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A Framework for Implementing Industry 4.0 Technologies to Improve Supply Chains Based on Lean Principles

by

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Summary

To keep the market share in today's competitive environment, supply chains (SCs) must be more interconnected than ever before. For such a purpose, SCs can benefit from having access to real-time data and information through the advent of Industry 4.0 technologies like cloud computing, big data, blockchain, and additive manufacturing, among others. This improves their adaptability and responsiveness. In addition, Lean Manufacturing concepts may play a significant role in improving SCs by helping to eliminate those wastes that arise from the process activities which do not directly contribute to provide value for customers. Therefore, the goal of this study is to explore how various Industry 4.0 technologies can revolutionize SC processes according to the Lean concepts, with the final aim to eliminate non-value-added activities.

In the first phase, two critical and extensive multi-dimensional systematic literature reviews (SLRs) are conducted. According to the results of the SLRs, one of the primary research gaps in the field of combined application of Lean and Industry 4.0 technologies in SCs has been highlighted as investigating each individual SC process, such as procurement, warehousing, delivery among the others. Additionally, the reviewed literature has revealed that it is of paramount importance to develop a structured framework to investigate logistic processes, identify, and analyze their wastes according to the Lean approach, in order to select the most appropriate Industry 4.0 technologies to either reduce or eliminate those wastes. In this context, developing roadmaps for the application of selected digital technologies based on company managers' priorities and opinions is highly desired.

To this end, warehouses, being one of the most important links in a SC that serve to keep stocks and deliver services to final customers, will be treated as a reference application area for the present research. In fact, optimizing warehouse processes and activities may lead to a significant decrease in the amount of time required for order fulfillment, as well as an improvement in the level of service provided to consumers. However, several warehouse activities do not provide value to customers due to their inefficient operating nature. In this way, Lean concepts may be used to increase efficiency in warehouse operations. As a result, in this research a framework is being

developed in order to address the activities that take place in warehouses.

To that purpose, the Supply Chain Operations Reference (SCOR) model is utilized to investigate real warehouse processes across a range of relevant industries (i.e., Automotive Industry, Food Industry, etc.). Moving steps from such an analysis, the research has been conducted to create a general process mapping for conventional warehouse processes in both the raw materials and the finished products warehouse, by focusing on the SCOR processes Source and Deliver. Process mapping can be helpful to identify the wasteful, non-value-adding activities of each process. Afterward, the "5 why" technique, which is one of the Lean tools, is used to determine the main root causes of the wastes that were detected. Then, the most effective Industry 4.0 solutions for addressing the causes of each waste have been proposed according to the performed SLRs.

The theoretical development of the framework is followed by two case studies that demonstrate the applicability and adaptability of the proposed Lean Digital SC (Lean DSC) framework to different real SC settings. To this end, two companies, from the Automotive and Food industry respectively, are selected. In fact, both the Automotive and Food industry are characterized by a high technological level in their production and logistics operations, which makes them more likely to adopt Industry 4.0 technologies. However, they have different degrees of Lean Manufacturing implementation for the purpose of standardizing and making more efficient their industrial processes. For the purpose of process mapping and waste root-cause analysis in the case studies, real observations have been carried out regarding the Source and Deliver processes. Then, the most effective Industry 4.0 technologies for deployment in each company have been suggested to reduce waste, according to the results of real observations and discussions with top managers and responsible employees.

Then, a Multi Criteria Decision Making MCDM technique named Full Consistency Method (FUCOM) is used to prioritize the identified wastes and rank them according to the judgments of each company manager resulting from a number of conducted workshops. Next, all the managers' results are aggregated together to provide an overall ranking that can be used to construct a Lean roadmap of the most critical wastes to be addressed. To complete the Lean DSC roadmap, the collected waste weights are mapped to the Industry 4.0 technologies previously suggested for obtaining the importance of each technology. This can assist companies to know which the appropriate deployment sequence of beneficial digital technologies is to reduce their waste. So that, the Lean DSC roadmap proposed by the present research can be recognized as a customized strategy for each company because it is built based on real observations of the logistics activities carried out in warehouses.

In conclusion, the present research seeks to overcome the DSC gap constructing a structured approach to implement Industry 4.0 technologies for eliminating wastes in SCs by developing an application framework and decision support tool that can be tailored to the specific requirements of each company. In fact, the objective is to integrate appropriate technologies related to Industry 4.0 by applying Lean principles in two of the crucial SC processes (Source and Deliver) in order to contribute to

provide a genuine value addition for the end customer. The continuation and expansion of this study might involve conducting more case studies to fully complete the validation and generalization of the framework, as well as integrating additional Lean tools.

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Chapter 1

Introduction

The present work is developed based on two key pillars, termed Industry 4.0 and Lean Manufacturing, in combination with Supply Chain (SC) as the primary research area. In order to help SCs gaining a competitive edge, this thesis will discuss how Lean concepts and Industry 4.0 technologies may work together to enhance SC operations by developing a new framework. As a result, the next part will begin with a short introduction that will explain what Industry 4.0 is and how it may be applied to SCs. In addition, the notion of waste is discussed in greater depth in section 1.2 by elaborating on the core SC activities that do not contribute to add value in accordance with Lean principles. As a conclusion, section 1.3 will explain why it is crucial to study Lean and Industry 4.0 technologies together in the field of SC.

1.1 Industry4.0 technologies in supply chain

Industry4.0, also known as “fourth industrial revolution”, first emerges in 2011 in German industries and refers to the trend of incorporating digital technologies into a self-regulating, knowledge-based manufacturing system relying on sensors (Dalmarco & Barros, 2018). The first step in gaining a deeper understanding of Industry 4.0 is to identify and define its technologies. In fact, Industry 4.0 encompasses a wide range of digital technologies. They are defined in Table (1), together with mentioning some examples of applications to SC environments.

Table 1 Definition of Industry 4.0 technologies

Industry4.0 Technology	Definition	Reference
Augmented Reality (AR)	AR is a technology to assist employees by enlarging the real world through a provision of additional information from different sources and of various types, such as text, video, sound, and even smell.	(Büyüközkan & Göçer, 2018; Raji et al., 2021)
Cloud Computing (CC)	Storage, sharing, and easy access to data remotely and on-demand, based on flexible information management services and according to customer requirements.	(Frank et al., 2019; Raji et al., 2021)
Robotics (R)	Applying automated robots to complete tasks either in an autonomous way or in collaboration with humans, with the ultimate goal of providing more flexibility and safety in workplaces.	(Moufaddal et al., 2019)
Sensor Technology (ST)	Enabling checking, monitoring, and controlling different activities related to the SC processes and production. Its capabilities range from sensing the quality status to several other applications, such as in shop floors and life cycle assessment.	(Büyüközkan & Göçer, 2018; Frank et al., 2019)
Internet of Things (IoT)	Making the linking between physical objects and information systems to collect real-time data about the location and other features of the objects and share them through the internet system.	(Dalmarco & Barros, 2018; Raji et al., 2021)
Self-Driving Vehicles (SDV)	SDVs are capable to find their way without human intervention by self-navigation and sensing. It can be useful in last mile delivery as a part of SC activities.	(Büyüközkan & Göçer, 2018)
Unmanned Aerial Vehicles (UAV)	A flying platform to be used for different proposes, without the need to pilot and control it, based on predetermined programs or remote control. For instance, it is valuable for delivering of light items as a part of SC activities for different purposes like shortening the delivery time in crowded cities.	(Büyüközkan & Göçer, 2018; Vergouw et al., 2016)
Additive Manufacturing (AM)	Producing customized or urgently needed products from 3D printing models by a layer upon layer procedure from using one source of materials. There is no need for the assembly of parts in AM.	(Frank et al., 2019; Raji et al., 2021)
Blockchain (BC)	A secure and safe manner to share and access tamper-proof real-time data about the origin of the items and different passing gateways in transportation among different stakeholders.	(Moufaddal et al., 2019)
Big Data Analytics (BDA)	Knowledge extraction by analyzing a huge amount of structured, semi-structured, or unstructured data to facilitate the decision-making process based on the obtained knowledge.	(Büyüközkan & Göçer, 2018)
Artificial Intelligence (AI)	Advanced analytical tool for providing better perception about future possible scenarios for different activities and operations in SCs.	(Frank et al., 2019; Moufaddal et al., 2019)
Cyber-Physical Systems (CPS)	The interconnected system of machines and humans in all aspects reports the actual state of each component to the central cyber via different ways, such as sensors, IoT, etc. in order to analyze, make the appropriate decisions, and learn from a problem.	(Moufaddal et al., 2019)
Simulation	Simulating SC processes and operations for different proposes such as education, product or process design, process improvement, etc. A variety of simulation methods can be applied.	(Frank et al., 2019)

The goal of modern societies is to provide, exchange, and access reliable information so that all their aspects can be managed effectively. Rapid progress in a variety of digital technologies and their widespread use in recent years have made this objective feasible. In fact, technological development is accelerating at an exponential rate. This may be because each new digital technology offers vast potential benefits in many aspects of human existence. In addition, as time goes on after a technology's first release, its cost typically decreases, which further encourages its widespread adoption. For instance, (Yan et al., 2018) indicates that in the future the adoption rate of the IoT technology among SC members may be boosted by lowering the price of RFID tags used in IoT systems. However, there are restrictions in the early phases of implementing new Industry 4.0 technologies, such as those related to patent licenses. For instance, the patent of the AM technique named "Fused Deposition Modelling" (FDM) expired in 2009, marking the beginning of a period of rapid innovation in 3D printing, often known as Additive Manufacturing (Ryan et al., 2017). As a consequence, it means that the passing of time might lead to further growth of Industry 4.0 technologies in our society and highlight the need for more in-depth research to uncover their potential areas of application in daily life activities.

In this context, one of the most important responsibilities in societies is providing goods to final consumers, an effort that largely relies on the operations of efficient SCs. In order to do this, a SC is defined as a chain of activities involving various stakeholders who collaborate in the production of a final product, from the procurement of raw materials through the manufacturing process and on to the delivery of items to end users (Mahdavisharif et al., 2020; Mostafa et al., 2019). As a result, SC members should have a great collaboration in order to produce and deliver goods in a timely manner. Therefore, Supply Chain Management (SCM) becomes one of the most critical areas in which companies might compete in order to boost their profits through improved levels of customer service (Mostafa et al., 2019). According to (Reschke & Gallego-García, 2021), timely data on customer requirements and other information within SCs should be made available to their members in real time. To achieve this goal, Industry 4.0 technologies are able to offer an environment that can be simultaneously quick and safe for sharing data and information across SC members (Mahdavisharif et al., 2022).

1.2 Lean Manufacturing principles

The Toyota Production System (TPS) is the inspiration for the Lean Manufacturing concept, a corporate strategy for maximizing productivity and reducing waste. The "waste minimization" idea of Lean, which was formerly used only in the automotive and manufacturing industries, is now widely applied in any industry looking to improve its processes (Hussain et al., 2016). The main aim of the Lean concept is reducing waste by eliminating non-value-added activities from processes. According to the categorization provided by (Ohno, 1988), there are seven different categories of wastes, which are as follows: Motion, Over Production, Over Processing, Wait, Transportation, Inventory, Defect. Under-utilized people have been lately recognized as an eighth waste in the Lean principles (Douglas et al., 2015). In the present study, the author concentrates on the first seven categories of wastes only, as they are more mature and developed in SCM. Therefore, here it is necessary to clarify the meaning of these types of wastes according to Lean Manufacturing.

Motion. Motion waste is any excessive movement of staff that occurs, for instance, during the supply or delivery of items. To be more specific, Motion waste is a situation in which personnel are required to have physical efforts, for example, bending to reach goods because they were not positioned at an appropriate height. Motion waste can also arise when employees are needed to store products in a position that is uncomfortable from an ergonomic point of view. It means that employees are making unnecessary physical efforts to complete their task. As a whole, any unnecessary physical efforts from employees are referred to as "Motion waste" (Arunagiri & Gnanavelbabu, 2014).

Over Production. Manufacturing of items without a matching order or demand from customers is one definition of the waste category known as "Over Production." When a company produces more goods than the market wants or produces those goods sooner than when they are needed, this is an example of Over Production. In general, the act of producing more than is needed to satisfy the requirements of the subsequent process is known as Over Production (Tahboub et al., 2019).

Over Processing. It is important to note that the concept of Over Processing is related to the repeated activities and unnecessary controls that can be removed because they do not provide value for the client (Tahboub et al., 2019). Complexity is a typical source of Over Processing. The more sophisticated a process is, the more probable that Over Processing will occur. Over Processing is a frequent waste in office work. For example, to make a choice, it's common to have to go through several assessments and approvals.

Wait. Waiting times are frequently caused by processing delays, equipment or system failures, slow response times, and the need for document approval (Tahboub et al., 2019). Moreover, items awaiting transportation or

packaging are considered to originate the Wait waste. Also, there may be a waste of time if employees are waiting for pallets to place the goods on (Arunagiri & Gnanavelbabu, 2014).

Transportation. This waste concerns unnecessary deliveries to and from sites outside the company warehouses. Additionally, waiting times and inventories give rise to transportation problems inside a facility. In fact, work in progress (WIP) may accumulate as a result of even the smallest delay in a procedure that causes an interruption. Therefore, as the amount of WIP grows, it should be stored and moved between storage sites. Moreover, when employees from different departments must often interact, yet their offices are situated on opposing sides of the facility, the Transportation waste may occur (Tahboub et al., 2019).

Inventory. Having excessive WIP and keeping additional goods in the warehouse even when there are no product orders are considered to give raise to the Inventory waste. Processes that are not well monitored result in larger lot sizes, more incorrect estimates, less effective communication with both suppliers and customers, and improper decisions made by management. As a consequence of all of these conditions there will be a greater quantity of inventory (Tahboub et al., 2019).

Defect. Any processing error that reduces the value of a product or service to the client or necessitates further processing to remedy the fault is referred to as a Defect waste (Tahboub et al., 2019). In warehouses, selecting the wrong item or keeping an inappropriate quantity might bring significant complications. In turn, this might lead to the client being under or over-supplied, or even worse, being supplied with the incorrect order. Incorrectly packed items, defective goods, incorrect invoices, inaccurate documentation of stocks, etc. are just a few examples of potential Defect wastes in warehouses (Arunagiri & Gnanavelbabu, 2014).

1.3 Lean Digital Supply Chain

The term "Lean Digital Supply Chain" (also referred to in this work as "Lean DSC") means the implementation of Industry 4.0 technologies in an appropriate manner to accomplish Lean principles and aims by attempting to either reduce or eliminate waste at all the SC stages (Mahdavisharif et al., 2022). However, SC practitioners still have difficulties in applying the multiple Industry 4.0 technologies in conjunction with the Lean principles, highlighting the necessity for a clear implementation roadmap and framework for doing so (Tissir et al., 2020).

In fact, it is important to note that each Industry 4.0 technology has unique characteristics that might either impede or promote the Lean SC setting. In this regard, as the use of digital technologies grows, it is absolutely necessary to do research into the effects these technologies might have on SCs in relation to Lean goals.

In addition, SC integration may result in enhancing the levels of

efficiency and competitiveness for the associated members. To be more precise, through the digital paradigm, SC processes have the potential to be better integrated and monitored, which may ultimately lead to a decrease in waste and the accomplishment of continuous improvement (Sahin et al., 2017), as it is recommended by Lean principles. In this regard, according to the results of a survey that was carried out by (Chiarini et al., 2020), the SC members have shown a curiosity in discovering the synergistic effects of applying Lean and Industry 4.0 technologies.

