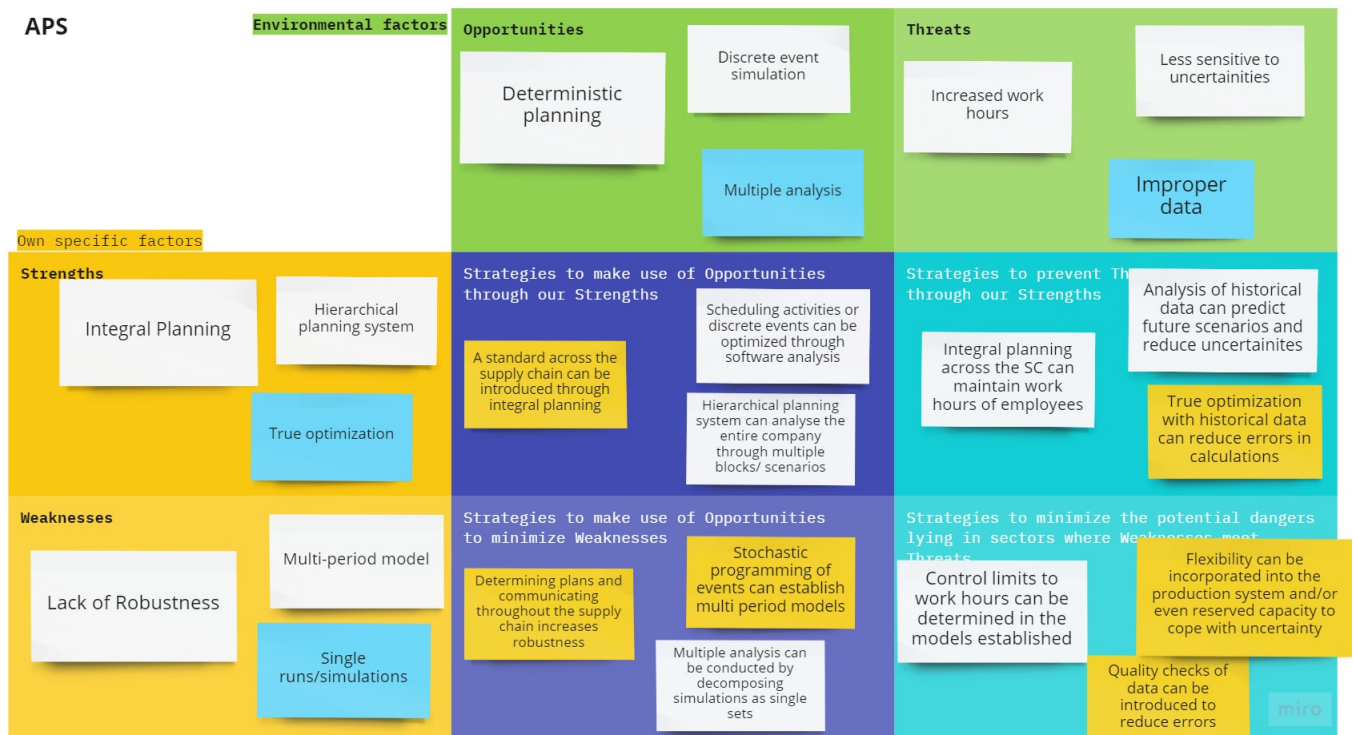


Figure 32: SWOT analysis-APS (Arrived by the researcher)

Strengths

1. **Integral Planning:** This contains planning of the entire supply chain. It can concentrate on internal supply chain concerns (for example, when a single firm has many manufacturing or distribution facilities) or it can theoretically consider the entire supply chain (from the company's suppliers to its customers).
2. **Hierarchical planning system:** Two key components of the APS must be examined in order to transform supply chain characteristics into an implementable APS system: the architecture (how the system is organised, including 'hierarchy' and 'integral planning') and the engine (how each component of the APS architecture carries out its planning functions).
3. **True optimisation:** To carry out planning and scheduling operations, APS systems use advanced analytical and supply chain optimisation technologies (exact ones or heuristics). When making decisions in a confined or limited resource setting, optimisation issues seek answers. When one, all, or both of these factors are restricted, most supply chain optimisation problems involve matching demand and supply.

Weakness

1. **Lack of Robustness:** When it comes to resilience, the APS software components are designed for deterministic planning, which does not allow for robust planning. APS systems' deterministic planning algorithms react swiftly to changes, but uncertainties are dealt with through a limited set of approaches.
2. **Multi-period model:** When the data size grows, it becomes difficult to analyse them in one single analysis. So, the data is split into sub-sets and analysed at different times. This might cause delay in a dynamic environment.

Opportunities

1. **Deterministic planning:** Material flow planning is more extensive than master planning, and APS takes care of transporting items directly to customers or via warehouses, as well as cross-docking. In addition to this feature the coordination between online systems such as ERP or data warehouse can be added to APS.
2. **Discrete event simulation:** APS has the capability to integrate horizontal and vertical flows of information in supply chain. Horizontal flows orient all building blocks based on customer requirements. Vertical flows, on the other hand, are a method of coordinating lower-level plans using the outcomes of higher-level plans.
3. **Multiple analysis:** Agents are commonly utilised in simulation because they readily simulate the concurrent operations of several agents in an attempt to recreate and anticipate the behaviours of complex phenomena.

One intriguing characteristic of this system is the ability to simulate the activities and interactions of autonomous persons in a supply chain (e.g., vendors, manufacturers, distributors, clients, etc.) and assess their influence on the system as a whole.

Threats

1. **Increased work hours:** The results generated by the models might result in increase of work hours to maintain the flow of goods and deliver it at the right place at the right time.
2. **Less sensitive to uncertainties:** Models generated for the APS system have to include uncertainties. In other words, have to provide room for human error. In reality, uncertain-

ties occur all the time, and what was intended as an inventory level for a given moment is not always what is obtained. This is due to factors such as machine breakdowns or the stochastic nature of the manufacturing system.

3. **Improper data:** Lack of standardisation will lead to improper results. This might result in downgrading the system rather than upgrading. Finally, in the absence of a clear sequencing logic between upstream and downstream resources, a bullwhip effect from downstream resources will occur.

8.3 Blockchain Technology

Blockchain is a system with a distinct set of characteristics, including a decentralised structure, distributed notes, storage mechanisms, a consensus algorithm, smart contracting, and asymmetric encryption to assure network security, transparency, and visibility (Dutta et al., 2020). From SC provenance to business process re-engineering to security, blockchain offers enormous potential to alter supply chain (SC) processes. Blockchain is a distributed digital shared ledger that is distributed over a network (Chang, Chen, & Lu, 2019). Once the records are uploaded, they cannot be modified without modifying the preceding records (with the approval of all/majority of interested parties), making business activities incredibly safe. Some of the characteristics of this technology are ((Dutta et al., 2020)):

1. **Decentralised:** The system's data can be accessed, monitored, saved, and updated across various systems.
2. **Transparent:** Data is recorded, transferred and saved on the network with consensus, and it is visible and traceable throughout its existence.
3. **Smart contract:** It is a simple automated software that aids in contract execution. It eliminates the requirement for a traditional contract while improving security and lowering transaction costs. Smart contracts are typically designed with rules, fines, and actions that will be applied to all parties participating in the transaction (Li & Chen, 2020). Smart contracting facilitates supply chain response operations.

Like any other technology there are strengths, weakness, opportunities and weakness to blockchain. The SWOT analysis for this technology in the supply chain domain in conducted in figure 33. The several factors depicted in the same figure are explained below ((Martínez Laosa, 2019)):

Strengths

1. **Fault Tolerant:** The blockchain is a distributed, decentralised system with a shared state. It also provides us with an extremely high level of fault tolerance. Blockchain, at its core, is a peer-to-peer network architecture in which every node is considered equal to every other node.
2. **Improves communication and information sharing:** Blockchain can enable smooth interfaces between applications via a decentralised cloud communication network. The complexity of communication is greatly reduced as a result. Blockchain technology has the potential to bridge the gap between different social communication apps that would not otherwise work together.
3. **Product Tracking:** The products are marked with an electronic value or with the help of RFID. This code enables all members of the blockchain network to keep track of essential data such as location related to the product.

Weakness

1. **Insufficient control:** Organisations can reduce transactions if they control the chain of blocks, but this means that crucial information is lost. This is achieved by establishing a private blockchain. Organisations can alter or even remove data from this type of network.
2. **Latency:** While storing information in a blockchain network, there is a minute delay experienced. The delay occurs when a block is created in the network. They are experienced when the level of load is high.
3. **Immaturity:** Blockchain is still a technology in its primitive stages. Especially, in the enterprise level. The technology itself, as well as the application cases to which it might be applied, are still in the early stages of development. Other reasons include lack of experts, lack of governance and lack of scalability.

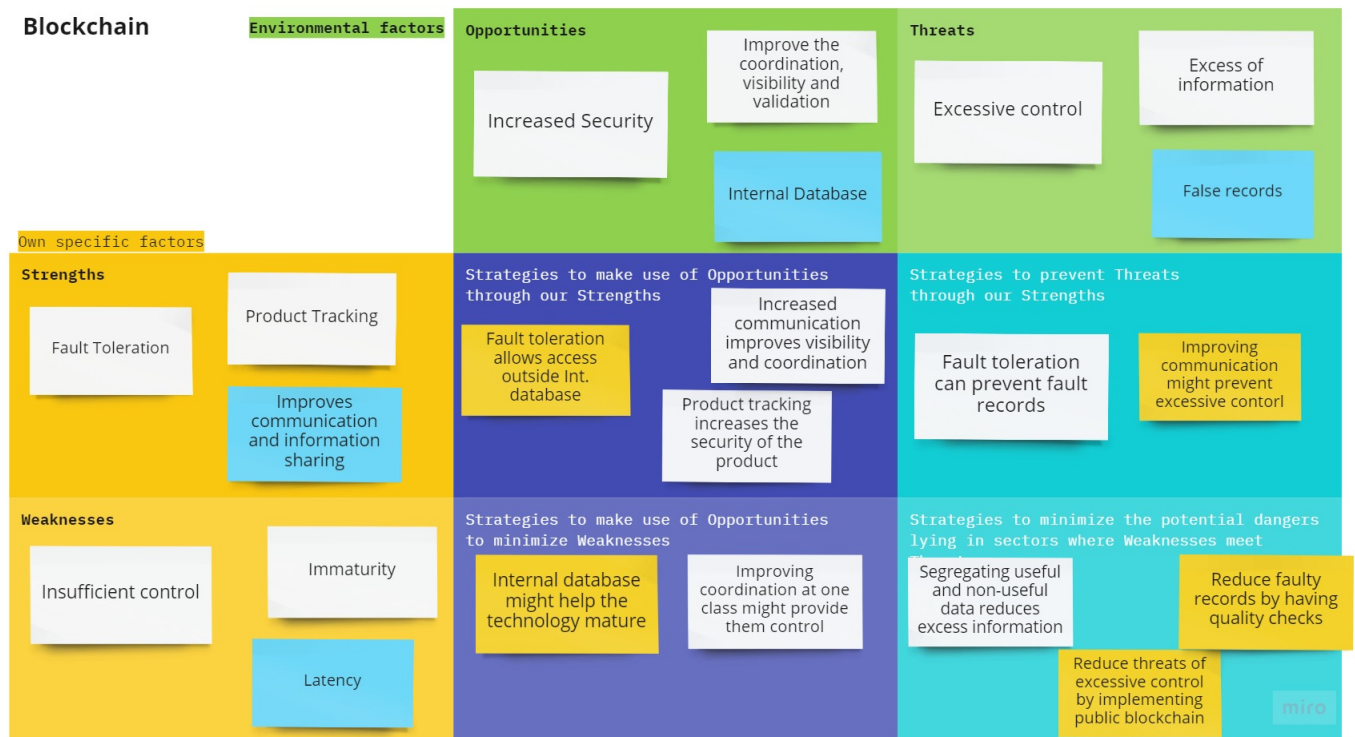


Figure 33: SWOT Analysis-Blockchain (Arrived by the researcher)

Opportunities

1. **Increased Security:** Blockchain technology offers better security than the other technologies. This is because organisations establish permissioned blockchains. Permissioned blockchains are only accessible to a specific group of users who have been issued identities via certificates.
2. **Internal Database:** Internal databases allow blockchain to function as a database for applications such as asset management, internal transaction recording, and identity verification.
3. **Improve the coordination, visibility and validation:** If the usual process is disrupted due to an unforeseen event or malfunction, Blockchain notifies not only the direct provider, but also all the agents participating in the supply chain (IBM, 2020). It also notifies them of the potential system interruption.

Threats

1. **Excessive control:** Establishing a private, permissioned blockchain network provides organisations with more control over it. This violates the equal, permission-less concept of blockchain.

2. **False records:** On the immutable blockchain network, the illegal or fraudulent transaction could be in-correctable (DAVID TREAT, 2020). This could create an alternative chain and result in activities such as hacking.
3. **Excess of information:** All information collected from actors or agents are recorded in the system. Overtime, it would become hard for organisations to segregate useful and non-useful data.