Therefore, it seems that there is a two-way connection between the concept of Lean and Industry4.0 in SCs. To be more precise, the concept of Lean can serve as the foundation for the effective implementation of Industry 4.0 technologies, which in turn can increase the overall efficiency of processes (Chiarini et al., 2020; Luz Tortorella et al., 2018). Moreover, real-time data, such as those provided by Industry 4.0 technologies, can make it easier to develop Lean principles in SCs (Müller & Birkel, 2020) by reducing non-value added activities.

As a result, due to the potential connection that may be anticipated between the two concepts, previous studies recommended that more research should be conducted to investigate whether Lean Manufacturing and Industry 4.0 are compatible with one another. The findings of a recent SLR analysis highlights the significance of focusing the investigations on logistics processes within the Lean DSC (Núñez-Merino et al., 2020). In fact, recognizing “when” and “how” to embrace Lean ideas in conjunction with Industry 4.0 technologies in SC processes is a strategic decision that companies need to make (Chiarini et al., 2020; Novais et al., 2020). Moreover, the adoption and integration of choices made by one SC member has a cascading effect on the choices by the other SC members (Sternberg et al., 2021). Therefore, it implies the significance of studying the concepts of Lean and Industry 4.0 technologies by focusing on SC processes rather than investigating the pure internal processes of a company.

Chapter 2

Research Goals and Methodology

2.1 Research questions

Based on what was discussed in chapter 1, more studies about the integration of Industry 4.0 and Lean concepts in SC processes are required. Also, the majority of the research that has been carried out in this field in the past has focused not so much on SC and logistics processes, but rather on determining the benefits that can be gained from applying Lean Manufacturing and Industry 4.0 technologies in single companies. As a result, the present work seeks to discover the connection between these two concepts at the SC level by providing a pragmatic Lean DSC framework for implementation.

For such a purpose, the research has been conducted to provide answers to the following Research Question (RQ)s in order to fulfill the primary objectives of the study. As a result, the appropriate approach to accomplish the aforementioned objectives is established, and a brief explanation of it is provided in section 2.3.

2.1.1 RQ1: What is the state of the art on applying Industry4.0 technologies in SCs?

Industry 4.0 and its associated digital technologies are novel notions in modern societies. As a result, their potential ought to be investigated in relation to different aspects of human life. Accordingly, SCs are one of the most important complex concepts across industries that need to be addressed for better integration (Núñez-Merino et al., 2020). Knowing how Industry 4.0 technologies might influence the various SC elements could be helpful in this regard. Thus, the present work addresses this issue by searching and analyzing papers that discuss the application of Industry4.0 to SCs. The purpose is understanding the state of the art about Industry 4.0 implementation in SCs.

2.1.2 RQ2: What are the main gaps to focus on for implementing Industry4.0 technologies in SCs to achieve Lean goals?

Manufacturing sectors have adopted Lean principles with the goal of reducing non-value-added activities in their processes. In this regard, industry 4.0 technologies should be investigated to reveal their potential role in reducing Lean wastes in the SC. Therefore, the current gaps in this field should be identified and addressed properly to pave the way for the real implementation of different Industry 4.0 technologies in Lean SC.

2.1.3 RQ3: How appropriate Industry4.0 technologies can be implemented to achieve Lean goals in the logistics processes of SCs?

Managers in a variety of sectors are interested in learning more about how and when they should use cutting-edge technologies within their SCs. In order to enhance their processes by utilizing new technologies, SC members will also need to make significant investments. As a result, SC members should have a decision tool as a tailor-made framework according to their specifications to help them choose which Industry 4.0 technologies would most effectively aid them in the optimization of their processes by minimization of non-value-added activities.

Warehouses are an important aspect of any SC since they serve as the main gate for the transfer of both raw materials and completed goods among the various SC members (Mostafa et al., 2019). As a result, the primary emphasis of the present research effort is placed on the logistics processes associated with warehouses. Hence, Source and Deliver are the focus processes in devising a structured approach to guide SC managers in setting Lean DSC implementations.

2.2 Research contribution and objectives

To answer the above-mentioned RQs the following main objectives should be set.

1. Discovering the state of the art about the application of Industry 4.0 technologies and Lean principles in SCs by investigating the existing literature. Accordingly, two Systematic Literature Reviews (SLRs) should be executed. Using such a method can be beneficial in determining the main trends and figuring out significant gaps that should be addressed as future directions in research and practice. Thus, it is necessary to develop a systematic framework in order to classify the current contributions from various aspects. In this context, a comprehensive classification is provided that investigates not only the different applied methodologies but also further pertinent aspects. Among them, the extent to which DSC and Lean DSC concentrate on the integration of multiple technologies is still a

major area for advancement. In addition, SC processes, SC applied theories, and SC associated issues also might be studied in depth to provide a comprehensive overview of the state of the art. In reality, classifying existing literature contributions from different perspectives can also provide a thorough view of the present gaps on how these various technologies can be implemented in accordance with Lean aims. (RQ1, RQ2).

2. The full potential of any Industry 4.0 technology cannot be realized if its use is treated in isolation from the impact of other technologies. As a result, concentrating on just one technological paradigm is a poor reference for practical implementations. Therefore, by considering the promising achievements out of applying more than one technology concurrently in managing SC processes, this work aims to explore how the combination of various Industry 4.0 technologies can be useful in the pursuit of Lean goals (RQ2, RQ3).
3. The ultimate goal of this study is to create a structured and practical framework that can help companies to develop their own Lean DSCs. Previous works have only provided conceptual frameworks outlining the potential benefits and application areas of Industry 4.0 technologies in SCs. Here, a framework is developed for Lean DSC to demonstrate how Lean objectives can be accomplished by integrating a variety of Industry 4.0 technologies in logistics processes. Two case studies are investigated from different industries to illustrate how the developed Lean DSC framework can be adapted to meet the unique needs of each company. As a matter of fact, companies may use it as a guidance when deciding how to deploy Industry 4.0 technologies in line with the Lean concept in order to achieve the best results (RQ3).

2.3 Research methodology

Figure (1) illustrates the methodological approach to carry out the research outlined in section 2.2. The work is broken down into four distinct phases that serve as the fundamental steps to build the framework developed in this thesis: 1. SLR and research gaps Finding research gap 2. Developing a theoretical framework for Lean DSC 3. Applying the framework 4. Constructing the Lean DSC Roadmap Developing Lean DSC framework. In particular, the third and fourth phases are based on the results of two real case studies that confirm and demonstrate the applicability of the proposed framework in the context of real companies. In addition, Figure (1) provides more information on the details of each phase that will be discussed in the following subsections.

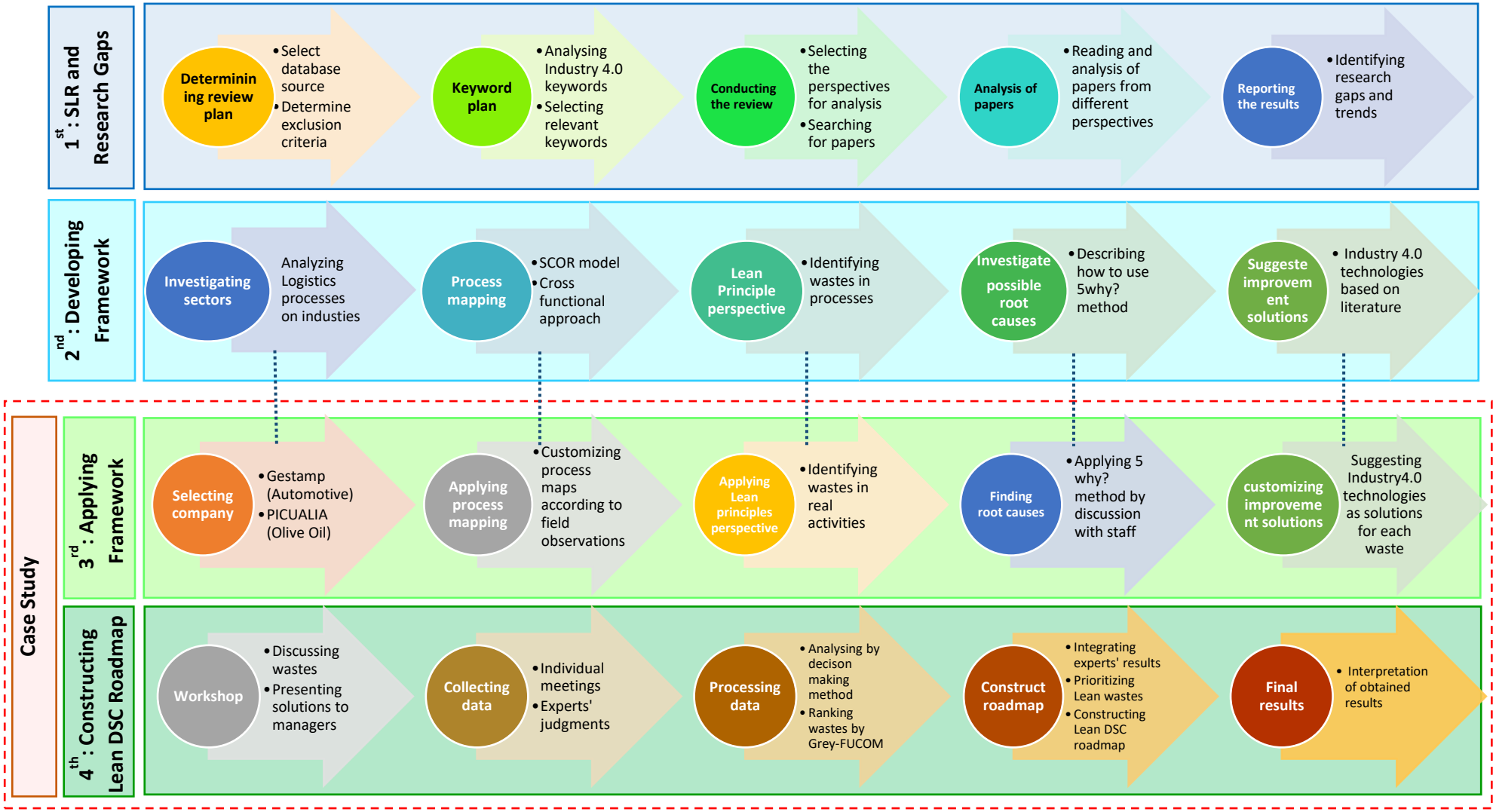


Figure 1 Research phases and steps overview

2.3.1 Systematic Literature Review and Research Gaps

In order to find the answers to RQ1 and RQ2, the search process begins with a thorough SLR about the area of focus. Moreover, all the efforts in this regard are aimed at accomplishing the first and second research objectives outlined in section 2.2. Thus, two separate SLRs have been executed. The first SLR is focused on studying the present knowledge relevant to Industry 4.0 technologies in SCs. The second SLR looks at how Lean principles, Industry 4.0 technology, and SCs can work together, and is meant to address the other central aspect of this research.

For the purposes of carrying out the SLRs, the keywords associated to the Industry 4.0 technologies are meticulously selected. In this regard, the current trends in SCM publications are investigated by searching keywords related to the different Industry 4.0 technologies. As a result, technologies are initially categorized in two groups as the most debated and least debated ones according to the pin-point analysis of the published works in this field.

In addition, a comprehensive and novel literature classification system is developed to identify all the trends and gaps from various viewpoints. In this regard, while reading the full articles, they are categorized depending on how they debate SC processes, address SC associated issues (e.g., Information sharing, Risk management/ assessment, Sustainability, Scheduling), applied methodologies, applied theoretical lenses (e.g., Game theory, Resource Based View, System theory, Contingency theory), or make use of a mix of technologies.

Therefore, the most significant gaps to target for performing the next phases of the research are determined on the basis of the outcomes of these two SLRs. This is an important step since it allows the author to build her study on the solid foundation of the previous works. Furthermore, it can provide other researchers with a broad overview of current literature and direct them in the right path for future studies.

2.3.2 Developing the framework

In light of the early adoption stage of Industry4.0 technologies in SCs, establishing a framework might be a suitable method for promoting their application. In this transition stage of the Lean DSC, implementing a framework might be more advantageous than other approaches like, for example surveys. In fact, a more accurate perception of the potential of Lean DSC can be achieved through the construction of a framework, which can lead to a detailed guidance for SC members. In this regard, the findings of other research methods, such as surveys, only give rise to addressing a general piece of advice in Lean DSC (Carvalho et al., 2020; Novais et al., 2020). The present research effort, however, intends to give a clear framework for implementing the Lean DSC in manufacturing.

The first stage of developing framework (step 3 in Figure 1), an overview

of the fundamental requirements to build a structure upon which the Lean DSC will be developed is presented. Accordingly, two distinct kinds of industries are chosen to lay the groundwork. The next step is to choose the main elements of the Supply Chain Operations Reference (SCOR) model to construct the foundation for process mapping. In this case, process mapping is used to describe the current state of company processes and identify non-value-added activities and the associated wastes in accordance with Lean principles.

The identified wastes are then analyzed using the "5 why" method in order to determine their main causes. The results of the current stage will help define the best strategies for reducing wastes through the application of Industry 4.0 technologies.

Process mapping, waste identification, and waste cause analysis bring to the development of a framework that helps building a roadmap to select suitable Industry 4.0 technologies to be applied with the ultimate aim of either reducing or removing the uncovered wastes.

The framework is developed in a theoretical way at this research step, mainly based on literature outcomes. In the next phases, the proposed theoretical framework will be tailored to actual case studies to test its applicability.

2.3.3 Applying the framework

After laying a solid groundwork in the previous steps, the developed framework is here applied to two case studies from selected industries. Thus, the theoretical mappings of logistics processes are adjusted in light of the actual information from the two case companies. The primary goal of this phase is to illustrate the adaptability and functionality of the previously created framework in different industrial sectors. To be more precise, it acts as a sort of overarching framework. As a result, having such a theoretical framework can aid in reducing the efforts required to develop process mapping, waste identification, waste analysis, and Industry 4.0 technologies selection for any new company from scratch.

The framework is then applied to two real cases, from the Automotive and Food industries respectively. Accordingly, as it was described in section 2.2, the main objective here is to identify the non-value-added activities and wastes in Source and Deliver logistics processes and find out the related underlying causes that may be alleviated by the technologies connected with Industry 4.0. At this stage, every step is carried out by detailed and meticulous observations of the logistics processes of each company. As a result, all the framework phases, such as process mapping, identifying wastes, determining their underlying causes, and recommending Industry 4.0 technologies, are carried out through real observations and many discussions with the managers and staff involved in each activity.

2.3.4 Constructing the Lean DSC roadmap

Large investments by SC members and associated companies are required to implement Industry 4.0 technologies. Therefore, decisions on how and when to integrate new technologies are crucial for managers to make. The ultimate goal of this endeavor is to equip SC company management with a tool assisting in such decisions. In fact, as revealed by literature (), it is not enough to only describe the use and advantages of various Industry4.0 technologies in reducing waste. The outcomes of the previous phase are here taken into account as a resource to assist managers in making better strategic decision-making in SCs. To do this, it is necessary to develop a scientific approach to perform knowledge extraction based on the current state of the company.

As a result, the main managers of the different departments within each case company are invited to a workshop, when they are given an explanation of the results of the framework development phases that come before the present one. The participants are then asked to express their preferences about the relative significance of the wastes that have been identified. Finally, the relative weights of the identified wastes have been obtained by employing Full Consistency Method (FUCOM) as a suitable Multi-Criteria Decision Making (MCDM) approach to demonstrate their significance. After that, the evaluation is finished by determining the overall ranking of each Industry 4.0 technology according to the requirements of each company for the implementation phase. These are the steps of the construction of the Lean DSC roadmap, which suggests to managers which of the wastes of their companies should be addressed first according to a Lean Manufacturing approach. Then, based on that, the roadmap also indicates an appropriate order of implementing selected Industry 4.0 technologies in the Source and Deliver processes affecting the company's warehouses.

Therefore, the proposed roadmap may aid managers in deciding which Industry 4.0 technology should be deployed first inside the company to guarantee the greatest possible waste reduction.

As an overall result, the present research provides a flexible and easily adaptable framework for recommending a unique Lean DSC Road map for each company.

2.4 Research outline

The next chapters cover all the aspects of the research that are necessary to answer the research questions presented in section 2.1 and achieve the research goals. The findings from the two SLRs conducted to identify the significant trends and gaps in SCs with respect to the Industry 4.0 and the Lean concepts are given in Chapter 3. In Chapter 4, the fundamentals and building blocks of the theoretical framework are described. In Chapter 5, the reader can look at how the developed framework is put in practice in two real case companies. Following this, the mathematical foundations for

implementing the best methods for extracting the company experts' opinions are provided in Chapter 6. Data collection is the primary focus of Chapters 7 and 8. Further, in these chapters the final Lean DSC roadmaps for the case studies in both the Automotive and the Food industry, together with their respective interpretations, are provided. Last but not least, the results as well as the academic and practical implications of the present work are discussed in Chapter 9. Additionally, the limitations of the current study and the suggestions for future research are discussed.

Chapter 3

Systematic Literature Review

Lean Manufacturing and Industry 4.0 technologies applied to SCs are examined in this chapter, whose goal is providing a holistic view of the current state of the art. In order to investigate that, a scientific approach known as the Systematic Literature Analysis (SLR) is applied. Finally, the next directions of the research work are decided in accordance with the identified gaps.

3.1 Planning the Systematic Literature Review process

The content analysis known as SLR is a systematic technique that provides an overview of a particular topic by means of a step-by-step and scientific procedure (Aryal et al., 2020; Pournader et al., 2020). SLR is different from the other methods used to investigate the state of the art of a topic due to its ability to reduce the influences of subjective judgment (Seyedghorban et al., 2019) and its capacity to deliver deeper insights that assist in the advancement of a field (Tranfield et al., 2003). The approach suggested in (Tranfield et al., 2003) is the one that the present SLR uses since it have been used in many SLR work related to the SCM in previous studies (Barbosa et al., 2018; Hald & Kinra, 2019; Pournader et al., 2020; Rejeb & Rejeb, 2020). This approach consists of three phases as follows: 1. planning the review process, 2. searching and conducting the review, 3. reporting results and recommendations. Figure (2) provides a visual representation of the different stages in SLR, along with the main focuses elaborated in each step, which will be discussed in greater depth in the subsequent sections. Moreover, the numbers in front of each step refer to the related sections for explaining that in more detail in the chapter.

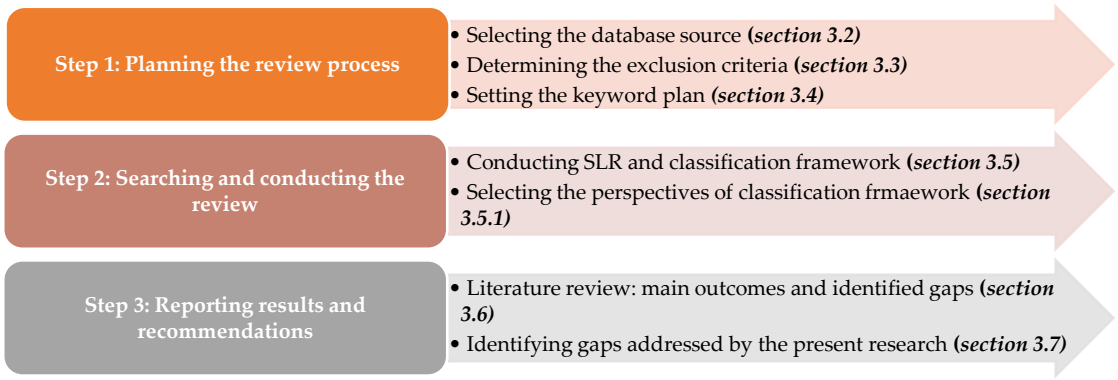


Figure 2 Procedure for conducting SLR

3.2 Selecting of the database source

The selection of a trustworthy and comprehensive database source is one of the fundamental phases involved in the SLR process. Scopus is acknowledged as the primary searching source by numerous SLR publications in the subject of SCM (D. Mishra et al., 2016). Scopus incorporates articles from databases such as Web of Science (Chang & Chen, 2020; D. Mishra et al., 2016; Seyedghorban et al., 2019) and hence covers a broader range of topics and publications than other literature resources (Bag & Pretorius, 2020; Chiappetta Jabbour et al., 2020). In this respect, (Buer et al., 2018) performed a comparative assessment among Scopus, ProQuest, Web of Science, Science-Direct, and EBSCO databases in the field of SC. The main aim was to find out which database contains the most relevant data. The investigation shown that Scopus is the most advantageous database since it retrieved most of the relevant publications. On the other hand, the minimum number of relevant publications was obtained from Science Direct and EBSCO. Based on the results of this work, Scopus is taken into consideration for carrying out the present SLR in order to search for the pertinent keywords.

To create a complete list of publications related to the studied area, the author of the present work decided to use both forward and backward snowballing as part of the SLR. It could be a guarantee that the data gathered is complete. It is also worth noting that through backward snowballing, scientific data sources other than Scopus were investigated, including ProQuest, Web of Science, Science-Direct, and EBSCO databases. Section 3.5 goes into greater information about this method.

3.2.1 Determining the exclusion criteria

In the SLR process, setting proper exclusion criteria enables researchers to focus on the publications that are the most relevant to their work (Gallo et al., 2021). In order to do this, two levels of exclusion criteria are established. Exclusion criteria are taken into consideration as the initial step in the filtering process for the search results that Scopus obtains.

In the present SLR, the language of the paper is restricted to English since it is the language that is most frequently used in scientific studies (Gallo et al., 2021). Due to the fact that Lean DSC is still a relatively new study subject that has not yet reached its full maturity, the examination includes both conference and journal articles. However, for investigating the part of the SLR related to the DSC, due to the higher maturity of this area compared with Lean DSC, just the English journal papers have been considered. At this level, to obtain more comprehensive results, there are no restrictions placed on the other fields, such as the subject area or the publishing stage.

After limiting the obtained results to the above-mentioned first level inclusion criteria, the search results are narrowed down by defining second-level exclusion criteria. To this end, the following criteria are taken into consideration while researching the title, abstract, and keywords, as well as when reviewing the entire papers: (a) Papers that do not refer to SCM; (b) Papers that are not linked to Lean Manufacturing principles; (c) Papers that do not include major contributions concerning the application of Lean and digital technologies to SCM; (d) Papers that are more related to Computer Science; (e) Duplicated papers; (f) Papers that were published before 2010 with zero citations, due to the fact that the concept of Industry 4.0 and the trend of research on its primary technologies were born after 2010. Figure (3) describes the main exclusion criteria for this research in different levels. The author is the one who has access to the exhaustive list of all of the rejected articles as well as the reasons for such rejections.

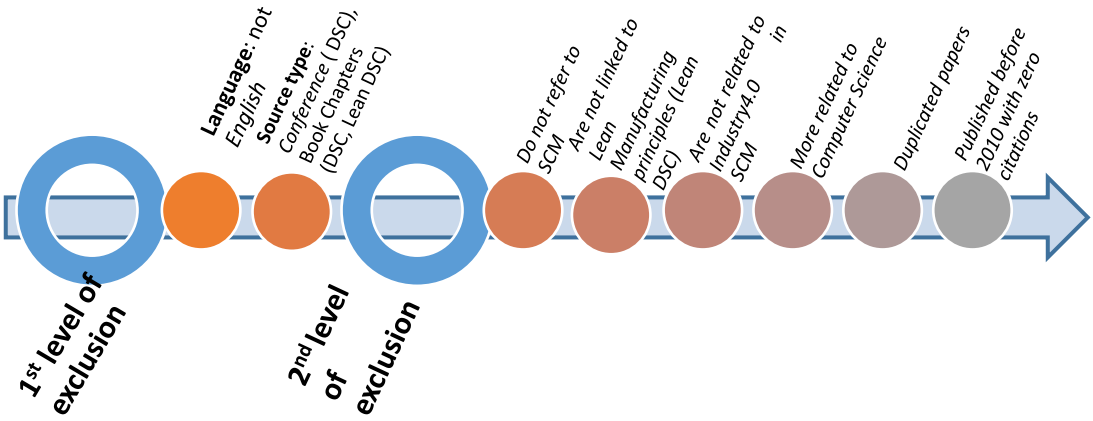


Figure 3 Exclusion criteria in different level of searching for SLRs

3.3 Setting the keyword Plan

The goal of this research is to determine whether it is profitable for SCM to use Lean concepts in conjunction with digital technologies. Accordingly, a look into the state of the art is required to provide an answer to this question. To that aim, the literature search is conducted utilizing three levels of keywords relating to the topic of study. The succeeding sub-sections will motivate the selection of keywords for each level.

3.3.1 First-level keyword selection (Supply Chain)

The search is first limited using the phrase "supply chain" which serves to define the scope of the search. In fact, finding papers by using the term “supply chain” is crucial in gathering all of the results that may be related to the field of SCM for conducting the SLR.

3.3.2 Second-level keyword selection (Digital technologies)

The general concept is known as "Industry 4.0" has numerous interpretations and integrates a range of digital technologies (Raji et al., 2021). The current SLR attempts to give a legitimate foundation for the literature search by identifying Industry 4.0 technologies that are extensively discussed in SCM based on a scientific step-by-step procedure. Using this technique is a step forward in SLR keyword selection when compared to the unclear and subjective selection of similar terms in previous studies (Buer et al., 2018; Núñez-Merino et al., 2020; Rosin et al., 2020; Yeen Gavin Lai et al., 2019).

Step 1: Identifying relevant keywords for emerging Industry 4.0 technologies in SCM

A thorough search was performed in Scopus by using broad keywords "digit*" AND "supply chain" in the first stage to become familiar with the subject's basic pillars and have first evaluation from the field as suggested by (Birkel & Hartmann, 2019; Tranfield et al., 2003). In fact, the primary goal here is to concentrate on the published SLR in this subject in order to recognize the possible related keywords for the following phase. Therefore, the initial related Industry4.0 technologies as keywords to search were chosen based on prior SLRs (Büyüközkan & Göçer, 2018; Dalmarco & Barros, 2018; Ghadge et al., 2020; Haddud & Khare, 2020; Makris et al., 2019; Moufaddal et al., 2019; Queiroz, Pereira, et al., 2019; Seyedghorban et al., 2019; Winkelhaus & Grosse, 2020) in this field, as well as the addition of overlooked technologies to expand the proposed list of keywords to have a comprehensive overview. Due to the fact that Industry 4.0 technology development in SCM is still in its infancy (Birkel & Hartmann, 2019; Chehbi-Gamoura et al., 2020; Pournader et al., 2020), this is required to carefully select the keywords and follow a scientific procedure to finalize them as describe in the next steps. Figure (6) depicts all different steps to follow for

selecting Industry4.0 technologies to serve as the second level of the keywords in the SLR more in detail.

According to the prior SLRs in this field, the initial collected list is included fourteen terms are as follows: Augmented Reality (AR), Cloud Computing (CC), Robotics (R), Sensor Technology (ST), Internet of Things (IoT), Self-Driving Vehicles (SDV), Unmanned Aerial Vehicles (UAV), 3D printing and Additive Manufacturing (AM), Blockchain (BC), Big Data Analytics (BDA), Artificial Intelligence (AI), Cyber-Physical Systems (CPS), and Simulation. In the following processes, the author only makes use of the terms that appeared more than once in the cited works to focus on the most related terms to the field of research (Büyüközkan & Göçer, 2018; Dalmarco & Barros, 2018; Ghadge et al., 2020; Haddud & Khare, 2020; Makris et al., 2019; Moufaddal et al., 2019; Queiroz, Pereira, et al., 2019; Seyedghorban et al., 2019; Winkelhaus & Grosse, 2020). Based on such a criterion, the terms "Sensors Technology," and "Simulation" are eliminated from the search terms since they do not pertain to the subject of DSC (See Figure (6) step 1).

Step 2: Overview of the field by searching the selected keywords

The searching protocol uses a combination of each keyword in second level, with "Supply chain" serving as the first level keyword (for example, "Supply chain" AND "Cloud Computing") in the paper title, abstract, and keywords. Additionally, in order to ensure that high-quality scientific contributions are addressed (Arunachalam et al., 2018), the search is limited to journal publications as the primary resource for determining which technologies as keywords should be included (See Figure (6) step 2). October 2020 is the period when these searches were performed.

In addition, in order to decrease the risk of overlooking pertinent works in Scopus, the search is performed using each and every conceivable version of the keywords that are included in the final list. For example, the terms "Block chain" and "Blockchain" are both included in the search.

Step 3: Investigating the relevance of the papers to SCM

The titles, abstracts, and keywords of the articles published in English journals are examined at this stage. The primary goal of this investigation is to re-narrow the list of Industry 4.0 technologies to exclude those that do not have a strong association with SCM according to the available papers.

The overall average percentage of “related” papers to SCM is taken into consideration as a criterion to identify the appropriate digital technologies for this SLR (μ_T). Such a percentage is calculated based on the results of reading the paper's title, keywords, and abstract. To be more precise by considering Table (2) and, according to the equation (3-1), as shown in Figure (6) step 3, the average of “related” articles for remaining keywords from step 1 is calculated for each technology (μ_i). Afterward, in order to obtain a unique criterion as a baseline to just focus on most related technologies to SCM, by

using equation (3-2) the average on all "related" papers to SCM have been calculated (μ_T). This criterion ($\mu_T = 35\%$) shown as a red line behind the chart presented in Figure (6) step 3. Therefore, the grey area under the red line indicates the excluding technologies for further investigation in step 4.

Table 2 Parameters description for Industry 4.0 technologies keyword selection in SCM

Notation	Description
$i = \{1,2,\dots,17\}$	Number of selected technologies as keywords from the step 1 and all possible combination of them
α_i	Number of "Related" papers to SCM for ith technology as keyword after reading Title, Abstract, and Keywords
β_i	Number of "Not related" papers to SCM for ith technology as keyword after reading Title, Abstract, and Keywords
δ_i	Total number of papers in Scopus by searching for ith keyword as described in Step 2
μ_i	Average number of "Related" papers to SCM for ith technology as keyword
μ_T	The criterion for accepting technologies as final keywords for further consideration in step 3

$$\boldsymbol{\mu_i = \frac{\alpha_i}{\delta_i}} \tag{3-1}$$

$$\boldsymbol{\mu_T = \frac{\sum_{i=1}^{17} \mu_i}{\sum_{i=1}^{17} \delta_i}} \tag{3-2}$$

In light of above-mentioned procedure, the following keywords are taken into consideration as main keywords for more in depth analysis at the subsequent step since ($\mu_i \geq \mu_T$) : BC, BDA, AM, AR, IoT, SDV, AI, UAV, and CC. This is accomplished by excluding CPS and R from the list of potential technologies (See Figure (6) step 3) since their percentages of "related" articles in SCM are less than μ_T =35% ($\mu_i < \mu_T$). In fact, their associated μ_i are equal to 31%, and 23%, respectively.