Each of the above described technology has certain applications in the field of supply chain management. The applications explored, aims to improve factors that in-turn improves coordination between the information and material flows of the supply chain. The author further will map the strength and opportunities of the three technologies against the material and information flow. This is done based on a literature analysis that categorises applications per flow in section 3.4.

8.4 Supply Chain Viewpoint of Digital technologies

The intent of this chapter is to show the relation between the strength, opportunities, factors obtained in section 7, material flow is section 5 and information flow described in section 6. This is achieved through the literature study conducted in section 3.4 and 8 of different digital applications in certain large firms. The outcome of this section shows the summarised view of strength and opportunities against each of the chosen applications that contributes to the improvement of factors in the material and information flow of supply chain. This is depicted in table 12 along with how certain big firms like Airbus are leveraging the strengths and opportunities of these technologies. This is arrived based on the understanding gathered by the researcher.

Output obtained from this study such as the use of capabilities to improve coordination between material and information flow is used for designing the interviews with supply chain experts/ decision makers. The response obtained from the interviewees will help to identify "which of the selected technologies help companies to influence factors and increase their order fulfilment rate". This study is conducted in section 10.

Table 12: Mapping Strength and Weakness of Digital Technology to Supply Chain Applications (Arrived by the researcher)

	Strength	Opportunities	Prototypes/ Full-scale applications	Concepts	Material and Information flow in Supply Chain
Advanced Planning and Scheduling System (APS)	1. Integral Planning 2. Hierarchical planning system 3. True optimization	1. Deterministic planning 2. Discrete event simulation 3. Multiple analysis	Boyum IT Integral Planning of upstream and downstream material flows	1. Work Flow Management 2. Information Sharing 3. Cross-chain collaboration	
Enterprise Resource Planning System (ERP)	1. Tracking of Re-order, replenishments and out-of-stocks	1. Sales Automation 2. Demand Forecast Management 3. Warehouse Management	Airbus, Boieng Invoices, warehouse data, trade documentation and transfer documents	1. Information Sharing 2. Data verification 3. Database Management	
Blockchain System	1. Fault Toleration 2. Product/ Asset/ Material Tracking	1. Security 2. Internal Database 3. Improving Coordination, visibility and validation	IBM and Walmart: Tracking Movements of Food items Airbus Tracking design concepts and integrating supply chain network	1. Visibility 2. Transparency 3. Provenance 4. Internet Of Things (IoT) 5. Machine to machine communication	

Table 12 depicts the use of strengths and opportunities of the three digital technologies in applications developed by different companies. The interpretation of this figure is provided below:

1. **APS:** The strength and the opportunities such as "integral planning" and "deterministic planning" of APS together is exploited to plan the movement of materials both upstream and downstream. The steps to focus for achieving this integration is by improving cross-collaboration and increasing the level of information shared.
2. **ERP:** The strength and the opportunities of ERP such as "tracking" and "sales automation" together is exploited to automate invoices, material flow and the associated documents. The steps to focus for achieving this automation is by allowing verification of data electronically and sharing information across the supply chain.
3. **Blockchain:** The strength and the opportunities of blockchain such as "asset tracking" and "improving coordination" is exploited to enable tracking movements of materials in real-time. This enables improved coordination between material and associated information that results in improved in order-fulfilment. The steps to focus on is for achieving

this coordination is to improve transparency and visibility in the supply chain network.

It is seen that most of the strengths and opportunities are used to improve the coordination of material and associated information flow through the use of the concepts or sets of actions (factors) such as *information sharing*, *cross-chain collaboration*, *database management*, and *transparency*. These concepts also convey a similar meaning to the factors mentioned in section 5 and 6 obtained from the SCOR and UML diagrams.

This section summarises the use and capabilities of the three shortlisted technologies such as, ERP, APS and Blockchain. The output obtained through the SWOT analysis of these technologies were mapped to indicate their capabilities in the field of supply chain.

9 Supply Chain Wheel:Pattern Artefact Development

This section aims to summarise the various factors that facilitate in increasing the order-fulfilment rate with the help of digital technologies. These factors are obtained from the study of material flow in section 5, information flow in section 6 and digital technologies in section 8. The information gathered from these sections are used to generate the pattern artefact, which is the main objective as stated in section 1. This makes the graduation project move towards the development phase as depicted in figure 34.

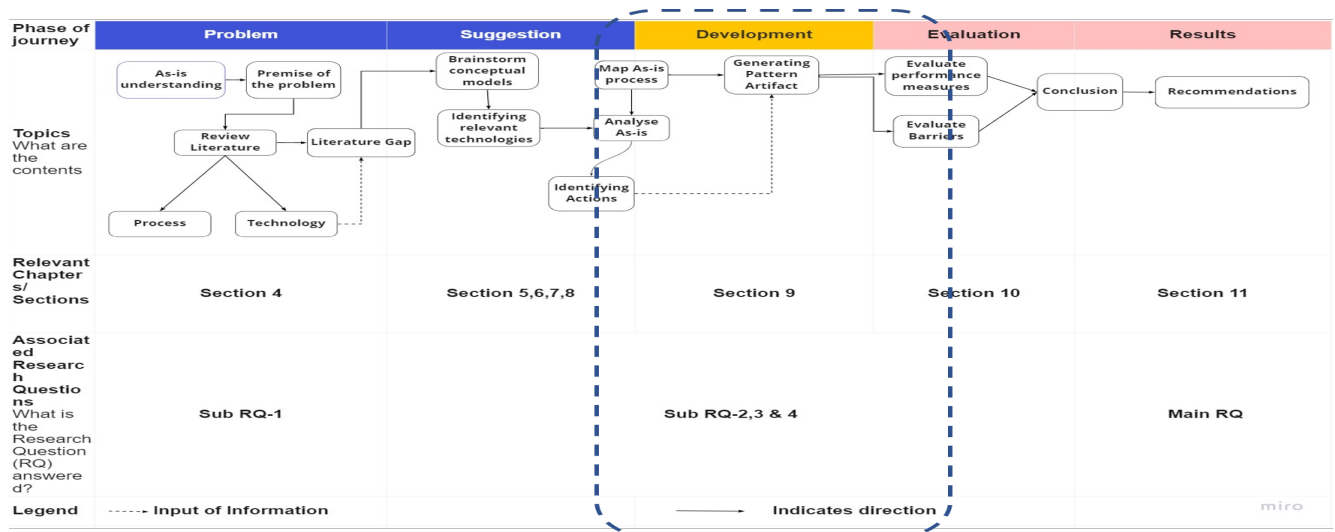


Figure 34: Development phase according to DSR approach

The summary of the factors identified is necessary to get the reader better acquainted with the application of this project. This section aims to present the key outcome of this thesis project "pattern artefact". This pattern artefact will be presented to the supply chain experts to obtain their understanding of the level of influence each technology has on each factor.

The development of the pattern artefact or a roadmap for technology implementation is developed through a four steps, they are:

1

Identification of Factors: The different factors have been identified in this study through the sections 5 and 6. The factors are seen as sets of actions for a firm like Airbus to take, in order to improve coordination between material and information flow that results in improved order-fulfilment rate. Some of these factors have been depicted in the business canvas in figure 30.

2

Development of Supply Chain Wheel: The identified factors are then represented in the form of a wheel diagram in section 9.1. This wheel diagram indicates the different factors, their categorisations and the use for the pattern artefact. This is further elaborated in the same section.

3

Use of Best-Worst Method (BWM): Step-1 and Step-2 are used as input to an interview process. The aim of the interview process is to obtain the level of influence each of the shortlisted technologies have on the identified factors. The BWM is used to interpret the responses of the interviewees. This process is further explained in section 10.

4

Generating tree map diagram: Once the results of the interviews are interpreted using the BWM, the values are graphically depicted using the excel software. The graphs depict the most and the least improved factors. Once, the graphs are generated the factor "responsiveness" is checked as it a direct measure of order-fulfilment rate. It is identified that the APS is technology improves this factor the most and is the most suitable technology.

All of these steps are performed and compiled to obtain the final pattern artefact, which is a "technology roadmap" for firms such as Airbus that assists them during digital transformation. This final pattern artefact or the roadmap is described in section 10. During each step the associated numbering is indicated with the diagram.

9.1 Supply Chain Application Wheel

Pattern artefact is defined in section 2. It presents generalised system design elements that help companies to implement disruptive technologies. The pattern artefact consists of different designs depicted such as abstract tables and figures indicating directionality by different authors ((Offermann et al., 2010), (Wang & Ma, 2006), (Kowalski, F Schatzki, T, & Stress, 1965)). Following the research approach stated and depicted through a flow diagram in section 2, this section presents the pattern artefact which is as input for interviews.

The intent of this section is to present one such pattern artefact arrived by the researcher that

aims to assist companies in implementing digital technologies into their supply chain. The thesis started out with the premise stating the improper material and information flow in large firms leads to delayed order deliveries as indicated in figure 34. The study conducted in section 5 and 6 resulted in describing the presence of factors that has a certain association with the different activities performed. The current level of these factors were identified to be poorly executed, and were categorised as non-value add activities resulting in low order-fulfilment rate. To improve order-fulfilment rate three different digital technologies were identified and studied. It is established from figure 12 that improving the identified factors associated with the activities can assist companies to better exploit the strengths and opportunities of the digital technologies. This is arrived through the lens of Airbus.

A pattern artefact provides generalised system design elements that assist firms in future technology implementation. The initial pattern artefact arrived for this graduation project depicts an abstract views of factors and describes the factors having a certain influence to order-fulfilment rate. These factors are identified for large aviation firms through the lens of Airbus. Undertaking the set of actions or factors described in section 5 and 6 will help companies like Airbus to convert non-value add activities to value add activities (section 6.1) and increase order-fulfilment rate are depicted in figure 35. The multiple factors presented in the wheel are seen as the *pattern artefact* as it provides generalised elements that assist companies to improve such as Airbus to increase their order-fulfilment rate.

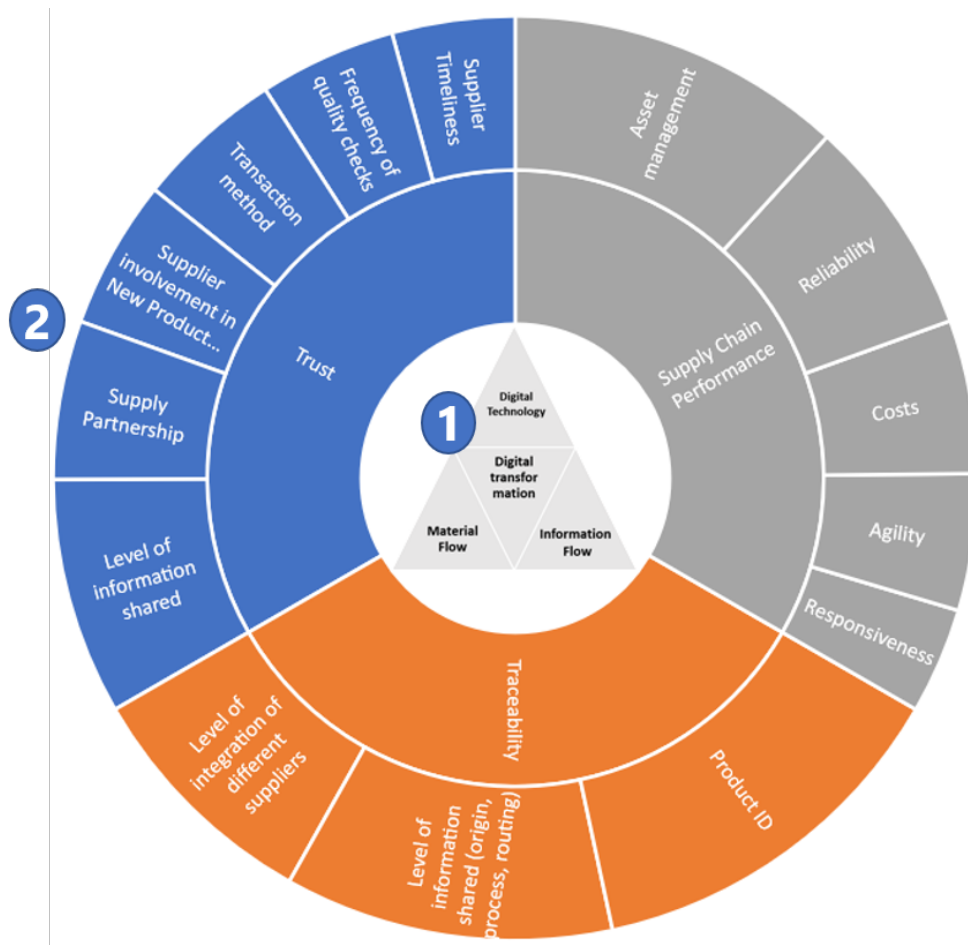


Figure 35: Supply Chain Wheel: Initial Pattern Artefact (adapted by the researcher from the this study)

The inner triangle in figure 35 indicates the use for the wheel diagram or the pattern artefact. It is such that this initial pattern artefact generated can be used by companies like Airbus to improve coordination between material flow and information flow through digital technology implementation. This entire process is also referred to as "digital transformation". The outer circle of the wheel describes the different factors that have been identified to improve the coordination between the two flows. These factors include "asset management", "product ID", and "level of information shared". Improving these factors are seen to increase order fulfilment rate. The researcher as mentioned in the flow diagram in figure 3 has further taken this supply chain wheel or initial pattern artefact in 35 and the SWOT assessment in figure 12 to the 10 interviewees, who are experts in the field of supply chain management and Industry 4.0. The responses of the interviewees are interpreted using the BWM method. This method helps to quantify the factors and aid in determining the suitable technology and further explaining the pattern artefact, which is the desired objective of this thesis project as described in section 3.

The description of the different factors in figure 35 is provided below in tables 13 and 14.

Table 13: Examples of strengths, opportunities influencing factors

S.No	Factor	Level	Description
1	Supplier involvement in New product development	medium	<i>Improving communication and Integral planning</i> can increase the level of involvement by providing the right information at the right time
2	Supply partnership	poor	The adoption of lean management will improve supply chain partnership, implementation of advanced technologies like APS and blockchain system (Integral planning, Hierarchical planning system, increased information sharing) can create and distribute functions for the whole organisation, thereby increasing partnership ((Qrunfleh & Tarafdar, 2013))
3	Level of information shared	poor	Information or knowledge sharing within the organisation positively affect competitive advantage (Azeem et al., 2021). The knowledge management systems should be better integrated to achieve this end result. <i>Improving ERP or developing Blockchain networks can improve information or knowledge sharing in organisations.</i>
4	Supplier timeliness	medium	Timeliness is an important aspect of velocity (rate in which information travels) because it determines whether data creation, analysis, and associated inferences are available at the appropriate time. As a result, any organisation must be concerned about the accuracy and timeliness of the data utilised in analysis and decision-making (Castka et al., 2020). <i>The blockchain technology has the capability to transfer information to all actors at the same time.</i>
5	Frequency of quality checks	good	The quality checks are overseen by quality control. The readiness of a part is communicated to the respective actor by the quality control. The frequency of these checks has increased due to COVID-19. If communication is not proper it could affect quality control strategies (Jraisat & Sawalha, 2013). <i>Strengths of APS and blockchain systems can be utilised to propose alternative strategies.</i>

Table 14: Examples of strengths, opportunities influencing factors

S.No	Factor	Level	Description
6	Transaction method	medium	Implementation of blockchain technology enables to create and handle transactions better than ERP systems / APS
7	Level of information shared (origin, process and routing)	medium	The other part of information sharing is displaying the origination of different parts and having the luxury to present customers the entire journey as it helps in developing trust and traceability (Kros et al., 2018b). <i>The strengths of APS such as integral planning helps improve the flow of these routes and blockchain helps in storing these information.</i>
8	Level of integration of different suppliers	medium	This refers to integrating suppliers vertically (within tiers) in supply chain. It is also called as "vertical integration", which has become a a channel approach that many businesses may pursue in order to boost profits (Li & Chen, 2020). <i>The strengths such as timely information and hierarchical planning system help in improving vertical integration.</i>

The important factors and their definitions that are established were presented to the 10 supply chain experts and industry 4.0 experts. This step is performed in order to arrive which factors are influenced best by the chosen technologies. An understanding of this will help Airbus to facilitate their digital transformation. This is obtained through the application of BWM method. The step-by-step analysis of the BWM is described in the coming sections.

9.2 Best-Worst Method (BWM): Description

The factors that are seen to have an influence or association with the activities have been established in section 6.2. There are a number of subjective and objective assessments possible for the factors. The study of alternative and objective assessments of the decision makers is classified as a multi-criteria problem as mentioned in section 7. During digital transformation, there are multiple stakeholders and scenarios involved. These stakeholders and scenarios contribute to complexity in the implementation process. Thus, the MCDM method is chosen to provide a definitive answer by acknowledging the complexity.

The Best Worst Method (BWM) is a method for dealing with multi-criteria decision-making (MCDM) problems (Rezaei, 2015). The purpose of the BWM for handling MCDM problems, is to choose the most useful alternative based on the supplied criteria. These methodologies

consider pairwise comparisons, in which relative preferences are compared to one another. This strategy is useful to assess all possibilities that is either impossible or meaningless.

The goal of using this method in this thesis project is to determine which factors are influenced the most among the three technologies chosen that will improve coordination of material and information flow. The result obtained explains the factor which is best influenced by each of the shortlisted three technologies. Data collection for this method are obtained through interviews as described in section 2. The candidates selected had knowledge in supply chain management and the digital technologies. These candidates work in different organisations facing the same problem. In some cases, the lack of consistency of pairwise comparison in the matrix is one issue in BWM. A MCDM problem is represented by the matrix below:

$$P = \begin{matrix} & \begin{matrix} c_1 & c_2 & \dots & c_n \end{matrix} \\ \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} & \begin{pmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \dots & p_{mn} \end{pmatrix} \end{matrix}$$

Figure 36: MCDM Matrix

(Rezaei, 2015)

The other methods used for analysing multiple criteria, are regression analysis and correlational analysis (Beulah Jeba Jaya & Jebamalar Tamilselvi, 2014). Both of these methods have not been considered for this research project as the end results only explain the relationship between the different factors and does not allow us to deduce the best technology. This is the reason, the BWM has been selected for this research project. The other reasons to use BWM are provided below (Rezaei, 2015):

1. The decision maker has a good grasp of the range of evaluation by defining the best and worst criteria (or alternatives) before conducting pairwise comparisons among the criteria (or alternatives). This could lead to more trustworthy pairwise comparisons.
2. In a single optimisation model, the use of two pairwise comparisons vectors produced based on two opposite references (best and worst) could offset the anchoring bias that the DM might have while conducting pairwise comparisons.

The set $a_1, a_2, \dots, a_m$ represents all viable options and $c_1, c_2, \dots, c_m$ represents the set of choice criteria; and p_{mn} represents the performance of alternative i in relation to criterion j .

The BWM employs the best and worst options to determine the weights of items in the middle. The decision-maker selects the best and worst criteria. They also select a comparison of all criteria with the selected best criterion as well as worse on a scale of 1 to 9. The analysis for the BWM is done in three steps, which are:

1. The first step is to determine the different factors or criteria for analysis. The different criteria for this study are level of information shared, product identity, level of integration of suppliers, supplier involvement in new product development, supplier partnership, supplier timeliness, transaction method, and frequency of quality checks. These factors and descriptions are provided in figure 35 and tables 13 and 14 respectively.
2. The definitions of the variables, constructs and the situation are explained to the interviewees and then a comparison of the best criteria across all other criteria is arrived. The score ranges from 1 to 9, with 1 indicating that i is equally essential to i and 9 indicating that i is more significant than i . The scores give the following vector:

$$A_w = (a_{1w}, a_{2w}, \dots, a_{nw})^T$$

3. This stage employs a min-max linear technique to determine the best weight. $[w_B - a_{Bj}w_j \leq \zeta^L]$ for all j . $[w_j - a_{jw}w_w \leq \zeta^L]$ for all j .

$$\sum_j w_j = 1$$

$$w_j \geq 0 \text{ for all } j$$

The ζ^{L*} or ksi, is a consistency indicator that is provided by the linear technique. This shows the validity of the factors or criteria chosen for this study or indicates criterion validity.

The results of each of these criteria are marked from one to nine and will be derived using the *Solver* function available in excel. The values in the choice variable are adjusted to satisfy the constraints and generate the desired outcome. The use of Solver function is to determine the maximum or the minimum value of the defined criteria by changing the values of adjacent cells. This is used to arrive at a numerical estimation for the level of factors represented in figure 35. This step also aims to improve the initial pattern artefact described in section 9.1.

9.3 Sub-Conclusion for Pattern Artefact

The pattern artefact is developed in this section and displayed in the form of a wheel in figure 35. This pattern artefact represents the the different factors to improve the coordination between the material and information flow that results in improved order-fulfilment. The factors are suggested steps to take and are compiled and defined thoroughly in tables 13 and 14.

To identify the enablers for these factors and the technology that increases the most are identified through interviews conducted with supply chain experts and decision makers. These interviews are interpreted using the BWM. The interview process and the results are discussed in the upcoming section.

10 Pattern Artefact Evaluation and Results

The previous sections discussed material flow, information flow, digital technologies, factors and the inter-relations between them. The focus of this section is two fold, one is to identify and describe the factors that have associations with the different activities performed at Airbus. Second, is to identify a suitable technology that assists companies to enhance the factors and thereby improve order-fulfilment rate. In order to evaluate the level of influence on these factors the best-worst method is used. The explanation and reason for choosing this methodology is provided in section 9.2.

The iterative steps that lead to the finding of the artefact design are explained using the DSR approach and framework outlined in Chapter 2. Figure 37 denotes the stage of the research framework that will be discussed in this chapter.

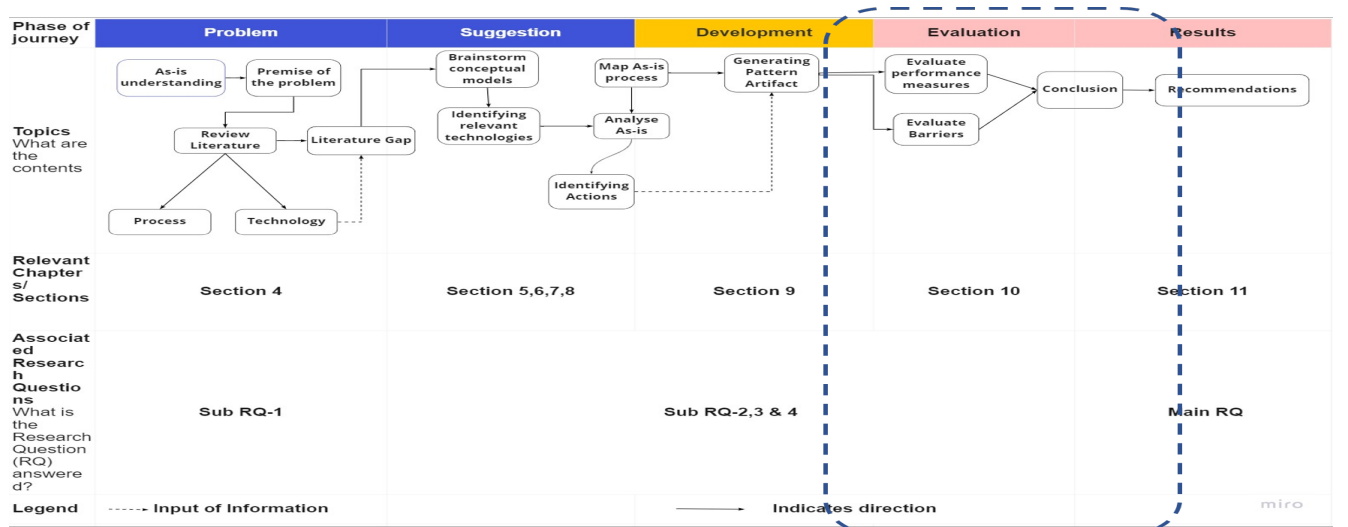


Figure 37: Evaluation phase according to DSR approach

It is established that the constructs such as "trust", "traceability", and "supply chain performance" are multi-dimensional in section 7. To evaluate the influence the identified technologies have on these multi-dimensional constructs and their factors, the BWM is used as described in section 9.2. The analysis process using the BWM is elaborated in the upcoming section.

10.1 Best-Worst Method (BWM): Analysis

The initial pattern artefact, its description and the method used to further analyse the influence of these factors were examined in the previous section. It is established that in order to convert non-value add activities to value add activities, to better coordinate material & information

flow and increase order-fulfilment rate choosing the right digital technology becomes the key. This will directly improve most of the factors. The relationship between the material flow and information flow, digital technologies, their constructs and the related factors are depicted through a wheel diagram in figure 35 and described in tables 13 & 14.

The intent of this section is to describe the process of analysis and identify the improvements (if any) made by the selected three technologies on the factors through the use of BWM. It is the researchers' understanding that the technology that improves most number of factors by certain percentages is the most suitable technology. The data for this section is obtained through interviews consisting of supply chain and Industry 4.0 experts. A group of 10 members were interviewed to understand their perspective on level of influence each technologies have on the factors described in figure 35. The overview of the interview process conducted is depicted in figure 38.