Moreover, according to the same Figure, certain keywords with μ_i less than 35% should not be eliminated because they are equal to other extensively used technologies with ($\mu_i \geq \mu_T$):

- 3D printing (25%) could be synonym of Additive Manufacturing (51%)
- Virtual Reality (11%) could be related to augmented Reality (40%)
- Self -Driving Vehicles (0%) could be synonym of Autonomous Vehicles (45%)
- Un manned Aerial Vehicle (19%) could be synonym of Drone (58%)

Step 4: Identifying the most debated digital technologies in SCM

As a step toward completing the list of digital technologies most frequently adopted in SCM, the trajectory of publications for each Industry 4.0 technology applied to SCM is examined. The major goal of this stage is to finalize the results of the previous stage by analyzing the publishing pattern for each digital technology. As a result, attention is directed to addressing the technologies that are already well established in SCM. Two distinct categories of digital technologies have been determined as a result of an investigation of the pertinent articles that have been published so far.

The first category consists of digital technologies having recently attracted a significant interest, as proved by the rising number of publications regarding SCM (Most debated technologies). It is worth mentioning that, for identifying the most debated and least debated technologies here the trend lines are obtained by applying polynomial and linear procedures. However, due to the bigger R^2 in Polynomial procedure it has been reported as the main criterion for selecting the most debated and least debated technologies as keywords. Therefore, Figure (4) presents the most debated technologies with their associated trend lines that show the increasing number and growing trend on publication on these keywords.

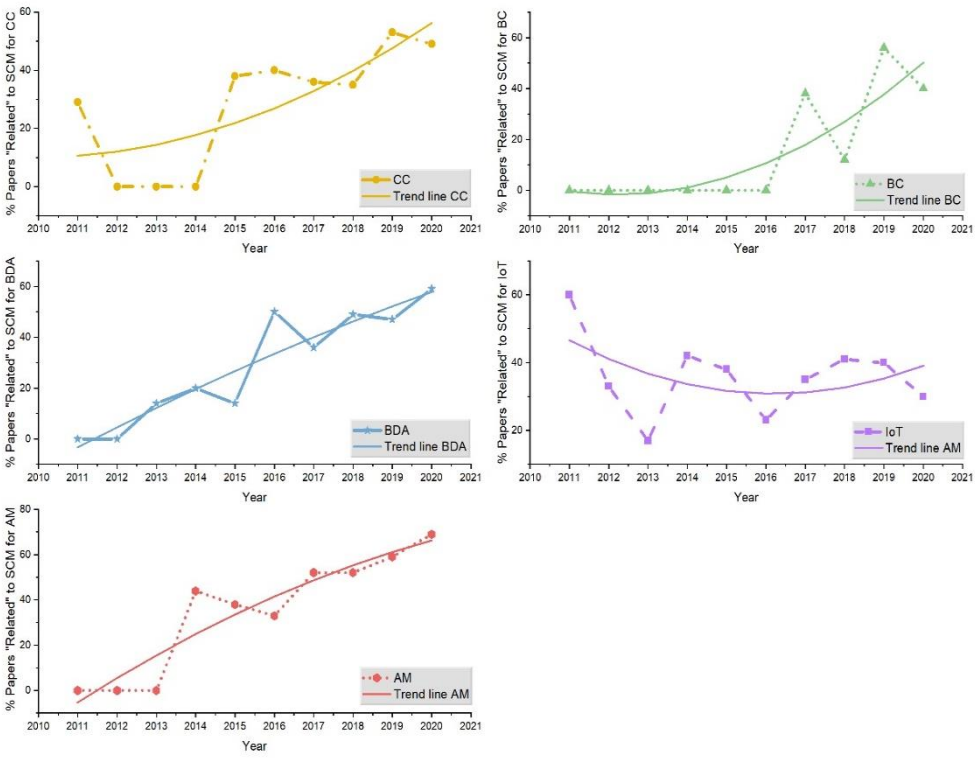


Figure 4 Trends of publication for most debated keywords in Industry 4.0 technologies

The second category includes those digital technologies that are discussed in fewer publications during recent years (from 2011 to 2020), or that do not demonstrate a consistent upward trend in the number of articles that are associated to SCM. These technologies fall into the

second category (Least debated technologies). As a result of this, Figure (5) This finding is displayed and supported by the obtained trend line for each of the least discussed technologies. More specifically, the reported trend line for AI is decreasing. However, the SDV trend line has remained largely unchanged since 2017, despite growing after 2011.

Furthermore, the trend lines for the other two technologies (UAV and AR) indicate ongoing growth. Nonetheless, the number of papers on SCM in UAV and AR has not steadily increased in recent years. It can stem from the novelty of these two technologies (UAV and AR) in SCM. Therefore, it will take them a longer time to achieve a stable yearly increase in the number of publications in SCM. As a result, UAV and AR can be identified as promising technologies to address in the near future. They cannot, however, consider in current SLR as the most debated technologies in SCM.

According to the findings shown in Figure (6) step 4, the most debated Industry 4.0 technologies are as follows: BC, CC, BDA, AM, and IoT. As a result, they are identified as the primary technologies to use when conducting a search for the second-level keywords in the present SLR. Figure (5) displays the least debated technologies, including UAV, AR, SDV, and AI.

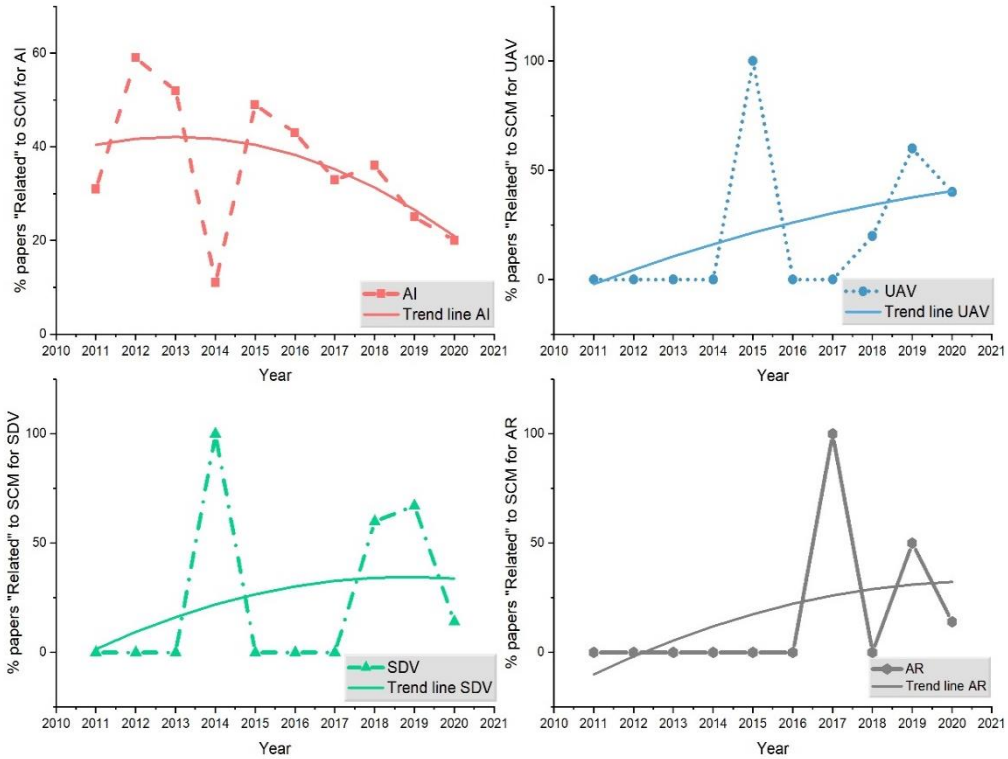


Figure 5 Trends of publication for least debated keywords in Industry 4.0 technologies

In the end, for the SLR part related to the search about Lean DSC, aside from the final most debated technologies "Industry 4.0" and "digital" are added to the list of second level keywords. Due to the infant stage of the Lean DSC topic, including such keywords can provide a more complete overview of the current literature contributions.

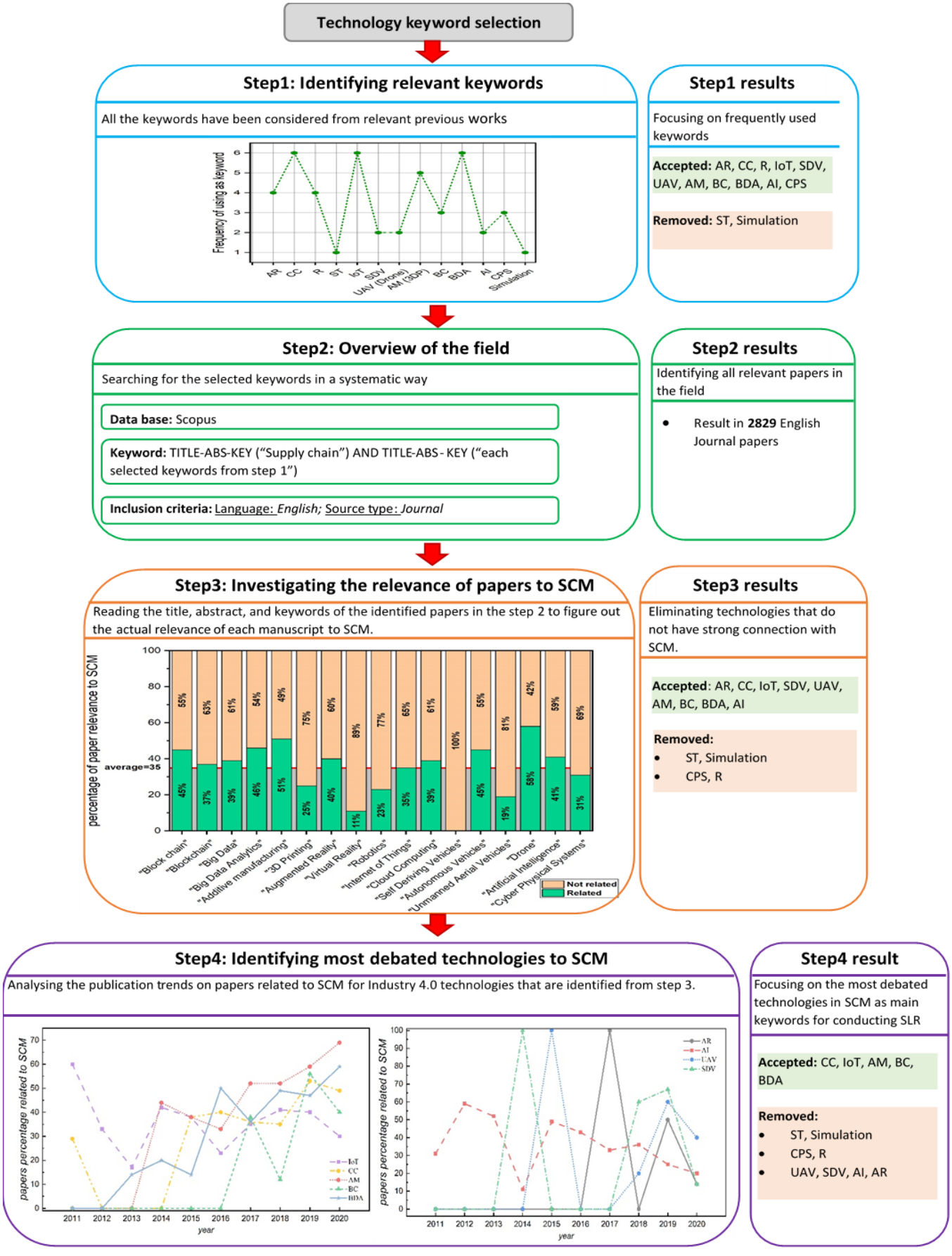


Figure 6 Overview of keyword selection procedure for Industry 4.0 technologies

3.3.3 Third-level keyword selection (Lean principles)

Previous SLRs on the connection between Lean principles and digital technologies have mostly addressed this issue by drawing a comparison between specific Lean tools (such as 5 S, Kanban, JIT, etc.) and individual digital technologies at the production level (Pereira et al., 2019; Rosin et al., 2020). Nevertheless, the influence of Lean concepts and digital technologies at the SC level is not adequately addressed by such studies. As previously stated, this might emerge from the first use of Lean tools and principles in manufacturing processes.

In order to fill the above-mentioned gap in the literature, the current effort takes into account "Lean" as a generic term, rather focusing on specific Lean tools, in connection with the keywords concerning digital technologies and SC that were defined in Sections 3.4.1 and 3.4.2.

3.4 Conducting the SLR and classification framework

After detailing the review process plan, the outcomes of the SLR for both Lean DSC and DSC are reported in this part, and a summary of the findings can be found in Figure (7). When searching for publications in Scopus using all the three keyword levels, for Lean DSC a total of 229 results papers are returned. Similarly, by the same method for DSC 4,831 papers have been obtained (by searching first and second levels of keyword plan in section 3.4.1 and 3.4.2). Thereafter, for the Lean DSC, due to the novelty of the field compared with DSC, the findings are restricted to English journal articles and conference papers, and a total of 172 papers are obtained. Similarly, for the DSC the same procedure has been applied but by limiting the results just to the English Journal paper and excluding the conference papers (Figure (7)).

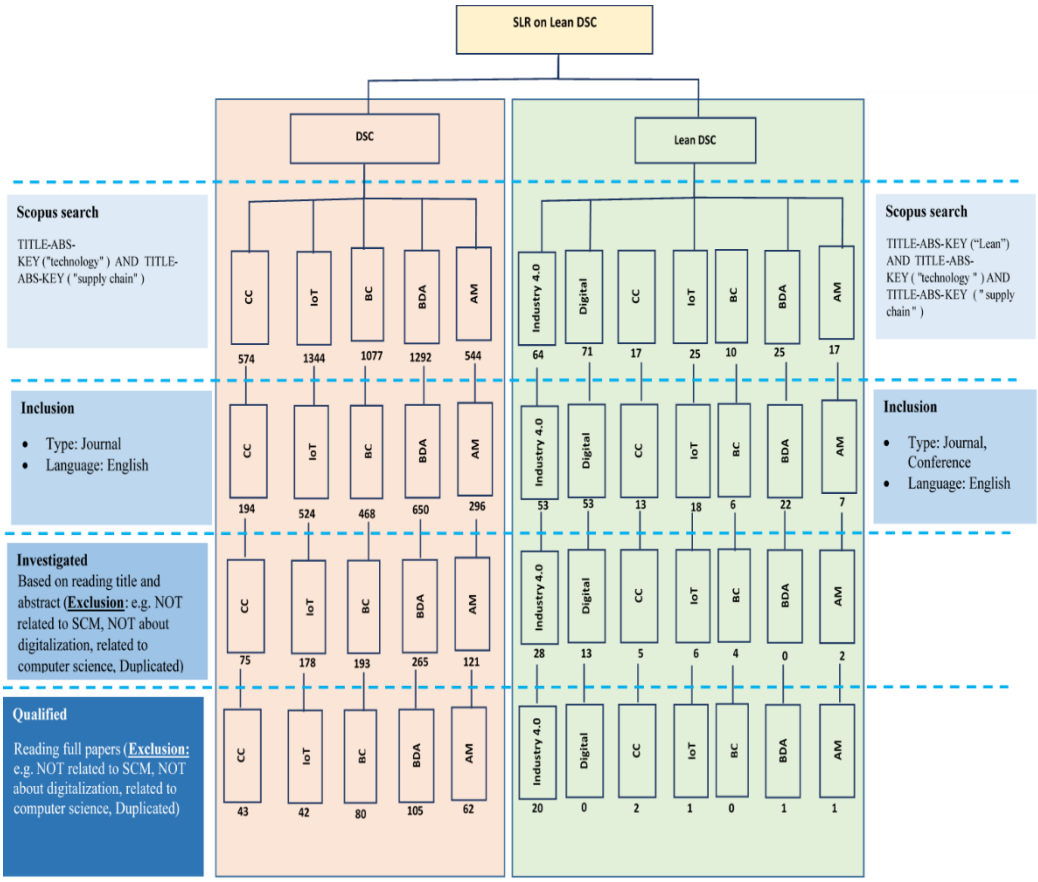


Figure 7 Summary of paper selection procedure for SLRs

As a result, for DSC a total of 2,132 articles are kept in the database. After that, in order to attend to the primary objective of the article and acquire consistent findings, the papers are eliminated based on the additional exclusion criteria indicated in Section 3.3 by reading the title, the abstract, and the keywords.