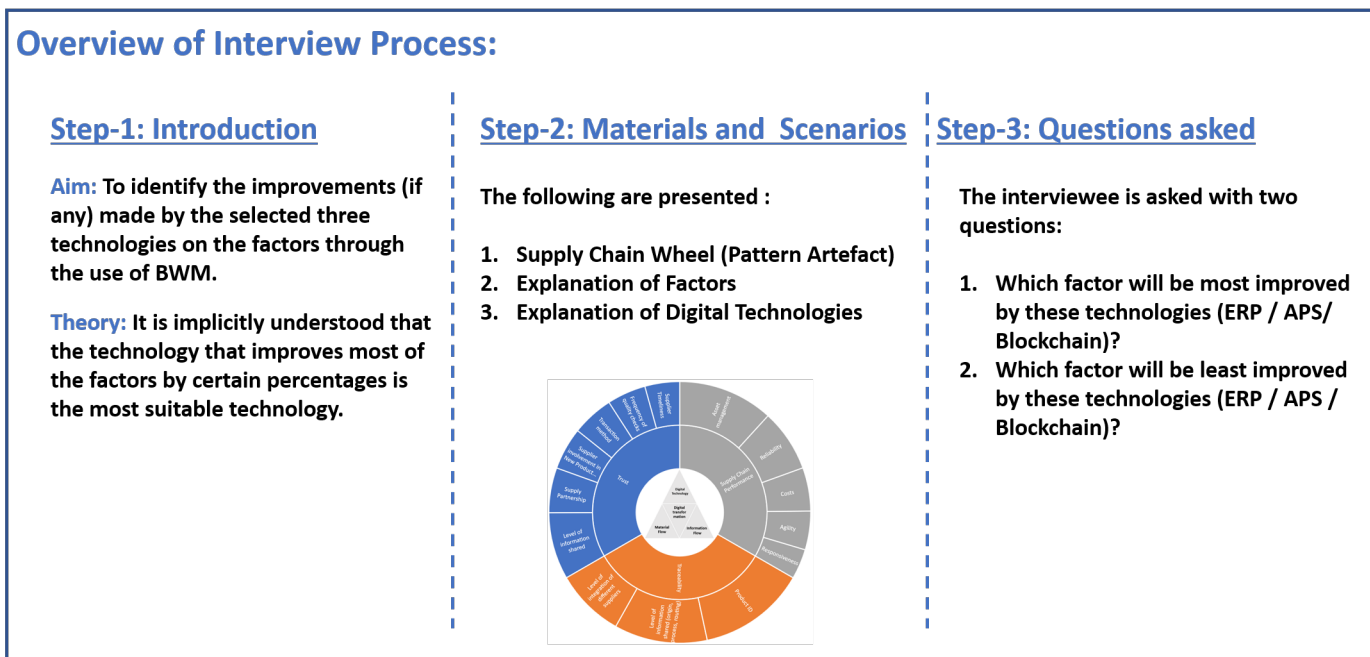


Figure 38: Overview Of Interview Process (Adapted by the researcher)

Figure 38 depicts the steps undertaken by the researcher in order to arrive at the desired objective. The aim and underlying theory were established before the interviews were taken. The candidates were chosen from the field of supply chain and exposure to digital technologies as they would have faced a similar situation in their respective organisations. The generated initial pattern artefact is presented, along with the description of factors and the selected digital technology. These explanations are provided in section 3.4, 8, and 9.1. The interviewees

were experienced to analyse different situation with respect to their companies and provide a definitive answer while ranking the factors using the BWM. This process undertaken by the interviewees enabled the researcher to study the alternative subjective and objective assessments of the decision makers as described in section 9.2.

The input of the interviewees were obtained in an excel worksheet as provided by the developer of BWM ((Rezaei, 2015)). According to the developer, if the number of criteria exceeds by 9, the worksheet has to be split into two or three depending upon the grouping criteria. This graduation project identified 14 sub-criteria (factors) and three main criteria (constructs) described in tables 13 & 14. The sample of input obtained from the interviewees are shown in figure 39. The steps involved in figure 39 are:

- **Step 1:** The interviewees were asked to select the "best" or the most improved factor by using the ERP/APS/Blockchain technology bearing in mind the specifications such as "features", "interperobility" and "ecosystem" (Figure 4) during development.
- **Step 2:** The interviewees were asked to select the "worst" or the least improved factor by using the ERP/APS/Blockchain bearing in mind the specifications such as "features", "interperobility" and "ecosystem" (Figure 4) during development.
- **Step 3:** The interviewees compared the other factors to the "best". This is done in order to determine if the technology has equal or lower amount of influence on the factors in different situations.
- **Step 4:** The interviewees compared the other factors to the "worst". This is done in order to determine if the technology has equal or lower amount of influence on the factors in different situations.

During technology implementation, there are several scenarios possible. These different scenarios result in subjective opinions on the level of influence the technology has on a factor. Most of the alternative scenarios are brainstormed with the interviewee and the final ranking is made. The steps three and four enables the interviewees to analyse these different scenarios and then provide a definitive answer.

Criteria Number = 6	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Names of Criteria	Supplier involvement in New Product Development	Supply Partnership	Supplier Timeliness	Transaction method	Frequency of quality checks
Select the Best	Transaction				
Select the Worst	Supply				
	Supplier involvement in New Product Development	Supply Partnership	Supplier Timeliness	Transaction method	Frequency of quality checks
Best to Others					
Transaction method	5	6	3	1	4
Others to the Worst	Supply				
Supplier involvement	2				
Supply Partnership	1				
Supplier Timeliness	4				
Transaction method	6				
Frequency of quality	3				
Level of information	5				

Figure 39: Sample of Interview answers

The figure 39 depicts the sample of input provided by the interviewees. A total of 10 interviews were conducted and each interviewee were expected to complete three sheets for each of the technologies (ERP/APS/Blockchain) and constructs namely, trust, traceability and supply chain performance. The results obtained from the analysis are interpreted and analysed in the next section.

10.2 Results and Discussions

The intent of this section is to tabulate, display and interpret the results obtained through the interviews. The results are categorised by the technology (ERP/APS/Blockchain) and interpreted. This categorisation is done in order to provide clarity of the results for the reader. The results for ERP, APS and Blockchain are discussed below.

10.2.1 BWM Results for ERP

Table 15 presents the weight (globally) of the fourteen factors / sub-criteria (as in table 13, 14) which are relevant for selecting the best fit technology according to experts and decision makers in the field of supply chain. Table 15, first column shows the main factors or criteria that are

utilised to weigh. The second column represents the sub-criteria or sub-factors and the respective cluster. The last column has the average weights taking all the experts into account. From the results it is seen that "Product ID" (0.398809524), "Asset Management" (0.353074832), and "Level of Information Shared" (0.345238095) are the three most improved factors of the ERP system. Similarly, by observing the final weights the factors such as "Responsiveness" (0.111468781), "Supplier Timeliness" (0.129298635), and "Agility" (0.143452004) are the least fit or yet to be improved by the ERP technology.

Table 15: Improvements in factors for ERP technology (Adapted from interviews conducted with professionals in supply chain management)

Constructs	Factors	Avg
Trust	Supplier involvement in New Product Development	0.1567
	Supply Partnership	0.1667
	Supplier Timeliness	0.1292
	Transaction method	0.1548
	Frequency of quality checks	0.1437
	Level of information shared	0.2485
Traceability	Level of information shared (origin, process, routing)	0.3452
	Level of integration of different suppliers	0.2559
	Product ID	0.3988
Supply Chain Performance	Reliability	0.2309
	Responsiveness	0.1114
	Agility	0.1434
	Costs	0.1610
	Asset management	0.3530

The weights for the above factors to indicate validity of results were obtained using solver function. The KSI values arrived against each respondent are presented in the figure 40. The last Column has the average KSI value taking all the experts into account.

	P1	P2	P3	P4	P5	P6	P7	Avg
KSI Values	0.07721	0.05735	0.07721	0.05735	0.07721	0.05735	0.07721	0.06870

Figure 40: KSI- Indicating the validity of results

10.2.2 BWM Results for APS

Table 16 presents the weight (globally) of the thirteen factors / sub-criteria (as in table 13) which are relevant for selecting the best fit technology according to experts and decision makers in the field of supply chain. Table 16, first column shows the main factors or constructs that are

utilised to weigh. The second column represents the sub-criteria or factors and the respective cluster. The last Column has the average weights taking all the experts into account. From the results it is seen that "Level of integration of different suppliers" (0.398809524), "Product ID" (0.30952381), and "Level of information shared (origin, process, routing)" (0.291666667) are the three most improved factors of the APS technology. Similarly, by observing the final weights the factors such as "Transaction method" (0.078389786), "Costs" (0.082745788), and "Frequency of quality checks" (0.114518523) are the least fit or yet to improved by the APS technology.

Table 16: Improvements in factors for APS technology (Adapted from interviews conducted with professionals in supply chain management)

Constructs	Factors	Avg
Trust	Supplier involvement in New Product Development	0.2093
	Supply Partnership	0.2312
	Supplier Timeliness	0.2075
	Transaction method	0.0784
	Frequency of quality checks	0.1145
	Level of information shared	0.1591
Traceability	Level of information shared (origin, process, routing)	0.2917
	Level of integration of different suppliers	0.3988
	Product ID	0.3095
Supply Chain Performance	Reliability	0.1942
	Responsiveness	0.2809
	Agility	0.221
	Costs	0.0827
	Asset management	0.2211

The weights for the above factors to indicate validity of results were obtained using solver function. The KSI values arrived against each respondent are presented in the figure 41. The last Column has the average KSI value taking all the experts into account.

	P1	P2	P3	P4	P5	P6	P7	Avg
KSI Values	0.05735	0.05735	0.08833	0.05735	0.08833	0.05735	0.08833	0.07062

Figure 41: KSI- Indicating the validity of results

10.2.3 BWM Results for Blockchain

Table 17 presents the weight (globally) of the thirteen factors / sub-criteria (as in table 13 and 14) which are relevant for selecting the best fit technology according to experts and decision

makers in the field of supply chain. Table 17, first column shows the main criteria or factors that are utilised to weigh. The second column represents the sub-criteria or factors and the respective cluster. The last Column has the average weights taking all the experts into account. From the results it is seen that "Level of information shared (origin, process, routing)" with a value of 0.541666667, "Level of information shared" with a value of 0.34438 and "Agility" with a value of 0.24723 are the most improved factors of the Blockchain technology. Similarly, by observing the final weights "Frequency of quality checks" with a value of 0.078649051, "Transaction method" with a value of 0.136484137, and "Supply Partnership" with a value of 0.14179306 are the least fit or yet to improve by the Blockchain technology.

Table 17: Improvements in factors for blockchain technology (Adapted from interviews conducted with professionals in supply chain management)

Constructs	Factors	Avg
Trust	Supplier involvement in New Product Development	0.1479
	Supply Partnership	0.1417
	Supplier Timeliness	0.1507
	Transaction method	0.1364
	Frequency of quality checks	0.0786
	Level of information shared	0.3443
Traceability	Level of information shared (origin, process, routing)	0.5416
	Level of integration of different suppliers	0.2380
	Product ID	0.2202
Supply Chain Performance	Reliability	0.2176
	Responsiveness	0.1804
	Agility	0.2472
	Costs	0.1519
	Asset management	0.2026

The weights for the above factors indicate validity of results obtained using the solver function. The KSI values arrived against each respondent are presented in the figure 42. The last Column has the average KSI value taking all the experts into account.

	P1	P2	P3	P4	P5	P6	P7	Avg
KSI Values	0.05735	0.05735	0.05735	0.05735	0.05735	0.05735	0.05735	0.05735

Figure 42: KSI- Indicating the validity of results

10.3 Enhancing Pattern Artefact: Comparing Results

The intent of this section is to depict the most and the least improved factors for each of the chosen technology (ERP/APS/Blockchain). This section move the thesis from suggestion

phase to evaluation phase of the DSR approach as indicated in section 2.4. The impact of each factor is differentiated and shown using a treemap chart for each of the chosen technologies. This chart will help the decision maker in large aviation firms to obtain an idea on the impact of the factors and to assist in decision making for their future implementation. The obtained values from the BWM in section 10.1 are graphically represented in this section. The graph is generated with the excel software and is setup to provide the values in percentages.

10.3.1 ERP

Figure 43 depicts the level of influence of each factor by adopting the ERP technology. It is seen that *product ID*, *asset management* and *level of information shared*, are rated as the most improved factors by the interviewees and the average weights comes to 40%, 35% and 35% respectively. Similarly, the factor *responsiveness* is rated as the least improved with 11%, which is a measure of order-fulfilment rate.