After completing this procedure, for Lean DSC there are a total of 58 eligible papers and for DSC 832 results are retained in the dataset. Additionally, when the author reviewed the entire articles, she repeatedly used the criteria outlined in Section 3.3 to ensure that the studies were relevant to the overarching goals of the work. As a result, for Lean DSC 25 papers and for DSC 331 papers are retained in the database.

In order to ensure that the database is complete, both forward and backward snowballing (Wohlin, 2014) are used in the next step. Figure (8) depicts the final outcome. A total of 33 papers on Lean DSC and 47 articles on DSC are identified by reviewing the reference lists of previously eligible publications using the "backward snowballing" strategy. For Lean DSC, backward snowballing has resulted in a larger number of articles compared to the forward snowballing for the same topic. It can stem from the fact that "Lean" is more commonly used in manufacturing than in SC. In fact, the great majority of the publications only mention the term "manufacturing" as a component of the SC processes in combination with "Lean." Consequently, a large number of results have been filtered from Scopus by searching "supply chain" as the main keyword. The author of this thesis attempted to compensate for it by undertaking backward snowballing, which allowed her to gather all relevant papers for doing SLR. Finally, "forward snowballing" is applied to the citation list of Scopus articles that were first accepted as part of the SLR database. As a consequence of this, the database now contains 147 new publications pertaining to DSC as well as 6 more papers pertaining to Lean DSC. An increase in the number of forward snowball articles compared to backward publications may indicate that the use of Industry 4.0 technology is expanding rapidly within the field of SC research.

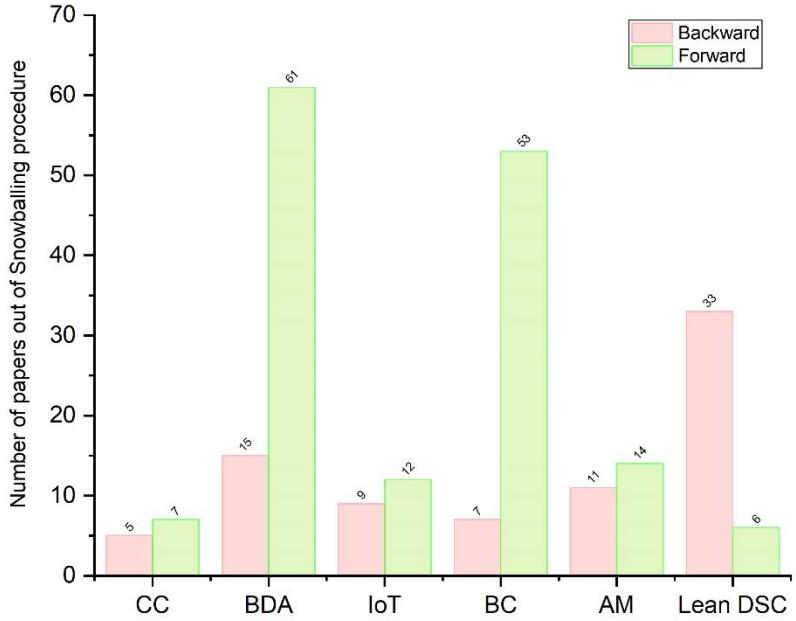


Figure 8 Snowballing results for DSC and Lean DSC

As mentioned before, after a comprehensive filtering process and doing both forward and backward snowballing, a total of 526 articles are evaluated and analyzed for DSC, and 64 complete papers for Lean DSC have been included.

Moreover, to provide a clear idea about the exact procedure adopted in this SLR, all the different rejection reasons are depicted in Figure (9) together with the related percentage of total discarded paper.

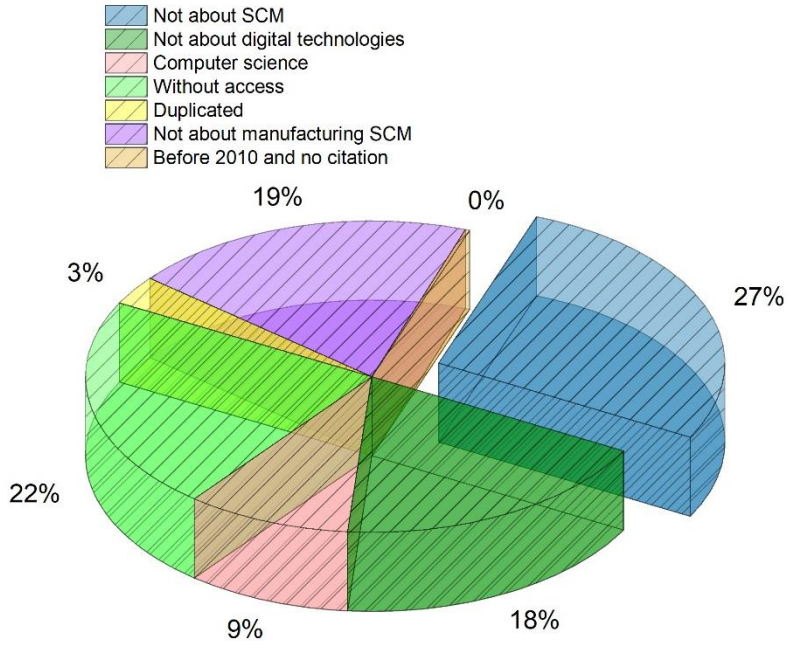


Figure 9 Distribution of the rejected papers for different reasons

These reasons have been mentioned as a part of exclusion criteria in Section 3.3. As it can be concluded from Figure (9), due to the early stage of applying digital technologies to SCM, the main rejection reason for the majority of the papers is “Not about SCM” (27%). In fact, although these papers mention some points or keywords about SC, they cannot be considered as papers directly focusing on SC as the main issue. Also, around (22%) of the papers have been rejected due to their inaccessibility from different sources. Moreover, around 19% of the papers have been dismissed since they are related to SC, but they are mainly focused on other SC kinds than manufacturing, like humanitarian SC, agriculture, or Food SC. Aside from the previously mentioned reasons, around 18% of the papers are related to SC, however they are not directly connected to the application of Industry 4.0 technologies. Besides, another 9% of the papers are rejected thanks to the fact that they discuss the application of Industry 4.0 technologies to SC mainly from a Computer Science point of view and it is out the scope for present work.

To explore the SLR results precisely and in-depth, a data extraction form is created on the basis of Microsoft Excel® including the following fields.

1. Information about the Paper (including the title of the paper, the publication year, the authors names, the journal name, and any other relevant information about the journal, such as the impact factor and the quartile of the ranking a Journal in the associated field (Q1, Q2, Q3, Q4.),
2. Searching Information (keywords for finding the paper in Scopus, link to the manuscript webpage),

3. Preliminary Paper Analysis (paper keywords, subject area, applied digital technologies, applied methodology, the source for data collection, research gap, research questions, main findings, limitations, future directions),
4. A Comprehensive Examination of the Paper (summary of the main points, critical analysis, relevance to the goal of the present research).

From October 2020 until June 2021, the author had regular weekly meetings with the supervisors of the thesis to check the progress of the work and discuss and resolved any questions regarding each paper. The goal of these meetings was to reduce the amount of bias that existed throughout the entire process of selecting and analyzing the papers.

As an outcome of reading the whole papers and filling out the data extraction form, a classification framework has been developed to classify the findings. This methodology is helpful since it paves the way for the development of novel research proposals in the subsequent stages. The next sections will describe how such a structure is built and the main arguments for the selection of each of its perspectives.

3.4.1 Selecting the perspectives of the classification framework

The following perspectives are incorporated into the structure of the framework that was used to conduct the analysis of the articles on both DSC and Lean DSC that were obtained from the SLR search. It is worth mentioning that assigning articles to each perspective is not mutually exclusive.

(a) Supply chain processes. It is important to discuss the benefits that digital technologies bring to each individual SC process (Moufaddal et al., 2019) in order to demonstrate their potential to boost each single process and also to identify the technologies that are most relevant to each process. In addition, the current body of research views Lean concepts primarily as a tool that can be used to raise the efficiency of the production process. Their use in the other SC processes is still relatively rare (Müller & Birkel, 2020). Therefore, this work aims to pay more attention also to the other SC processes. In the following the supply chain processes that are discussed in this thesis have been listed.

- Procurement
- Warehousing
- Inventory Management
- Manufacturing (Production)
- Transportation
- Customer Relationship
- Demand Forecasting
- Marketing, and Pricing

These processes have been selected based on the research performed by (Giménez & Lourenço, 2008; Kisperska-Moroñ, 2003). The purpose of considering this aspect of classification framework for investigating SC processes is carrying out a thorough view on all of the processes associated with different activities in the SC. It is worth highlighting that when the author refers to "warehousing," she means all the activities related to the management of the warehouse processes and the storage of items. On the other hand, Inventory Management actually refers to the various procedures for regulating and arranging the stock levels as well as all to the associated inventory policies. The works that did not concentrate on one single SC process or specifically define the considered SC processes were identified as a separate category named “overall supply chain”.

(b) Supply chain associated issues. The proposed structure gives particular consideration to the influence that each digital technology has on the operational and organizational challenges faced by SC members. A list of the different associated issues for this aspect have been presented in the following:

- Information sharing
- Revenue/cost-sharing
- Risk measurement/assessment
- Performance measurement/assessment
- Sustainability
- Financial
- Scheduling
- Business model

The above-mentioned list of issues included some of the frequent and significant operational and organizational challenges that are investigated by the literature as discussed in the following.

Lean DSCs have a significant impact on information sharing through the manner in which they connect echelons and the manner in which they manage their value-added flows (Sanders et al., 2016). In addition, the real-time data that are offered by digital technologies can make it easier for DSCs to work toward a more sustainable future (Kouhizadeh et al., 2021). For example, the information provided by block chain can reduce the Over Processing waste in tasks such as managing and verifying sustainability indices related to the social and environmental parts such as the amount of carbon emission (environmental) or working hours of employees (Social). In a similar manner, they may contribute to an improved level of risk management in SCs (Bittencourt et al., 2021) by providing more transparent information about real state of the suppliers of potential SC disruptions in advance by combining IoT, BC, and BDA. The methods of scheduling SC operations may also be altered by real-

time data, which can make the scheduling process more adaptable to meet the ever-evolving requirements of production. In addition, experts in both business and academia are curious about how Lean principles and digital tools affect SC productivity. Furthermore, a stronger collaboration among SC members is needed to reduce Inventory, Over Processing, and Over Production as Lean wastes, and here is where revenue cost/sharing comes in. In fact, applying Revenue/ cost sharing contracts to adopt digital technologies for obtaining and sharing real-time data among SC members like manufacturers and retailers can lead to providing better inventory and production control throughout the SC.

(c) Applied methodologies. There is not yet a structure available to practitioners that may help them in the process of adopting the Lean DSC (Tissir et al., 2020). To this purpose, doing research into the methodologies utilized by previously published articles can provide academicians with advice in choosing acceptable methods for appraising the current theoretical contributions in order to develop guidelines for proper deployment. As a result of this, and with reference to earlier studies (Giménez & Lourenço, 2008; Kotzab et al., 2006; Novais et al., 2019), the present SLR examines the following methodologies:

- optimization/mathematical modeling
- Simulation
- Survey/case study
- Literature review
- Conceptual framework
- Hypothesis testing
- Model/architecture development
- Development of tool/platforms/computer system
- Multi-Criteria Decision Making (MCDM) models.

It is worth mentioning that here Survey and Case studies have been grouped together since both methods are dependent on having close relations with field experts in order to acquire real data and information for future analysis.

(d)Applied theoretical lens. In the subject of DSC and Lean DSC, considering that the research is still in its infancy, having an overview of the theories that have been used within the framework of the various technologies might open new opportunities for conducting future studies. Investigating this viewpoint also facilitates the identification of prospective applications of digital technology based on findings according to the different theoretical lens (Kummer et al., 2020). In addition, Jede and Teuteberg (2015) state that utilizing various theories promotes to grow up developing fields, such as Industry 4.0 technologies

,from the infant stage to greater degrees of maturity(Jede & Teuteberg, 2015). Because there is no preset list of suitable theoretical lenses for applying in SC, the theories presented here were chosen based on their availability in research articles for executing the current SLR.

(e)Combination of digital technologies in SCM. The efficiency and output of SCs are greatly impacted by integration (Bruque-Cámara et al., 2016). To achieve the goal of developing a stable basis for seamless SC integration (Helo & Shamsuzzoha, 2020) the adoption of various digital technologies is required. To this end, pioneering practitioners often integrate several digital technologies (Frank et al., 2019). In addition, because the cost of deploying digital technologies requires a significant initial investment, it is important to determine which combinations of these technologies would be most advantageous (Raji & Rossi, 2019).

3.5 Literature review: main outcomes and identified gaps

3.5.1 Outcomes of classification framework for the SLR on DSC

(a) Supply chain processes

Figure (10) depicts the results of the SLR on DSC for the analyzed SC processes. According to that, the majority of the previous studies investigate the overall SC without a focus on a specific process (62%). It is worth mentioning that the least studied SC process is Warehousing (1%), although it has a large impact on the performance of the other SC processes, like Procurement, Production, and Delivery (Mostafa et al., 2019; Novais et al., 2019; Yudhistyra et al., 2020). On the contrary, Manufacturing/Remanufacturing is the most investigated process (11%), due to its pivotal role in the SC in order to produce goods. This finding motivates the importance of studying the effect of Industry 4.0 technologies in each single SC process.

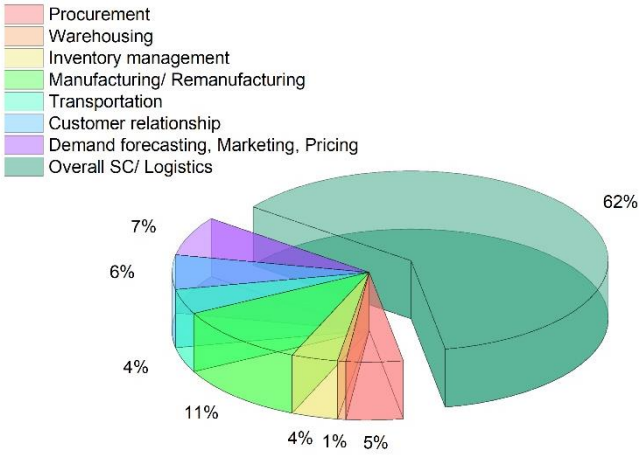


Figure 10 Distribution of papers for each considered SC process in DSC

the SC processes addressed by the present SLR. According to such a figure, BDA is mostly applied in Demand Forecasting, Marketing, and Pricing (78%), Procurement (67%), and Customer Relationship (64%). On the other hand, its least application is in Manufacturing/Remanufacturing (11%). It can be explained by the main role of BDA in different activities in the previously mentioned processes. For instance, in Demand Forecasting, Marketing, and Pricing BDA can assist to analyse parameters related to customers demand and preference learning and planning, or help companies to decide about best prices or the best time for starting discount policies (Feng & Shanthikumar, 2018). Moreover, in the Procurement process BDA can pave the way for supplier selection (Lamba et al., 2019; Roßmann et al., 2018). However, the application of BDA in manufacturing is limited to specific tasks, such as determining the time of starting production or its amount. Therefore, developing the role of BDA in Manufacturing/ Remanufacturing still needs more SC integration since the essential data as the input for BDA algorithms should be collected and shared by the other Industry4.0 technologies like IoT, BC, and CC.