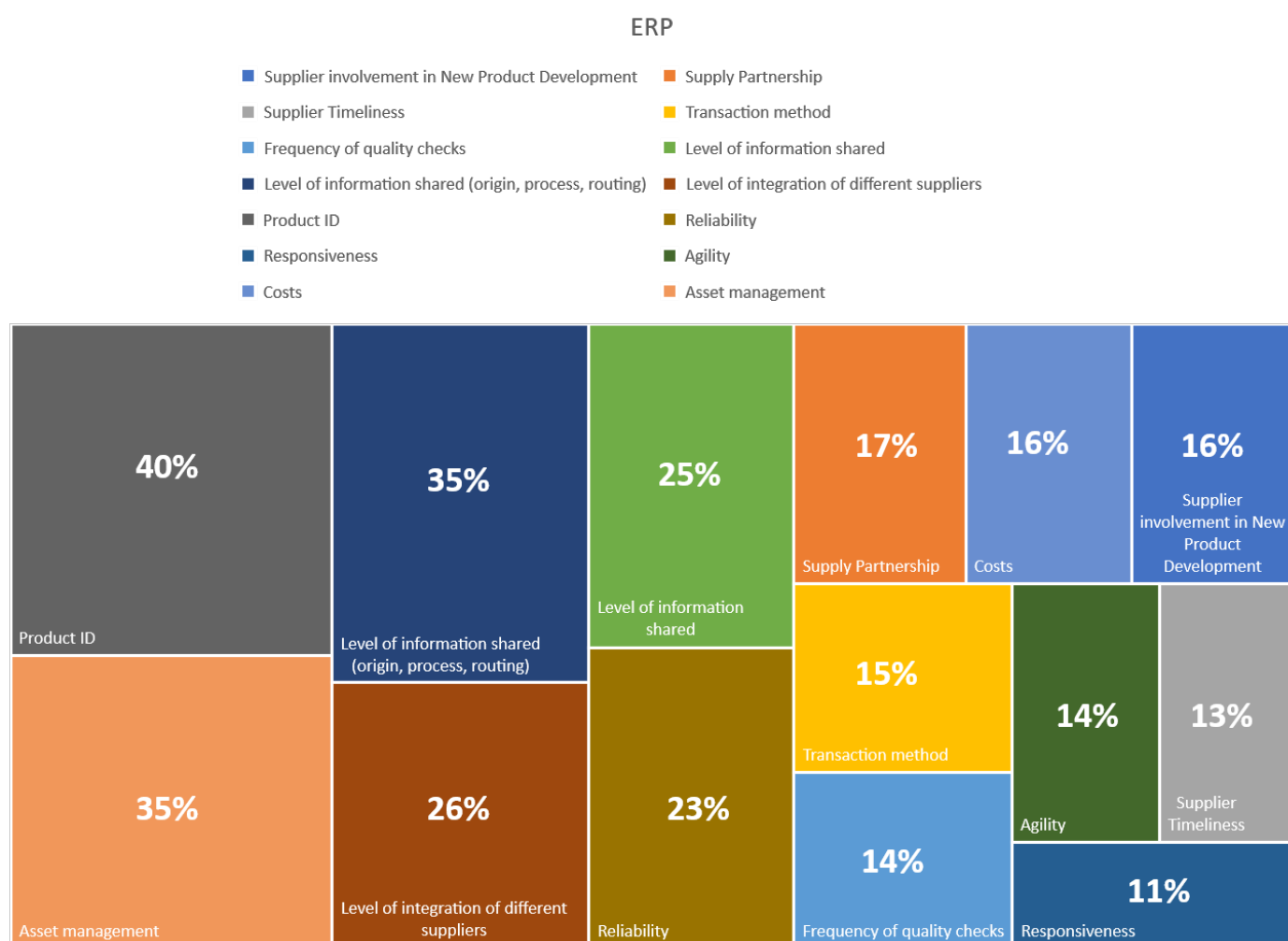


Figure 43: ERP Treemap- Influence on Factors (Obtained from the BWM for ERP)

Figure 43 indicates the different percentage of factor's improvement when an ERP system is used. The factors such as "product ID", "level of information shared", and "asset management" should be focused by large aviation firms. Focusing on improving these factor would improve the order-fulfilment rate. One of the ten interviewees stated that *"issuing contracts or any form of certifications to the employees or suppliers might increase the companies trust and allow the company to share more information"*. If these steps are undertaken the factors would be improved and thus improving the coordination between material and information flow that results in high order-fulfilment rate of the company.

10.3.2 APS

Figure 44 depicts the level of influence of each factors by adopting the ERP technology. It is seen that *level of integration of different suppliers*, *product ID* and *level of information shared*, are rated as the most improved factors by the interviewees and the average weights comes to 40%, 31% and 29% respectively. Responsiveness is followed by the three mentioned factors with a rate of 28%, which indicates a good order-fulfilment rate. Lastly, the factor *transaction method* is rated as the least improved with 8%.

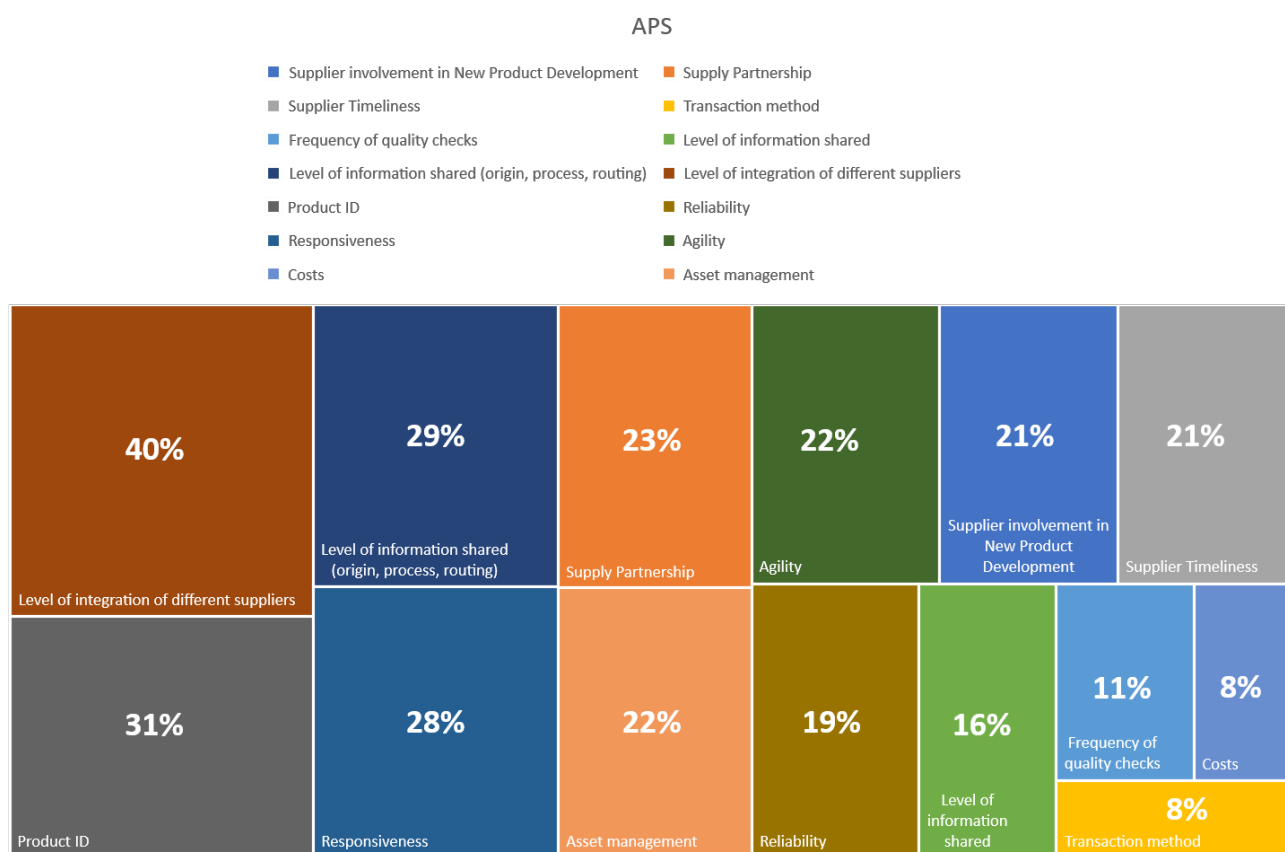


Figure 44: APS Treemap- Influence on Factors (Obtained from the BWM for APS)

Figure 44 depicts the different percentages of factor's improvements through the use of APS technology. The factors "level of integration", "product ID", and "level of information shared" should be focused by large aviation firms. Focusing on improving these factor would improve the order-fulfilment rate.

One of the interviewees stated that *"in the context of order-fulfilment or delivery, creating a preliminary production plan using optimisation models would allow for integration and for information sharing"*.

10.3.3 Blockchain

Figure 45 depicts the level of influence of each factors by adopting the ERP technology. It is seen that *level of information shared (origin, process, routing)*, *information (invoices, documents)* and *agility*, are rated as the most improved factors by the interviewees and the average weights comes to 54%, 34% and 25% respectively. Level of influence on the factor *responsiveness* is at 18%, which indicates a medium order-fulfilment rate when compared to the other two technologies. Lastly, the factor *frequency of quality checks* is rated as the least improved with 8%.

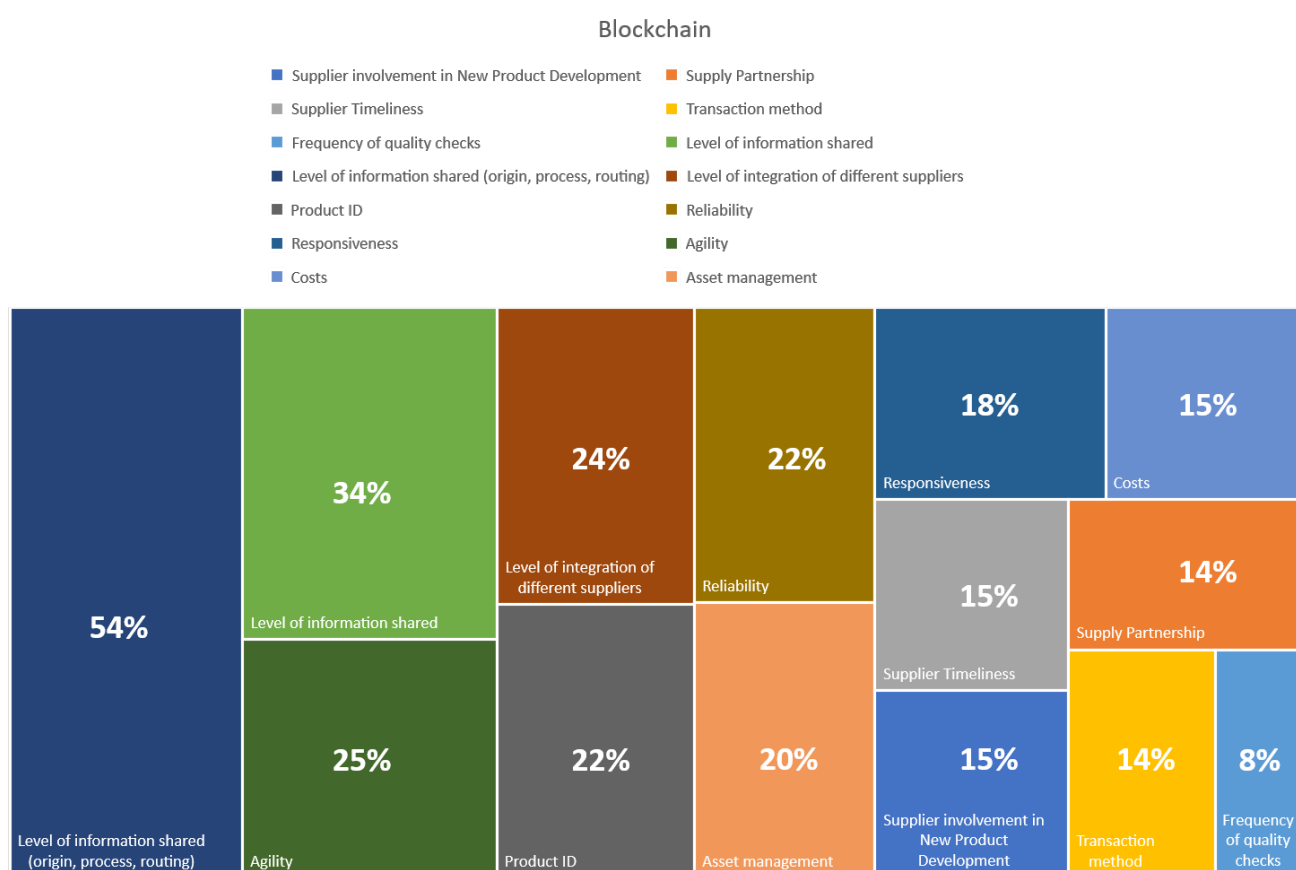


Figure 45: Blockchain Treemap- Influence on Factors (Obtained from the BWM for Blockchain)

Figure 45 depicts the different percentages of factor's improvements through the use of APS technology. The factors "level of information shared (origin, process, routing)", "information (invoices and documents)", and "agility" should be focused by large aviation firms. Focusing on improving these factor would improve the order-fulfilment rate.

One of the interviewees stated that *"blockchain is still not mature to be used in complex supply chains even IOTA but building a prototype, testing and improving the system can help the company to understand blockchain better and help in information sharing"*. This suggests that the decision makers themselves are not entirely aware of the blockchain technology. The advantages of this technology is theoretical at this movement. Improvements using this technology can be carried out using the mapping performed in section 6.1.

10.3.4 Comparing the results for ERP, APS and Blockchain

The graphical representation of the level of influence each of the technology has on the factors have been arrived in the previous sections. Following the research flow of DSR described in section 2.4, this section focuses on comparing these obtained results to determine the most suitable technology to increase order-fulfilment rate in large-aviation firms. The steps taken in order to arrive at the conclusion are:

- **Step 1:** The number of factors under each constructs were noted. That is, the construct "trust" consists of six factors, "traceability" consists of three factors and "supply chain performance" consists of five factors.
- **Step 2:** This step involves in identifying how many factors are influenced the most by the three selected technologies out of the given factors. The improvements were noted for each of the constructs. That is, ERP influences one of the five factors in "trust" the most, APS influences three of the five factors in "trust" the most and blockchain influences one of the five factors in "trust" the most. Similarly, the influences on other constructs have also been identified. Table 18 displays the summary of this step.
- **Step 3:** The technology that improves the highest number of factors the most is implicitly understood as the most suitable technology. The treemap was used to depict the table 18 graphically.