Also, AM mainly applies in Manufacturing/Remanufacturing (39%) and Inventory Management (32%) processes. As a matter of fact, AM in Manufacturing/Remanufacturing can lead to more production flexibility for different kinds of products (Franco et al., 2020; Meyer et al., 2021; Zanoni et al., 2019). Moreover, AM can provide an opportunity for controlling the Bullwhip Effect by applying it for producing the items, with the aim of minimizing the holding cost and related costs and issues to avoid backlogs and inventory shortage (Ashour Pour et al., 2017; Ghadge et al., 2018; Kretzschmar et al., 2018).

In single SC processes, BC is mainly used in the transportation process (35%). Such an outcome can arise from the advantages of this technology in providing tamper-proof data about products during transportation, which is a very desirable characteristic for certain types of goods, such as pharmaceutical and Food ones (Wang et al., 2019).

Additionally, there is a lack of applications of CC in Procurement and Warehousing. Nevertheless, applying CC to these processes can bring about better information integration among different SC members (Giannakis et al., 2019; Novais et al., 2019; Queiroz, Pereira, et al., 2019; Shee et al., 2018).

It is worth noting that just BDA and IoT have been investigated in warehousing, which is the individual SC process least investigated as far as the application of Industry 4.0 technologies is concerned. It reveals the importance of taking into account and studying the usefulness of the other Industry 4.0 technologies in warehouses. In this regard, adopting CC can bring about real time analysis of data collected by IoT for BDA. It can result in more efficiency in warehouse management in assigning storage locations and retrieving items (Addo-Tenkorang & Helo, 2016; Bevilacqua et al., 2019; Yudhistyra et al., 2020).

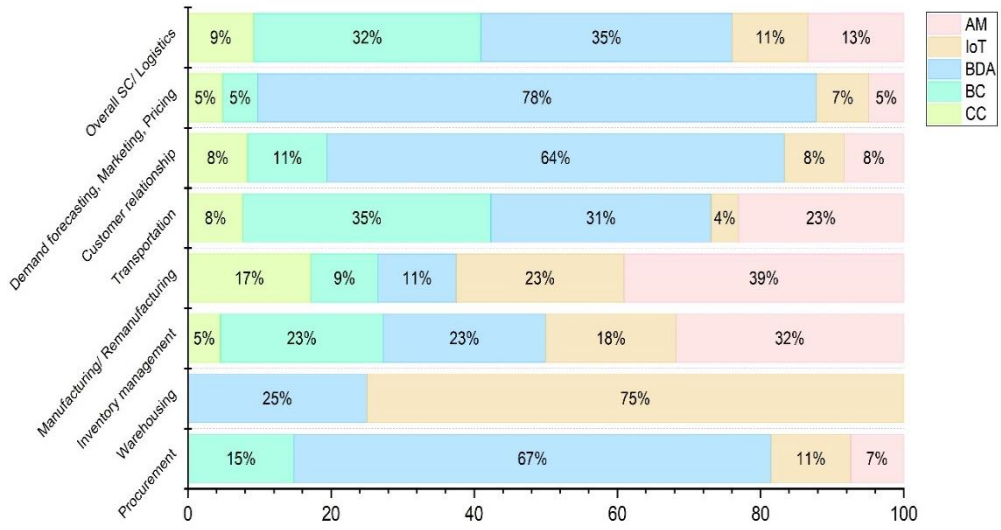


Figure 11 Distribution of Industry 4.0 technologies in considered SC processes for DSC

(b)Supply chain associated issues

According to Figure (12) information sharing is the issue most explored when talking about the adoption of Industry 4.0 technologies in SCs (34%). At the first glance, it sounds reasonable since one of the initial missions of applying Industry 4.0 technologies to SC is facilitating information sharing at different levels, both inside and outside companies (Chan et al., 2017; Ghadge et al., 2020). Moreover, applying Industry4.0 technologies can have a direct or indirect effect on enhancing the SC performance (de Vass et al., 2020; Fosso Wamba et al., 2020; Shee et al., 2018). According to the obtained results from the SLR many studies focus on discovering the effects of digital technologies on the SC performance as the second prevalent issue (23%). Moreover, sustainability is the third prevalent issue (18%). In fact, as stated by (de Vass et al., 2020; Shee et al., 2018; Yadav et al., 2020), there is a close relationship among improving information sharing and successful efforts in achieving sustainability goals by providing transparency with real time data in social, economic, and environmental aspects. Financial, Scheduling, and Revenue/Cost sharing are among the least investigated SC issues in relation to the Industry 4.0 technologies. Such a result recommends these issues as some of the most potential rooms for future studies. In fact, the promising usefulness of Industry 4.0 technologies in these need to achieve more integration among SC members at the basic levels like Information sharing.

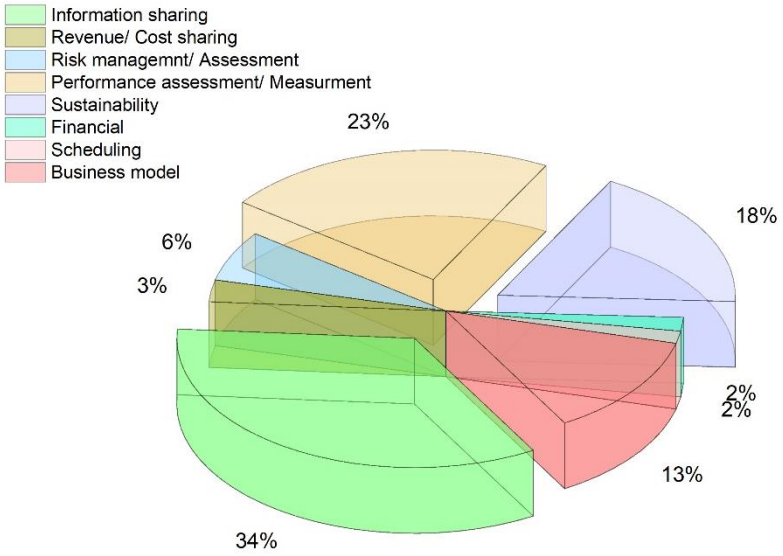


Figure 12 Distribution of papers for considered SC issues in DSC

Figure (13) describes the related percentage for application of each technology in studying different SC issues compared to the other ones. In this regard, AM is the most studied technology in relation to Business models (66%) and Scheduling (56%). As a matter of fact, AM has a great role as a game-changer in defining the business models for companies since AM methods can reduce lead times to the final customer and increase the flexibility for customized production. To this end, it can be applied to offer customized products like spare parts with minimum lead time compared to the traditional business models (Togwe et al., 2019; Verboeket & Krikke, 2019). Therefore, it is one of the trendy topics in recent years to study the effect of applying AM in different industries to compare it regarding the traditional production procedures (Ashour Pour et al., 2019; Strong et al., 2018). Aside from the mentioned point, AM can assist companies to re-schedule item production according to the received orders and provide a flexible scheduling also by considering this approach as a manufacturing method to compensate any shortage or delay in production. However, it is imperative to not only consider the pros but also the cons of AM. In fact, AM is not directly related to other SC issues like information sharing or revenue/cost sharing. Nevertheless, better SC integration through increased information sharing and the adoption of Revenue/Cost sharing contracts in SC can influence the rate of AM acceptance in companies.

CC is more applied to information sharing than to other SC issues. Indeed, CC is one of the main recent tools to support information sharing among SC members (Ghadge et al., 2020; Gonul Kochan et al., 2018). However, the SLR results disclose the prominent role of BC in addressing the information sharing issues. It stems from the primary goal of this technology in providing a secure and tamper-proof way to transfer information among

different partners in a timely manner (Rane et al., 2021).

In addition, studies about IoT have concentrated on its capability for information sharing. In practical terms, IoT has the potential to become the major method of data collection and dissemination across many SC partners by using different devices like RFID tags, GPS, sensors (David et al., 2015; Helo & Shamsuzzoha, 2020; Marinagi et al., 2018; Sahin et al., 2017; S. Shah & Ververi, 2018).

Aside from the limited studies that have been carried out on Revenue/Cost-sharing, Figure (13) demonstrates that BDA and BC will be the most helpful technologies in facilitating this issue. In fact, BC is able to ensure the data authenticity that is necessary to build trust among the various involved parties in such Revenue/ Cost sharing contracts. In addition, BDA can assist SC members to make new marketing decisions such as joint advertisement by finding the appropriate amount of parameters for investment and costs for SC members based on the Revenue/ Cost sharing contracts (Xiang & Xu, 2020; L. Xu et al., 2019).

It is important to note that BDA has the potential to play a significant role also in other aspects of SC, including risk management and assessment. By evaluating a wide range of data coming from a variety of sources, BDA is able to foresee the potential risks that may arise in the future as a supporting tool to increase the performance of the risk.

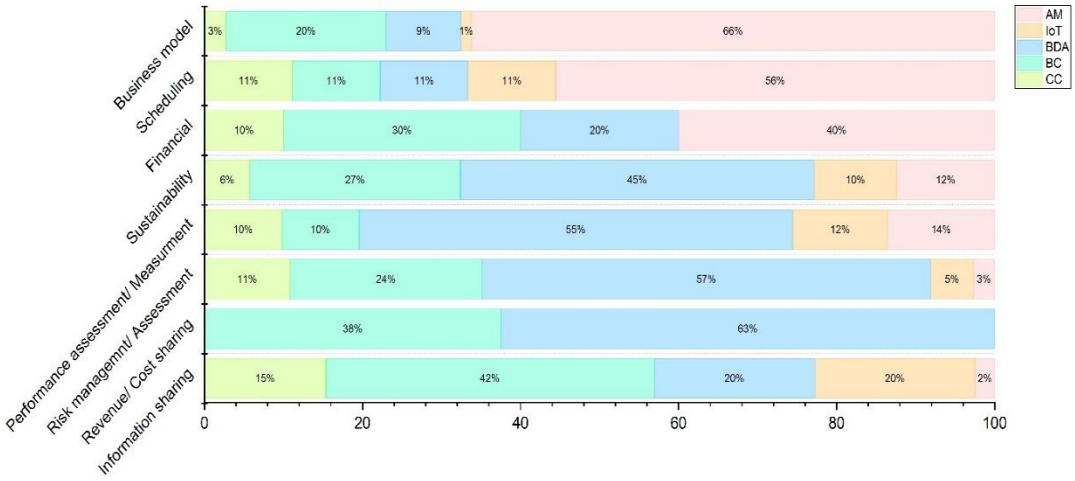


Figure 13 Distribution of Industry 4.0 technologies in considered SC issues for DCS

(c) Applied methodologies

Figure (14) depicts the distribution of papers applying different methodologies in the realm of DSC. According to this figure, the most prevalent methodologies to study DSC are surveys and case studies (30%) as well as conceptual frameworks (17%). It indicates that this field is not enough matured (Ghode et al., 2020; Kurpjuweit et al., 2021; Nakayama et al., 2020) to use other advanced methods such as architecture development or tools and platforms. In fact, academics must first collect data from practitioners through questionnaires and surveys to examine the likely implications of different

Industry 4.0 technologies based on their perceived values. Also, descriptive tools, like conceptual frameworks, are crucial for elucidating the potential SC impacts of digital technologies.

The total number of works included in the present SLR using MCDM techniques and Simulation is limited to (6%). This issue arises because SC is still in the first digitalization stage. To be more precise, approaches such as MCDM and Simulation can be helpful for the next maturity level in the DSC in the real implementation of them. However, currently, the majority of DSCs are in the infant stage to evaluate the usefulness of Industry4.0 technologies rather the practical implementation of them in SC. In fact, MCDM methods can help in determining how to deploy the digital technologies depending on the main obstacles and enablers (Lamba & Singh, 2018; Moktadir et al., 2019; Öztürk & Yildizbaşi, 2020). Moreover, simulation models may be helpful in demonstrating both the prospective benefits and potential drawbacks of actually putting Industry 4.0 technologies into practice.

In addition to the methodologies that have been discussed so far, hypothesis testing is another method that may be utilized to investigate the potential implications that digital technologies may have on various SC aspects and components. In this sense, the defined hypotheses may be tested by the collection and examination of data through the use of surveys and case studies.

Additionally, due to the fact that DSC is a newborn area, doing literature reviews can help the academicians toward identifying most relevant topics and creative ideas as the main rooms for research.

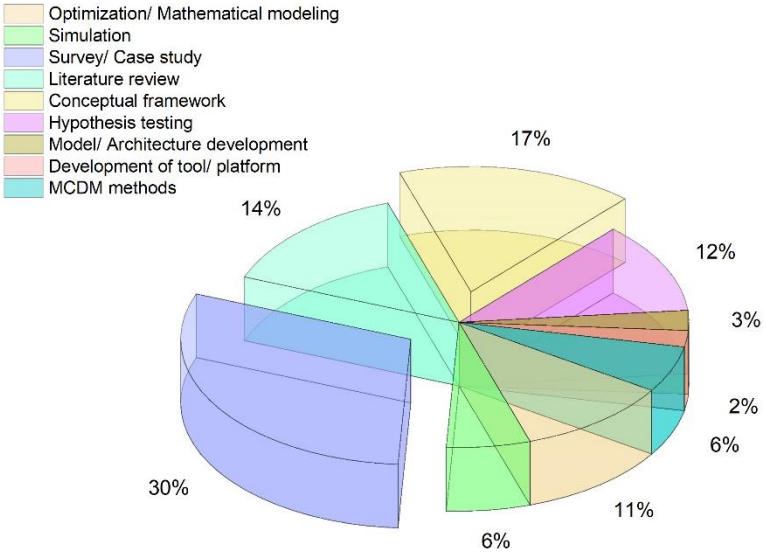
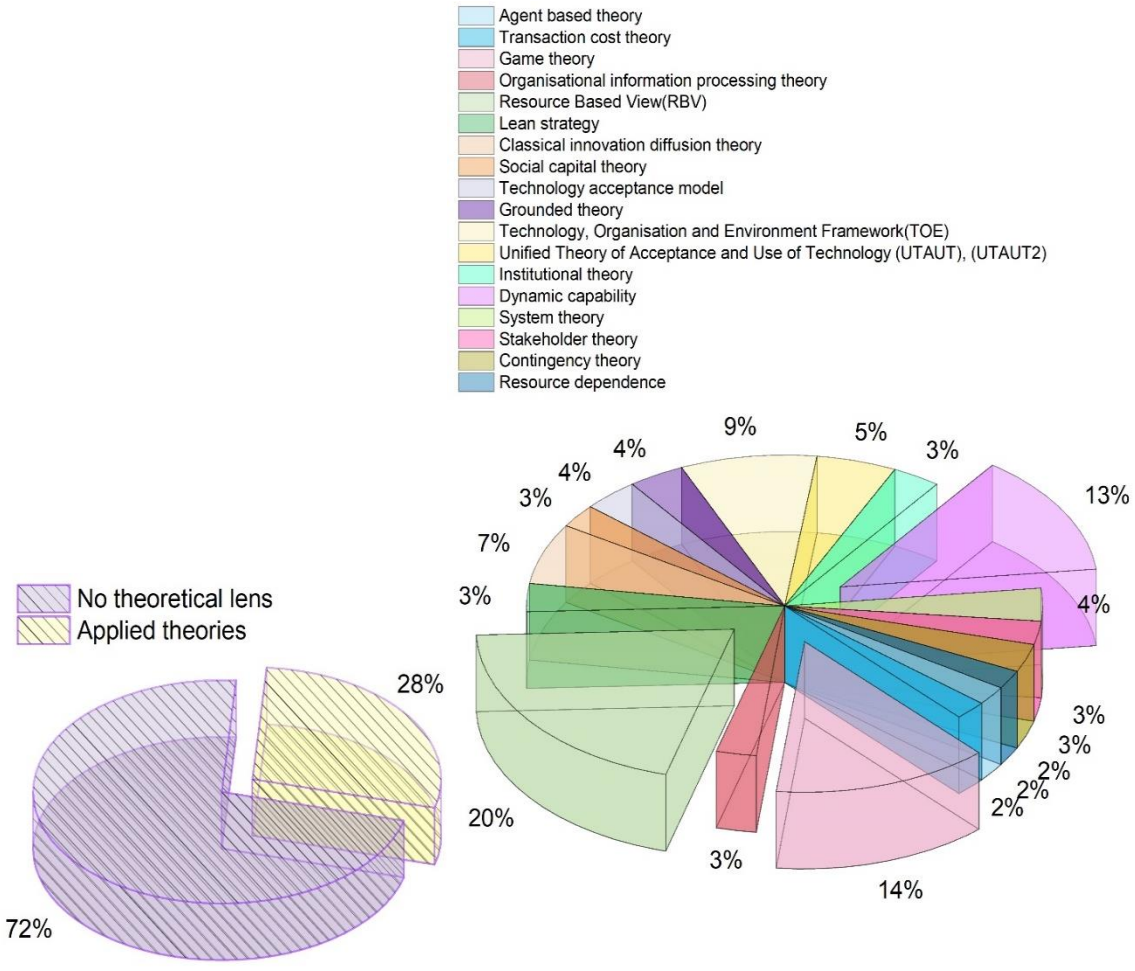


Figure 14 Distribution of papers according to the applied methodologies for DSC

(d) Applied theoretical lens

Over forty distinct theories for investigating Industry 4.0 technologies in SCM have been developed and presented in the articles addressed in this SLR. As a result, only those that are discussed in more than three papers are considered for the present analysis. Figure (15) shows the distribution of papers from the perspective of the applied theories. In this regard, Figure (15(A)) describes the amount of papers that adopted a theory to develop their research versus the papers without any applied theoretical lens. Figure (15(B)) presents the most applied theories in the field of DSC. As mentioned before, it represents just those theories used for more than at least three times in the reviewed papers. In reality, the great majority of the analyzed research did not attempt to establish a theoretical foundation for investigating the DSC (Figure 15(A)). However, among the several applied theories, Resource-Based View (20%), Game Theory (14%), and Dynamic Capability (13%) seem to be the preferred ones (Figure 15(B)). It is worth mentioning that, according to Figure (15(B)), Lean as one of the primary pillars of the study in the current work is rarely explored in the field of SCM. In fact, Lean appears in only 3% of the DSC papers reviewed. It suggests the necessity for more study by using Lean as the theoretical perspective in SCM.



(A) Distribution of papers with and without theoretical lens in DSC (B) Mostly applied theories in DSC

Figure 15 Distribution of papers according to the applied theories for DSC

In addition to this, Figure (16) reveals that BDA is the Industry 4.0 technology whose related studies make use of the greatest percentage of different theoretical lenses in the field of SCM. It's conceivable since the largest number of articles included in the SLR is related to this technology. In fact, this huge number of papers may be indicative of a higher degree of maturity in the investigation of BDA in the SCM context compared to the other technologies.

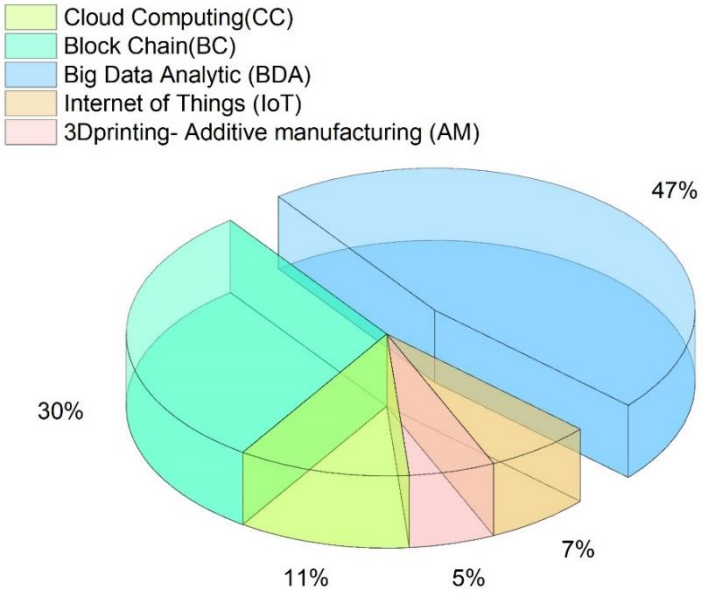


Figure 16 Distribution of theoretical lenses application in studying Industry 4.0 technologies

(e) Combination of digital technologies in SCM

Figure (17) displays a complete overview of all those digital technologies that make up Industry 4.0 according to the present research. This figure aims to discover how much power each pair has for concurrent use by considering all the digital technologies that were identified in step 1 in Section 3.4.2. Each pair of digital technologies in Figure (17) is connected by a line of a given thickness. This thickness is set according to the results obtained from the SLR. In fact, each line is correlated to the total number of the papers that mention both the technologies applied in combination. To this end, a line thickness of 0.5 pt is considered as representative of each paper that applies the combination of each pair of technologies.

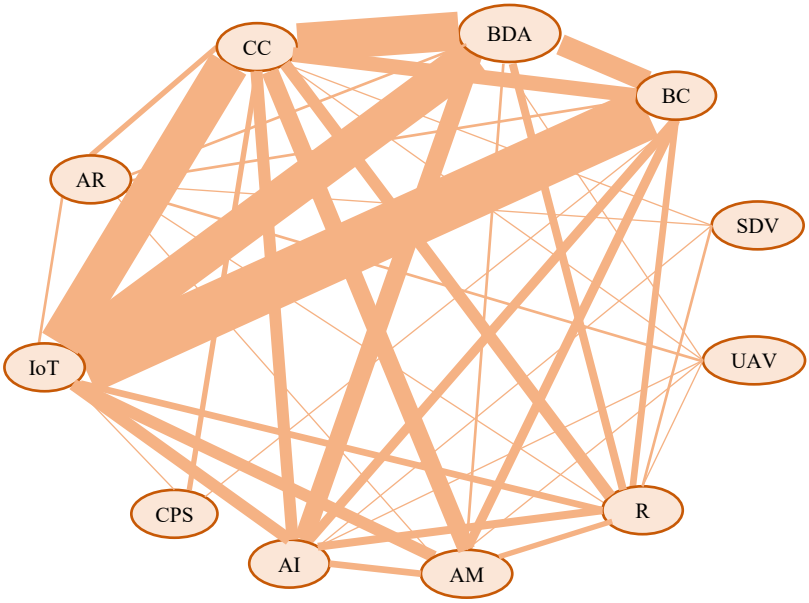


Figure 17 Assessing combinations of Industry 4.0 technologies for DSC

According to the obtained results, CC, BC, IoT, and BDA are the most dominant technologies applied in combination with the other ones. Moreover, as another emerging technology in the recent years, AM connects to a variety of technologies. However, due to the novelty of AM in SC, these connections should be strengthened in future studies by investigating the combination of AM with other technologies.

IoT has the strongest connection with most of the other technologies including CC, BDA, BC, R, AM, AI, CPS, AR. It can imply the pivotal role of IoT as the main tool for real time data collection in the initial steps for constructing a DSC (Tan et al., 2020). Afterward, CC is the next prevalent technology analysed in integration with the other ones. In fact, CC can play the role of a bridge to share the information gathered by IoT devices among different SC members or to provide data as input for BDA algorithms. To be more precise, as evident from Figure (17), CC has the strongest connections with IoT (31 papers) and BDA (29 papers). CC is also useful to share the results of BDA analyses and make them available to the involved SC members.

Moreover, AI and R are in the developing phase of their application in combination with the other technologies. Indeed, these technologies have not been integrated as much as CC, BC, IoT, and BDA. They are in the middle of the way for integrating more with the other technologies. Finally, CPS, UAV, and SDV, as new-born technologies, are less studied in the realm of SC and therefore it is needed to carry out more research on their potential in combination with other technologies to facilitate SC processes.

3.5.2 Critical analysis on findings about DSC

The results from the previous section 3.6.1 have been given a more comprehensive and detailed interpretation in this section. As a result, the main goal here is to describe identified trends and gaps from another perspective by performing cross analysis among mentioned perspectives in the SLR framework. Therefore, in the following the first cross analysis is presented about investigating different SC processes versus the Supply chain associated issues. Following that, the second section focuses on the interrelationship and impact of applied methodologies versus supply chain associated issues.

According to Figure (18), Demand forecasting, marketing, and pricing is one of the dominant SC processes investigated in relation to Information sharing, Revenue/cost sharing, and Risk management/ Assessment. In fact, applying digital technologies to demand forecasting, marketing, and pricing can bring about great improvement on these issues. For instance, better understanding of future demand can lead to less risks for SC members in various tiers such as suppliers, retailers, manufacturer. In this regard, by applying digital technologies such as BDA and BC for providing and sharing tamper proof data about demand, it should be easier for the SC members to use revenue/cost sharing contracts in a fair way. As a matter of fact, all parties can trust to the originality of the data provided by BC and precision of analysis by BDA to decide about the appropriate way for collaboration.

In addition, performance assessment is mainly addresses in three different individual SC process, namely Demand forecasting, marketing, and pricing, Customer relationship, and Manufacturing/remanufacturing (see figure (18)). In fact, these three processes are among the most critical processes to determine the overall performance of the companies in SC. As a result, it is important for companies to put their efforts to improve the performance of the mentioned processes by applying digital technologies.

Moreover, as Figure (18) depicts, Transportation can have relatively high impact on the scheduling issues and business models. In fact, timely deliveries to customers can be one of the main issues in the transportation process since it can lead to providing more advance logistic service. Moreover, applying digital technologies to transportation can result in sharing real time data and bring about more customer satisfaction as a part of adopted business models inside the company.

In Scheduling the most studied SC process is Manufacturing/Remanufacturing. In fact, one of the main issues in the manufacturing process is related to the scheduling of tasks on production machines. In this regard, applying digital technologies like CC and BDA can assist companies to assign the tasks in a flexible way by BDA according to the real time data shared by CC.

Moreover, according to Figure (12), there are very few studies on the application of Industry 4.0 technologies to financial issues in SCs. In these

contributions, Manufacturing/Remanufacturing and Procurement processes are mainly investigated (See Figure (18)). It can arise from the importance of the financial issues in Procurement and their consequences on manufacturing of the products. For instance, applying reliable and trustful environment by BC to do payments to suppliers can make stronger relationship in the procurement process to obtain. As a result, a more reliable and strong connection with suppliers can lead to smoother raw material feeding for the production process.

The research about digital technologies in relation to inventory management is relatively limited and mainly addressed in Performance assessment and Revenue/ Cost sharing issues. It can be explained by the role of the inventory indices as main parameters to evaluate SC performance in manufacturing companies. Moreover, one of the main goals of revenue/ cost sharing contacts is in defining appropriate inventory policies to either reduce SC costs or increase the revenue for SC members (De Giovanni, 2020). For instance, CC and BDA can facilitate adopting the Vendor Managed Inventory (VMI) policy that can be followed by revenue/cost sharing contracts among SC members. To this end, CC can share real time data about instant inventory in the retailer side and by applying BDA algorithms manufacturer or supplier (as vendor) be able to predict the best inventory policy for the replenishment of the retailer warehouse.

Based on the performed SLR, warehousing has been investigated rarely in relation to the different SC issues. According to Figure (18), warehousing just studied in relation to the limited SC issues, such as Business models, Performance assessment, and Information sharing. However, for example, improving warehousing by adopting technologies like IoT and CC can reduce SC backlog or Over Production risks by informing all the related members about the real state of inventories as soon as any change happens in the warehouse inventories. As a matter of fact, warehousing as one the main SC processes to provide raw materials and finished products can have a great role in risk controlling and bullwhip effect.

Moreover, applying technologies such as IoT and BC can assist companies in reducing counterfeiting during warehouse operations such as picking and packing (Mostafa et al., 2019). Therefore, it can improve the sustainability aspects of the company including social part from the social perspectives criteria by providing more transparency of the original data.

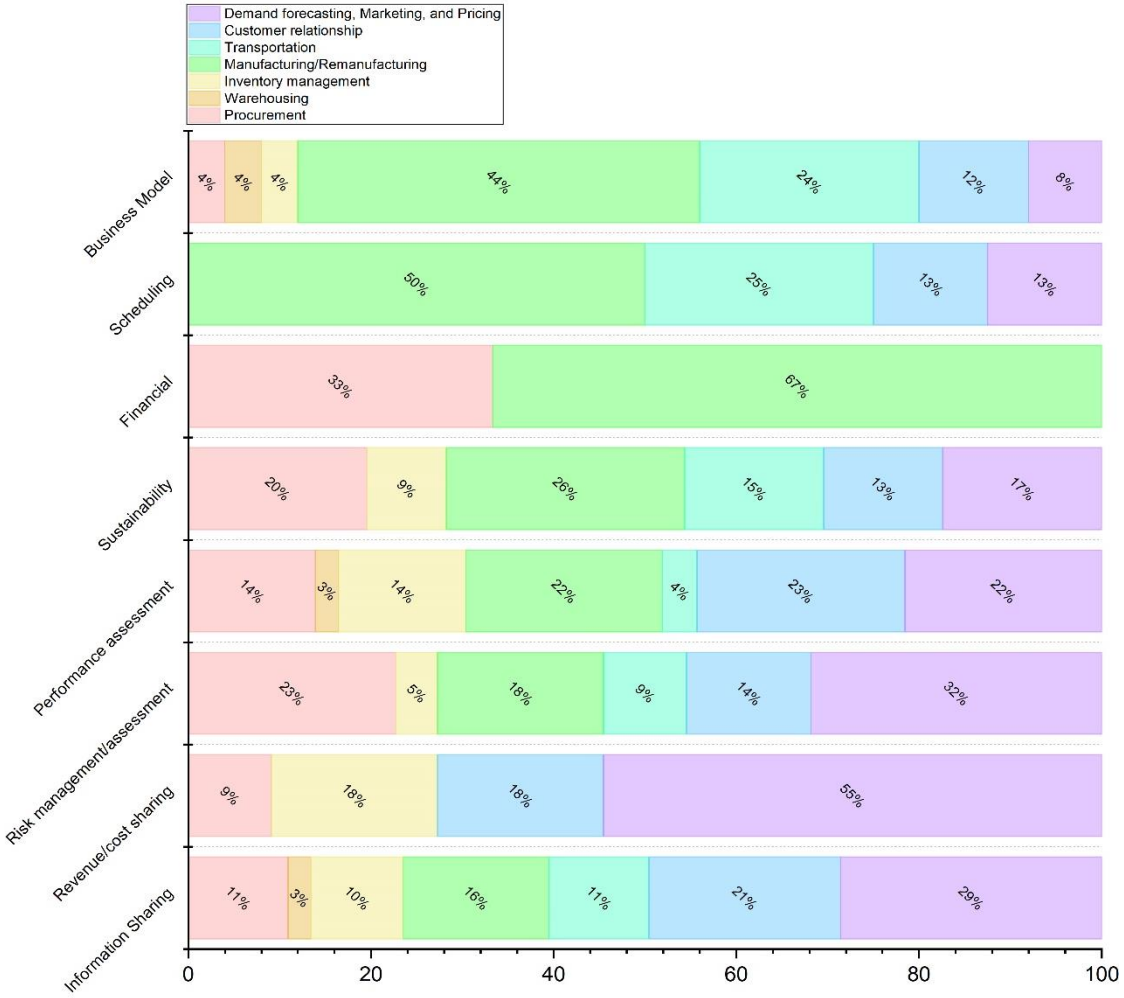


Figure 18 Analysis of SC issues in relation to SC processes for DSC

Figure (19) depicts the application of different methodologies in relation to studying the digital technologies to address SC issues. Optimization/Mathematical modeling is the most prevalent method applied to investigate Revenue/Cost sharing and Scheduling. It is reasonable due to the fact that in Revenue/ Cost sharing contracts one of the main challenges is related to deciding the best values for different parameters and variables for each SC participant. Therefore, here applying Optimization/Mathematical modeling can help to evaluate the effect of applying digital technologies on changing the contract conditions and responsibilities of SC members in these contracts. Furthermore, applying digital technologies like BDA in Scheduling should be evaluated and tested by Optimization/Mathematical modeling.