Figure 46 depicts the values obtained from the table 18. It describes the technology that influences the most number of factors when implemented in a large firm. From the same figure,

Criteria / Technology	APS	ERP	Blockchain
Trust	3	2	1
Traceability	1	1	1
Supply chain performance	1	2	2
Total	5	5	4

Table 18: Comparison table

it is seen that Advanced Planning and Scheduling (APS) system improves most of the thirteen factors and can be the most suitable technology for large size aviation firms.

The table 18 is created using the excel software and the figure 46 is generated. It is depicted in table 18 that both APS and ERP improve equal number of factors. But, as the focus of this thesis is towards improving the coordination between material and information flow that results in increased order-fulfilment rate, the priority is set to the factors "responsiveness". This factor "responsiveness" directly measures order-fulfilment rate as described in section 7. This is the reason APS is graph generated shows APS as the suitable result.

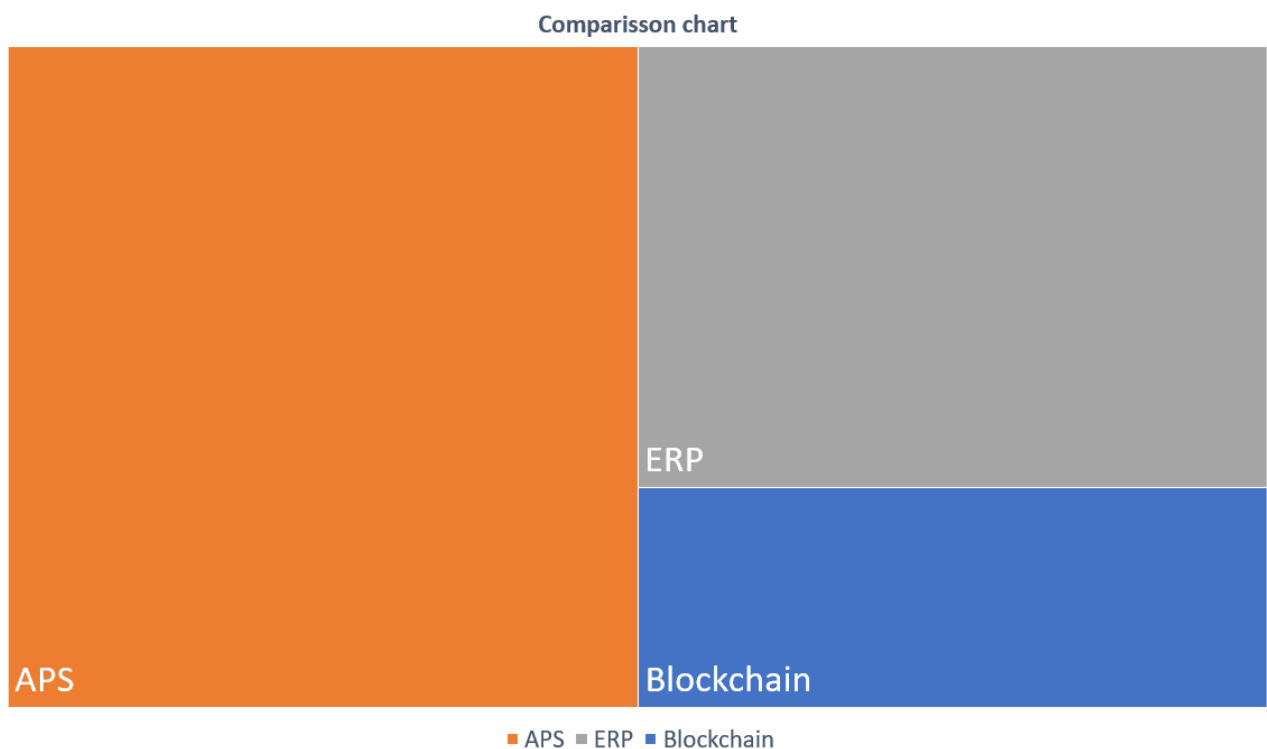


Figure 46: Comparison chart of ERP, APS and Blockchain (Arrived by the researcher from the results of BWM)

The graduation project focuses on finding which technology will be most suited to increase the order-fulfilment rate at large aviation firms through the lens of Airbus. The factor "responsiveness" describes the order-fulfilment rate of a company (ILIM, 2003). When the three technologies are compared to each other it is seen that ERP influences this factor by 11%, APS influences it by 28% and blockchain influences it by 18%. The higher percentage score of APS indicates that this technology would better assist companies to increase their order-fulfilment rate.

The entire pattern artefact is presented in figure 47. This supply chain wheel generated in section 9.1 is depicted in the centre of the figure and the results obtained through the Best-Worst Method is depicted on the top and bottom of the figure. This compilation of the different elements is done in order to provide better clarity to the reader.

The figure 47 explains the different components involved during digital transformation in large aviation firms. These different components are "*material flow*", "*information flow*" and "*digital technologies*". It is established that to improve coordination between material and associated information flow a suitable digital technology has to be implemented. The technologies have to be user-friendly to implement and integrate with the existing ecosystem at the respective aviation firms (3.4). Also, they have to improve the associated factors and constructs that have influences in different activities such as "order placement", "quality inspections", "transporting", "verification of information", and "receiving". These associated constructs were identified to be "trust", "traceability" and "supply chain performance".

At present, these different constructs were identified to be "medium" or "poor" (Tables 9, 10, 11). Three technologies (ERP/APS/Blockchain) were identified to increase these factors and thereby improve order-fulfilment rate. The different levels of influence each technology has the respective factors is depicted graphically on the right of the figure 47.

This artefact is seen to provide companies with a direction for aviation firms seeking to digitally transform their supply chain operations. The artefact aims to assist companies to choose suitable digital technologies for improving their current process. The next steps of this artefact would be to translate the different factors into strategies that further contribute in the technologies success⁴. The pattern artefact developed by the researcher based on this study is coined as "Technology Roadmap" as depicted in figure 47. The interpretation of this roadmap is described

⁴The term "success" is defined by the respective organisation

below in the form of steps:

- **Step 1:** The inner triangle describes the three streams for which the digital transformation roadmap could be used. These three streams are "material flow", "information flow" and "digital technologies". This first step is indicated by ① in figure 47.
- **Step 2:** To choose a suitable technology for their digital transformation, a firm such as Airbus should consider the relevant factors obtained through the study of material flow in section 5 and information flow in section 6. For example, to improve order-fulfilment rate the relevant factor is "responsiveness". This is indicated as ② in figure 47.
- **Step 3:** Once the firm chooses the relevant technology, the influence of the factors can be referred to this thesis paper. Any other factors that maybe of influence for their digital transformation, need to be additionally assessed. This is indicated as ③ in figure 47.
- **Step 4:** The researcher has additionally published the influence of the factors on each of the chosen technology that can act as a ready reference for firms like Airbus during their digital transformation. This is indicated as ④ in figure 47.

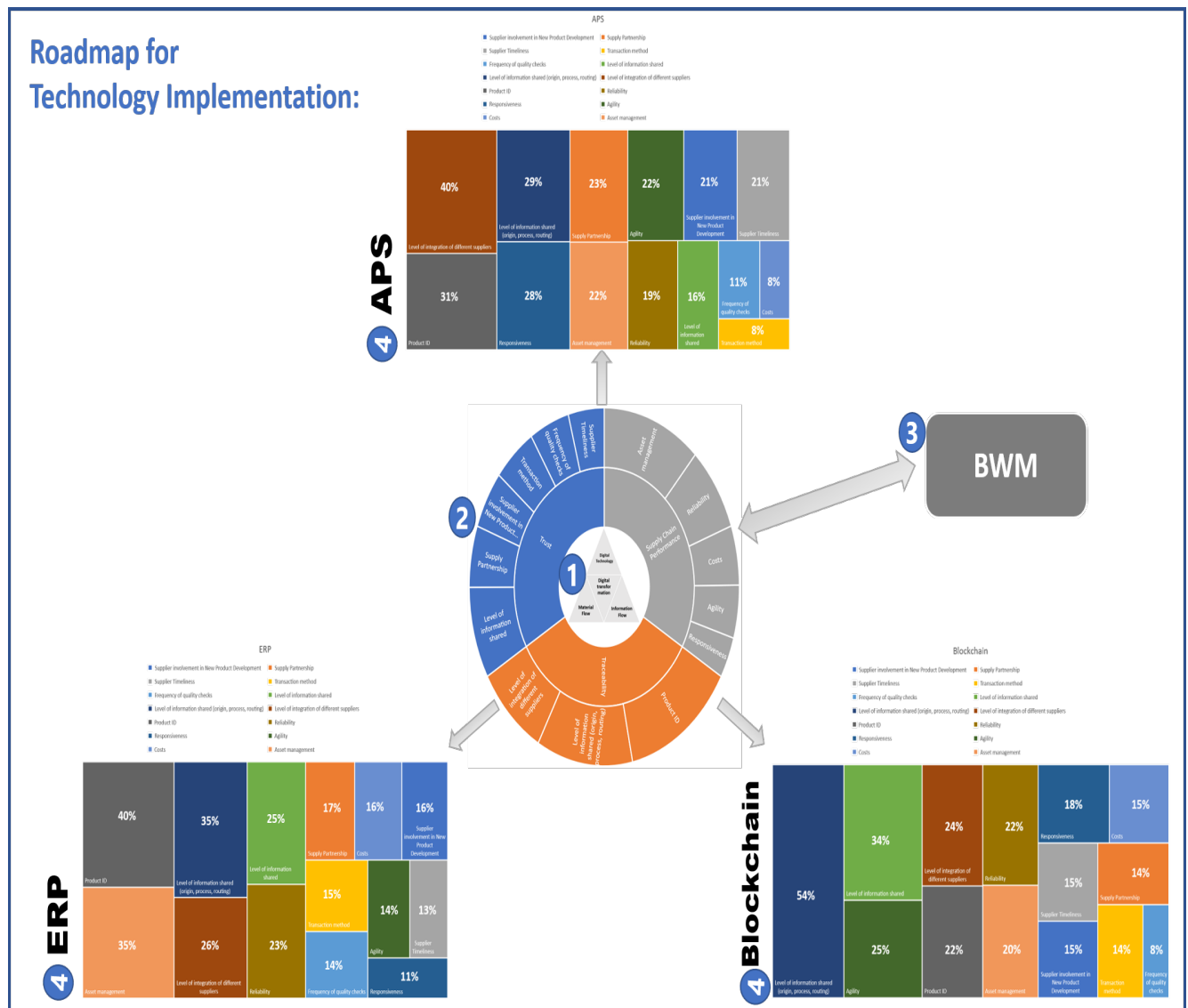


Figure 47: Technology Roadmap:Final Pattern Artefact (Compiled by the researcher based on this study)

11 Conclusion, Challenges and Limitations, Reflections

The pattern artefact was developed and evaluated in the preceding sections. The developed artefact aims to serve as a reference roadmap for the adoption of digital technologies by large aviation firms. The report's last chapter is devoted to answering the research questions that were developed in order to achieve the study goal and will be evaluated with the guideline of the DSR approach. The limitations of the thesis are also described in this section. Lastly, the thesis will close with providing recommendations for future work on this topic. This part of the thesis project is depicted through the DSR framework in figure 48.

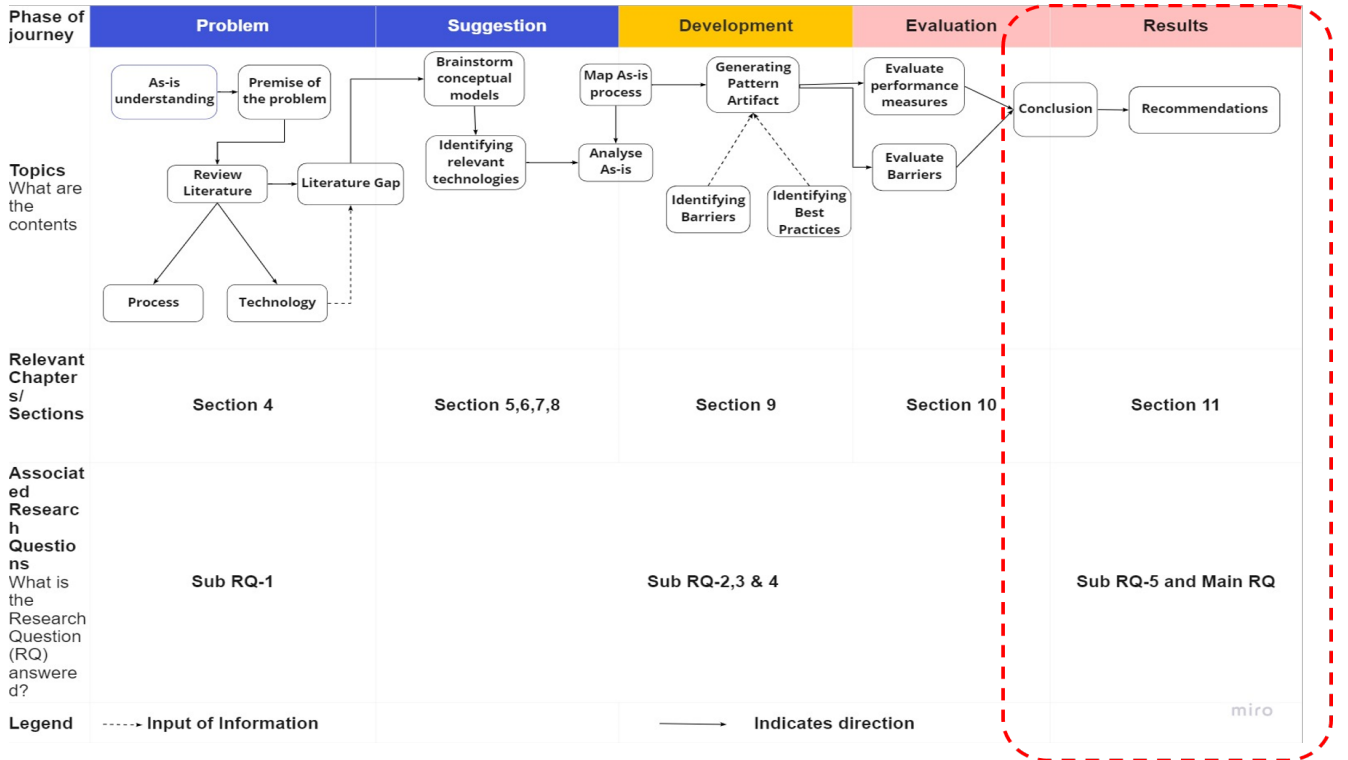


Figure 48: Final phase according to DSR approach

11.1 Conclusion on research questions

The sub-research questions and main research questions were framed in order to achieve the objective of this thesis project. From all of the above sections, through a combination of literature study, individual interviews and applying scientific methods on the understanding, the researcher has arrived at the conclusion of this research objective.

The intent of this section is to summarise the findings against each research question described in section 1.3, they are:

- **How does a material, flow between a seller and a buyer in the A350XWB Supply Chain?**

The material flow between a seller and a buyer is understood by the researcher by going through the Airbus official website as suggested by one of the interviewees. The general concepts of material flow, common challenges, complexities and transformations is understood by the researcher through multiple literature studies. The combined understanding helped the researcher to identify certain tasks in the material flow between a buyer and a seller as non-value added activities. These non value added activities are related to the process undertaken by Airbus during the material flow resulting in low order-fulfilment rate.

The process of arriving at the conclusion of some non-value added activities are resulting in low order-fulfilment rate, are elaborated in section 5 and 6. It is also found that improving some of the processes can result in increasing order-fulfilment rate.

The researcher has further identified that these processes can be enriched through a set of actions in combination with digital technologies. These set of actions are termed as "factors" in this thesis project. Further questions helps to find how these factors can be improved through implementation of digital technologies.

This sub-research question helped the researcher to arrive at the outcome-1 referred in 3 of the suggestion phase as in indicated through a business canvas diagram as in figure 26.

- **How does an information, flow between a seller and a buyer in the A350XWB Supply Chain?**

The information between the different actors such as procurement, manufacturing, quality and assembly flows in the form of a FAIR document. The document entails information such as kit number, quantity, quality and all hardware part numbers. To enable the flow of material between a buyer and a seller, this document is drafted, checked and then proceeded. Two scenarios were identified during the transportation of material in which, which delays the transportation of materials and results in low order-fulfilment rate. The two scenarios were:

- **Scenario 1:** The FAIR document is uploaded onto the ERP system 10 days prior to the transporting schedule, which can be accessed by Rolls-Royce and the other

suppliers. Two days prior to transporting, there are quality checks conducted and compared to the document. If the lot passes the checks it proceeds to being transported. If not, there is a delay experienced.

- **Scenario 2:** This is the scenario where the document is not ready 10 days prior to the planned transporting schedule. In this case, the supplier has to inform the quality representative who informs the transporting department about the delay. This scenario leads to a significant delay in production and in turn assembly.

From this it is identified that the factors such as "supplier timeliness" and "level of information shared" were identified as set of actions to avoid delay in communication and delivery of orders between the actors. These obtained factors and the actors associated are represented through a business canvas in figure 29. These factors are further grouped together under the constructs "trust", "traceability", and "supply chain performance". The constructs are identified by the researcher through a literature study. The factors were grouped in order to establish the relationship between the factors and the order-fulfilment rate.

This sub-research question helped the researcher to arrive at the outcome-1 referred in 3 of the suggestion phase as indicated through a business canvas diagram as in figure 29.

- **How can the different processes pertaining to material and information flow be coordinated better using the capabilities of digital technologies such as APS/ERP/Blockchain?**

The steps to take to improve coordination and order-fulfilment rate were identified by researcher from the sub-research question RQ1 and RQ2. These steps to take were termed as "factors" that have an influence on the five different activities, such as, "*Order Placement*", "*Quality Inspection*", "*Transporting*", "*Verification of Information*", and "*Receiving*".

It is identified through qualitative analysis that most of the factors identified are described as "poor" by the decision makers. This causes for poor order-fulfilment rate and is elaborated in section 7.4 and is validated through interviews. These factors were presented by the researcher in the form of an application wheel and is one of the main outcome of the thesis project as referred in figure 3.

Parallel to the interviews, the general strengths, weakness, opportunities and threats of three shortlisted technologies namely ERP, APS and Blockchain were studied.

When exploring the supply chain view point of digital technologies in section 8.4, it is identified that the strengths and opportunities of chosen digital technologies (ERP/APS/Blockchain) improved the material and information flow related factors such as "*level of information shared*", "*supply partnership*", and "*supplier timeliness*".

This sub-research question helped the researcher to arrive at the outcome-2 referred in 3 of the development phase as indicated through a supply chain application wheel and SWOT assessments in figures 35, 31, 32 and 33.

- **Main Research Question: What percentage of improvement on different processes will digital technologies such as APS/ERP/Blockchain provide to improve coordination between material information flow and order-fulfilment rate?**

Exploring the three streams namely, "material flow", "information flow", and "digital technologies" through the lens of Airbus helped the researcher to arrive at the supply chain application wheel and understand the strengths, opportunities of each of the shortlisted technologies.

This enables the researcher to move the focus of the thesis project to evaluation phase and obtaining the final results. The supply chain application wheel in figure 35 along with SWOT assessment of the shortlisted three technologies are presented to ten supply chain experts in the industry to assess the influence of each technology against each factor. The assessment of the interviewees are evaluated using a scientific method called BWM. This method is used to interpret the understanding and opinions of the decision makers. The output for the BWM indicates the suitable technology to improve coordination between material and information flow that results in increased order-fulfilment rate.

Application of this method helps the researcher to arrive at the main research question. This is initially depicted in the form of a treemap in figure 43, 44 and 45.

This concludes the thesis main objective as referred in figure 3 indicated as outcome-3. The multiple treemap's are integrated to a pattern artefact by the researcher as in figure 47. This should help companies like Airbus during their digital transformation.

11.2 Reflections

The freedom to write a thesis project in any domain, about any industry and on any topic is a dream to writing students. However, this freedom made my mind go in a hundred directions. The first challenge I came across is the lack of restriction to choose a topic. I always had a liking towards understanding upcoming technologies and one of my favourite subjects is Supply Chain Management. I was sure I wanted to do something combining the two. During my end of first year, I also got the opportunity to do an internship with ATOS. This experience also added to my interest in studying digital applications for the electricity market inspired me to do something with Supply chain and Digital technologies. While I tried to extend my ATOS experience and build more towards this Thesis project, I should admit that I was not successful. This process of starting, searching, stopping, re-configuring my research topic was quite frustrating. At the same time this is the point I realised the importance of the process of narrowing down on a topic – My learning 1. The next step in the journey for me was to choose a proper research question that not only gives me enough input on the topic but also manage everything remotely due to the current Covid-19 pandemic. After careful thinking I thought I have arrived at the research question and my sub-questions that would help to navigate to my research question. Soon I realised my learning 2. After I started to understand more on the sub-questions through individual interviews, the company's official website and literature study I realised my research is much broader and pursuing in this direction can add more value to the industry. But I was lost in terms of how to realign my paper and make it more understandable to the reader. This is my learning 3. Here is when my professor gave me a tip to make a flow diagram that could help me in streamlining the entire content and make it more reader friendly. It was during this stage, I identified the method of categorising the thesis project to three flows, which are, "material flow", "information flow", and "digital technologies". Excited about this structuring of the thesis project, I could rephrase my research question again and ensure it is more readable to the reader through forward and backward references.

I am very happy in this process that I have collected rich experience through this journey and I am quite confident that my research findings will help companies like Airbus during their digital transformation. I am very grateful to my professor and my chair to guide me in this journey with utmost patience. My learning's and the outcome would have never been possible without them.

11.3 Evaluation of Pattern Artefact against Guidelines

The graduation project is compared or evaluated against the guidelines put-forth by (Hevner, March, Park, & Ram, 2004). This step is done in order to show the effectiveness of the pattern artefact generated in section 9.1. The evaluation of the DSR against the guideline is shown in figure 49.

Guideline	Explanation
Pattern as an Artefact	The outcome of this report is a pattern artefact in the form a wheel diagram coupled with a treemap. This artefact presents and quantifies the influence of different factors that could help implementation of digital technologies in large aviation firms through the lens of Airbus.
Relevance of Problem	The research question were framed to solve a business problem by providing elements (factors) that could be embedded into strategies for implementing digital technologies in the future to improve the mis-matched flow.
Evaluation of Output	The output is obtained by utilising scientific methods such as SCOR and UML. The artefact was evaluated using the BWM in this report
Contribution of Research	The contribution of research are : 1. Mapping the material flow and associated information flow of aircraft parts in the A350XWB supply chain to identify factors that impact order-fulfilment rate and to develop a pattern artefact. 2. Identifying and mapping different factors that have an influence on the different processes in the A350XWB supply chain to identify methods for improving order-fulfilment rate. 3. Identifying and mapping the influence of digital technology on the factors to improve order-fulfilment rate.
Rigor of Research	Several rigorous approaches were used during the construction and evaluation of the pattern artefact. The DSR approach was used, and supply chain management principles were applied as well.
Search Process of Pattern Artefact	Literature reviews were used to arrive at a literature gap and the solution was arrived through a combination of literature review and interviews with supply chain experts.
Communication of research	The communication of this graduation project is achieved by uploading it in the TU Delft repository and is suitable to be presented to a management oriented professionals.

Figure 49: Evaluation of Patter Artefact using the DSR guidelines

(Hevner et al., 2004)

11.4 Challenges and Limitations

To meet with the master's standards, the report was tallied within a certain time frame. Even if it is acceptable for a master's thesis, the 6-month time constraint prevents an extensive examination of the issue. The topics explored in this report were supply chain management, business process and information systems. This was done in order to provide the reader a spherical picture. Exploration of the topic entirely from a supply chain perspective would fit best for an business administration or optimisation discipline.

The lack of availability of data, documents and use cases prevented the author from deep-diving into the implementation of one specific technology even though it might prove to be important for future implementation of the technology at large aviation firms. Due to the pandemic most professionals were unavailable for most of the times and this made the collection of information even more challenging. This scenario made the researcher broaden the scope of data collection from only just Airbus professionals to supply chain experts in general.

Mapping the entire process with all stakeholders would also be beneficial, since the advantages of presenting the elements may have been evaluated as a whole. Mapping the entire process, on the other hand, would increase complexity. For example, between tier 3 and tier 2, there are around 237 interactions possible and there are 95 interactions within tier 3 and 140 interactions within tier 2 approximately (Brintrup et al., 2015). Including these tiers in this study would result in more interactions and adds complexity to the study.

These interactions would certainly make the content unmanageable, divert the researcher's attention away from identifying the useful elements (factors) for technology implementation, and dramatically increase the time necessary to complete the research.

The other challenge faced by the researcher were during the filtering process of academic journals. A smorgasbord of articles presenting very generalised conclusions with respect to blockchain and digital supply chains in general. In addition most of the articles focused on improving demand management for the external department Manufacturing, Repair and Overhaul (MRO). This made it difficult to find suitable academic journals.

11.5 Future research and Recommendations

To begin, it is recommended to map out all or most trading process at Airbus and other large aviation firms such as Boeing, including all stakeholders and associated activities. The flaws

and consequences of the supply chain process as a whole can be discovered this way. It may also be demonstrated whether and how network effects boost the advantages of digital technology implementation and balance them against the risks associated with increased supply chain complexity.

Mapping the customs clearance procedure, bank payments, surveyor duties or port operations and determining how each process interacts with each other in terms of actors and data components would be more beneficial for real-life implementation of digital technology.

From the current work, additional factors can be identified and mapped with the associate activities which would assist companies better for future digital technology implementation. This graduation paper excluded the flow of people and costs in the supply chain network. The study of these flows could serve as a starting point for identifying more factors.

Furthermore, more precise quantitative data (for example, data from event logs) on the time necessary for each job may be utilised to assess the correctness of the results in this study and to create interactive business process maps. Further levels of the SCOR model could contribute in identifying more non-value add activities and can serve as an input for a predictive analysis. A predictive analysis consists of determining the benefits of digital technology with various new to-be scenarios, such as typical job automation or the advantages of system interoperability.

Another recommendation would be to further develop the pattern artefact to a system design artefact and a algorithm artefact. Other digital technologies could also be seen as a potential replacements for the traditional ERP systems used by most large aviation firms.

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Appendices

Appendix A Thread Diagram

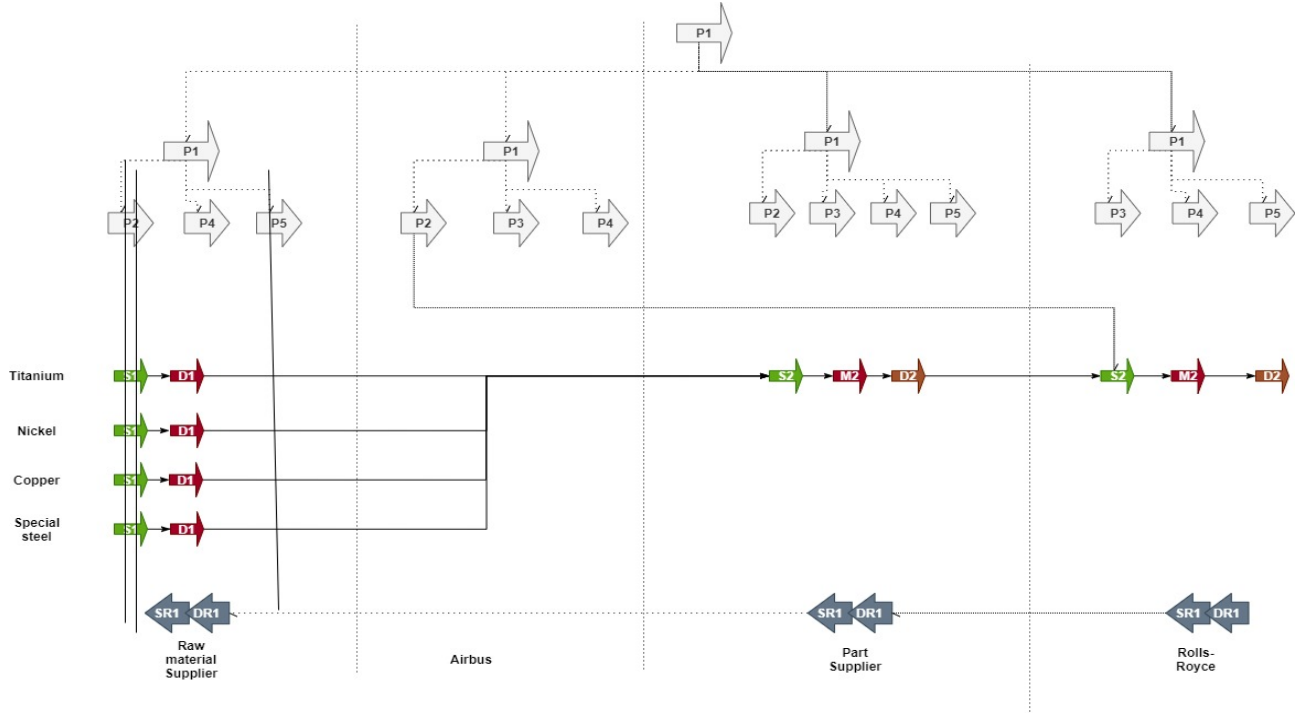


Figure 50: Thread Diagram

The thread diagram in figure 50 depicts the planning involved in the different process undertaken for transporting components by Airbus, Rolls-Royce and their suppliers. Each of the actors facilitate the movement of materials in their supply chain by planning source, make, delivery process and returns. This planning entails different types of information documented and delivered to different departments with the aim of maintaining order-fulfilment rate. The detailed description of this planning process (P1,P2,P3,P4) are provided using the UML diagram in the coming sections.

Appendix B Returns(SR1, SR2, DR1, DR2):

Rolls-Royce has a return policy with suppliers in case raw material shipped to the main manufacturing plant from suppliers is damaged (SR1) or a mistaken shipment leads to excess inventory (SR2) ((Airbus, 2020f), (Rolls-Royce, 2020)). Despite the fact that the chances of Rolls-Royce obtaining damaged or insufficient material are limited, suppliers refill the stock by returning the goods (DR1, DR2).

B.1 Local Warehouses and global distribution centres(S1, D1, DR1):

For products that are still under warranty, local warehouses must send the return as soon as possible(DR1). If a stored product is damaged during delivery to worldwide distribution centres, a replacement delivery is issued as soon as possible (DR1). However, as previously stated, worldwide distribution centres maintain a reserve of safety stock.Damaged or defective products are recycled in Rolls-local Royce’s marketplaces, and the returns are utilised to create new items. In the event that any damages or malfunctions are repairable.

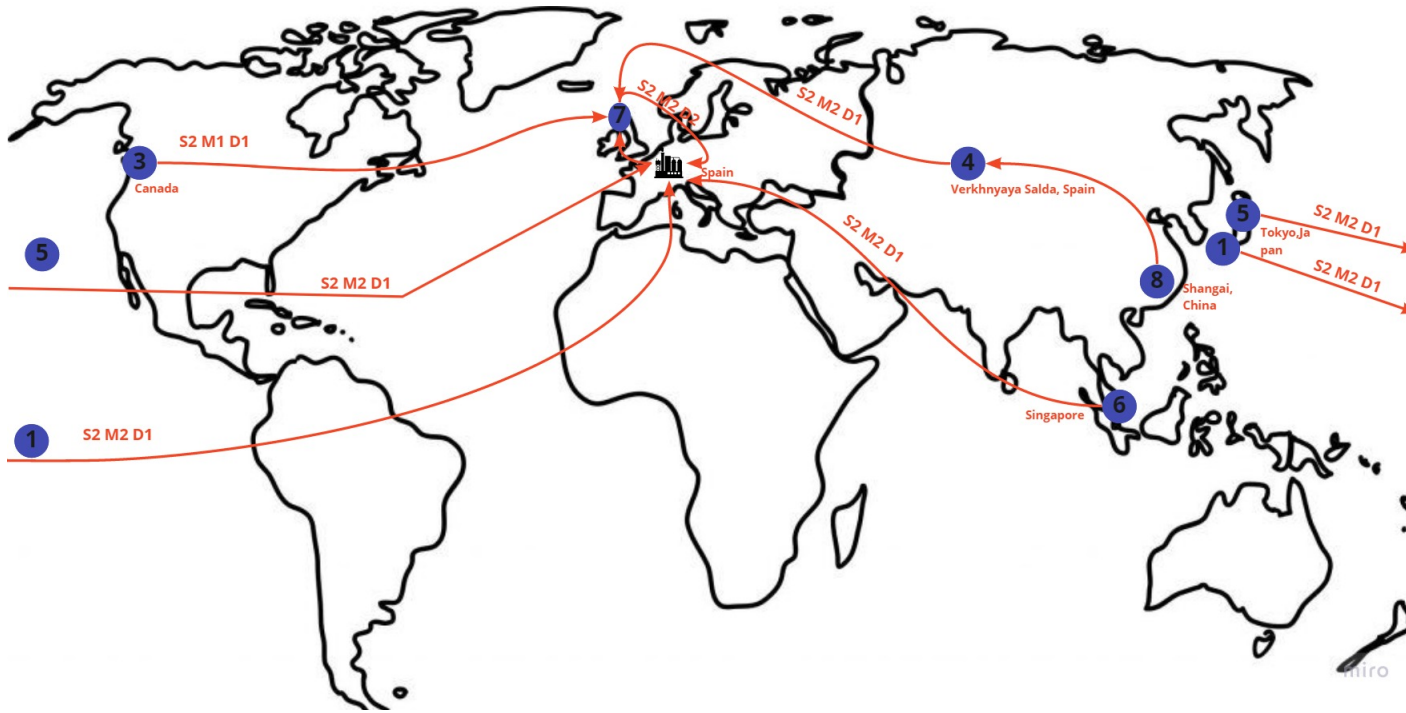


Figure 51: Geographical map indicating the different raw material and parts suppliers (adapted from the interviews and publicly available information)

(Rolls-Royce, 2020))

Figure 51 is extension of the Derby map. This figure indicates the the location of the different suppliers in the world and the mode of transportation used by them to transport the different parts to the production facility. Most of the parts are transported by air using the beluga XL (Airbus, 2020f). One of the exception is that, the local Redditch factory that supplies the rear fan case is transported by land. The communication between the different actors mentioned above are indicated using the tread diagram in figure 50 (Appendix A).

B.1 Local Warehouses and global distribution centres(S1, D1, DR1):

There are various warehouses located around the world as depicted in figure 52, which store materials required in case of emergency and for MRO purposes. These materials which are

stored are not used during the production of the aircraft and are used after the aircraft is in function. This is the reason this is excluded from the SCOR model.



Figure 52: Warehouse locations

(Airbus, 2020f)

Appendix C Image at Airbus

The intent of this chapter is identify the type of implementation that Airbus executes into their supply chain. The concepts and models obtained from this section along with the previously mentioned models in section 3 will be presented to experts in supply chain management. This is done in order to identify which technology increases which factor the most using the BWM. All the data points obtained would form the pattern artefact.

Airbus is exploring the new blockchain technology at various fields with various names for the project such as ADAM, RAY20, LEIBNZ, and VAHANA. The project tackling the issue of tackling segregated database is the ADAM project.

ADAM is the blockchain network made by the company Ethereum for digitising process for Airbus involving the several departments such as, manufacturer, customers, auditors, manufacturing repair & overhaul (MRO) , and Rolls-Royce began in the year 2018 ((Tim Alper, 2018),(Schyga, Hinckeldeyn, & Kreutzfeldt, 2019)). Ethereum uses a mechanism known as Proof-of-stake⁵ to authorise transactions between users in the public or private network (Ethereum, 2020). The studies were entirely theoretical and a prototype of design was presented in the

⁵Proof of stake protocols are a type of blockchain consensus method that selects validators based on their crypto-currency holdings (Yaga, Mell, Roby, & Scarfone, n.d.)

year 2018. The scope of the study for MRO involved several actors across the world. This was the reason for this being neglected from this research.

The project was started in order to unify the different stages of process as depicted in figure 28 into a single platform. This was also one of the problems stated above which is to be solved by Airbus. The features of this digitising project includes (Syntexys, 2020),

1. **Semantic extraction:** The required information of the aircraft is instantly extracted. The information contain legal concepts, parties, dates, quantities, and more.
2. **User-Trainable:** Airbus provides easy training tools to the respective employees to enable them to perform tasks in a simpler form than before.
3. **Advanced Probabilistic Core:** Syntexys is a highly adaptive system based on statistical natural language processing and machine learning. Leave the brittle hard coded rules in the past.

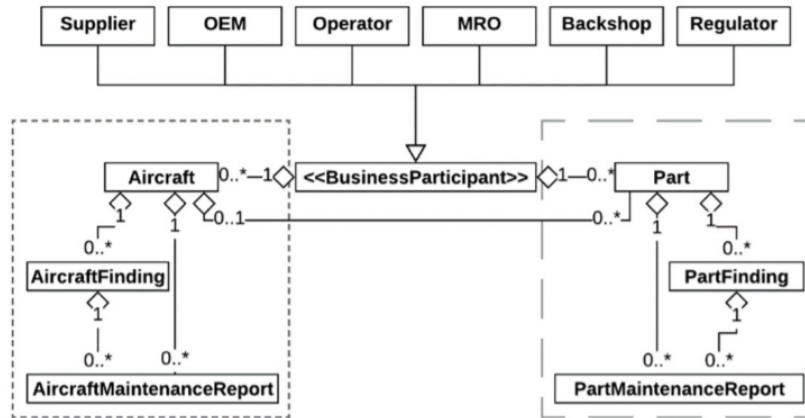


Figure 53: Process after blockchain implementation

(Schyga et al., 2019)

The physical assets of an aircraft and their parts are the two fundamental layers of the software, while parts are made up of Aircraft (Schyga et al., 2019). The equivalent portion of the class diagram is shown above figure 53, with the methods and attributes concealed for clarity's sake. The classes on the left are allocated to the Aircraft level of the program, while the ones on the right are allocated to the Part level. Participants can construct and remove objects, send and receive messages, modify property rights, and grant or revoke the relevant information. It is also possible to register the installation and removal of parts in an aircraft. The classes finding and report are developed to perform the main role of recording and keeping log books. Here

the actor Rolls-Royce is considered under the title "Backshop".

There is a possibility that Airbus is exploring blockchain technology due to its hype in recent times. It might be the case that, other technologies might be a better fit for such applications, such as APS mentioned above. There are various factors that influence performance of supply chain and influence the success of technologies. These factors might not be considered by Airbus to implement the technology. Therefore, it is vital to identify the best-fit technology to solve these problems before proceeding to the next stages in blockchain research.