In analyzing the other SC issues, the most beneficial methodologies are surveys and case studies. As mentioned in Section 3.6.1 such a result can arise from the infant stage of developing Industry 4.0 technologies in SCs. On the other hand, Model architecture development, Development of tools and platforms, and MCDM methods are among the least adopted methods to study SC issues.

In particular, MCDM methods are mainly applied in risk management/assessment to identify or rank risk factors (Wu et al., 2017; Zhao et al., 2017). Thus, there is a need to apply these methods to different SC issues in order to construct and implement DSC framework for practitioners. For instance, MCDM method can reveal that by applying Industry4.0 technologies and their related benefits on the sustainability indices which aspect and which technology should be most important from the practitioners' perspective. In fact, MCDM methods can help to have a better perception of the real attitude of practitioners about DSC regarding various SC issues. As another example, MCDM methods can assist to figure out the perception of SC members about applying Industry 4.0 technologies based on Revenue/cost sharing contracts to share the related costs and risks of implementation. Therefore, the results of such methods can bring about clearer idea for main decision makers in industries for accelerating adoption of these technologies in SCs.

In addition, outcomes in Figure (19) highlight a need to focus more on studying SC issues by simulation approaches. In this regard, simulation methods can be beneficial to provide better understanding of the different situations, possible issues, and influence of Industry 4.0 technologies on SC. For instance, System Dynamics (SD) as one of the simulation methods can assist both academicians and practitioners in providing more realistic assessment about the effect of applying Industry4.0 technologies like BDA, CC, and IoT on different SC members (Hoshimov et al., 2021).

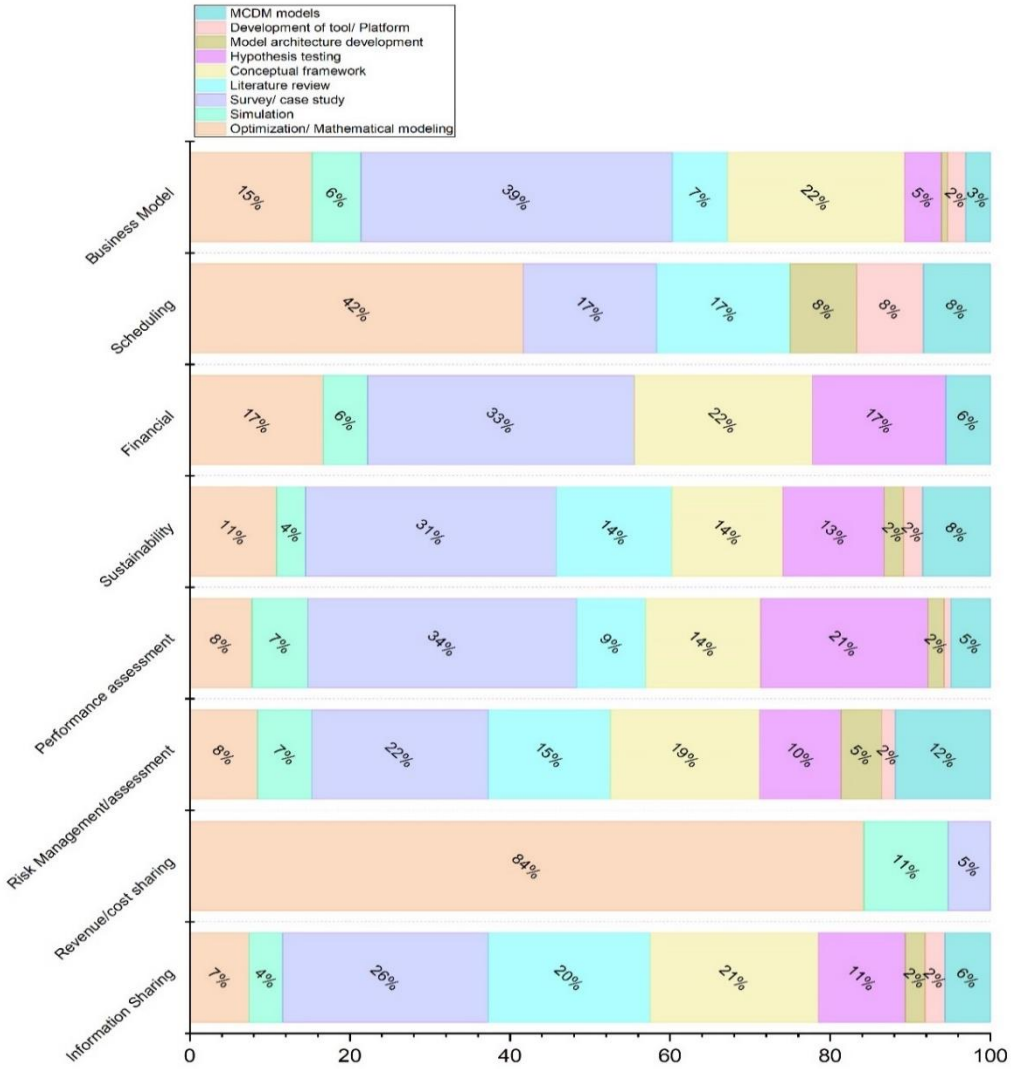


Figure 19 Analysis of SC issues in relation to the applied methodologies for DSC

To sum up, all the points discussed in Sections 3.6.1 and 3.6.2 are summarized in Table (3) as short ideas to describe the present gaps and trends in literature about DSC from different perspectives.

Table 3 Identified trends and gaps from DSC SLR

Perspective	Trends	Gaps
Supply chain processes	• The majority of the papers consider applying digital technologies to the SC as a whole, without focusing in specific processes. • In manufacturing/remanufacturing, most of the papers are related to using Cloud Computing (CC), Internet of Things (IoT), and Additive Manufacturing (AM). • In the transportation process, Blockchain (BC) is the most investigated digital technology. • In demand forecasting, marketing, and pricing, many papers apply Big Data Analytics (BDA). • Among the papers related to procurement, BDA has been more focused in comparison with CC, IoT, AM, and BC.	• There are almost no papers in warehousing (There are only two papers studying the implementation of IoT). • A special attention should be paid to inventory management due to the fact that there are very few papers that have used CC, IoT, AM, and BDA in the field of inventory management, and no papers considering BC. • Procurement is another process that has been scarcely studied in the light of digital technologies. • The effect of digital technologies on customer relationships is another literature gap .
Supply chain associated issues	• Information sharing is the focus of many papers applying CC, IoT, BC, and BDA. • A large body of literature investigates the effects of AM on SC business models. • Sustainability is the focus of many studies about all the considered digital technologies. • Performance assessment/measurement is considered as one of the main SC issues that can benefit from BDA application. • Risk and revenue/cost sharing are the most studied SC issues when talking about BDA and BC application.	• The application of digital technologies to production scheduling needs to be more investigated. • There is some room for studying the effects of BC and CC on performance assessment/measurement. • The adoption of CC, IoT, and AM to risk management and revenue/cost sharing policies should be more studied. • There is a need to focus more on new business models taking into account the positive effects on SCs of digital technologies such as CC, BC,BDA, and IoT.
Applied methodologies	• surveys, case studies, and conceptual frameworks are the most prevalent methodologies when studying all the considered digital technologies. • Literature review and hypothesis testing have been frequently used when investigating CC, BDA, and BC. • There are some papers that apply optimization and mathematical modeling. It should be noted that the number of these papers is less than the number of contributions relying on conceptual frameworks, surveys, and case study.	• There are few papers using simulation to investigate digital technologies in SCs. Simulation could be a deserving methodology to study the effects of digital technologies before their real implementation. • Applying MCDM is rare. However, it can be fruitful to decide about the most appropriate digital technologies to be implemented. • Developing information technology architectures could be one of the future promising topics for the real implementation of digital technologies in SCs.
Applied theoretical lenses	• The majority of works addressing all the considered digital technologies do not adopt any clear theoretical lens. • Game theory and resource-based view are the most prevalent theories when analyzing all the considered digital technologies. • A wide range of different theoretical lens have been used to study BDA and BC in SCs	• Investigating the effects of digital technologies from the lens of different theories is not prevalent in the field of SCM. • There are a few applied theories in CC, IoT, and AM compared.
Combination of digital technologies	• IoT is the technology mostly applied in SCM in combination with BDA, CC, and BC. • BDA has been mostly combined with CC to study their effects on SCs. • BC has been more frequently investigated in combination with IoT than the other technologies.	• AM needs to be investigated in combination with the other digital technologies in the SCM context compared to the CC, BC, BDA, and IoT. • There is a need to study more connected and digitalized SCs by using a proper combination of digital technologies.

3.5.3 Outcomes of classification framework for the SLR on Lean DSC

In this section the main outcomes of the SLR part conducted on the Lean DSC topic are presented. It is worth noting that Lean Manufacturing resulted as one of the least studied theories according to the outcomes of Section 3.6.1. As a consequence, in this SLR the analysis related to the application of different theories is not addressed anymore. Nonetheless, the other perspectives of the defined literature classification framework are analyzed carefully and presented in the following sections.

(a) Supply Chain processes

Figure (20) demonstrates that, based on the findings of the performed content analysis, the preponderance of the previous articles studied the impact of digital technologies in Lean DSC on the overall SC (Jede & Teuteberg, 2015; Queiroz, Telles, et al., 2019; Shee et al., 2018). The influence of each technology on a given SC process is rarely examined in academic studies. IoT seems to be the focus of more research than the other technologies to support the application of Lean concepts in a variety of processes, such as warehousing, manufacturing, and inventory management. Moreover, BDA has also been studied in relation to Lean warehouse management in a few articles. On the contrary, there is little evidence about the use of AM and CC in individual processes together with Lean Manufacturing, despite the fact that they are largely studied to improve the overall SC.

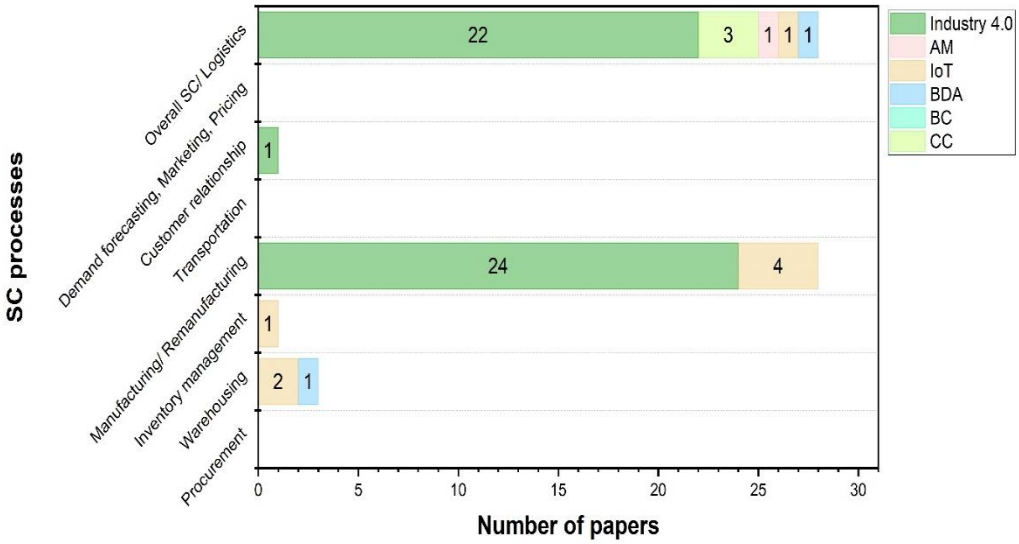


Figure 20 Distribution of Industry 4.0 technologies with Lean in SC processes

In the light of these findings, further research is needed on the use of various technologies to reduce waste in each SC process.

The use of Lean and digital technologies in manufacturing is a hot topic (See Figure (20)). This is because of the introducing the Lean concept in manufacturing processes for the first time. But the principles of Lean Manufacturing may eliminate non-value-adding operations in all the other SC

processes. One of the biggest shortcomings of the current state of Lean DSC research is that no study has been performed on procurement, transportation, demand forecasting, marketing, and pricing processes. This deficiency may be attributable to the fact that the aforementioned processes are mainly connected to the Manufacturing process through defining the SC. However, the previous works just focus on Manufacturing as a standalone process to study the effect of Lean without addressing its role and connection with the other SC process. Since Lean DSC is still in its infancy, there are less research on how these processes can benefit from the combined application of digital technologies and the Lean Manufacturing approach.

However, SCs face marketing issues to estimate demand, particularly for short-life cycle commodities. Accordingly, BDA may provide improved insights into customer demands by analysing SC data at multiple levels for retailer, manufacturer, and suppliers, resulting in a reduction of inventory waste. In addition, by identifying the most likely recipients of advertising as prospective target audiences, BDA applications can help advance marketing policies and minimize the related expenses (Ma & Hu, 2020). For the sake of increasing advertising efficiency and attracting as many customers as possible, it may help define marketing strategies and goals. The marketing team can focus on establishing the optimal strategy for each customer category instead of just analysing the customer behavior to classify them in appropriate groups. Thus, the Over Processing waste in marketing efforts can be reduced as a result of applying digital technologies like BDA. In addition, BDA may assist in determining the optimal time to consider offering discounts on perishable items that have a short shelf life, in order to minimize the amount of inventory that is lost to spoilage. In order to accomplish this goal, practitioners may integrate BDA with IoT and CC to gather and analyse real-time data, respectively, and communicate information to various SC echelons.

In addition, tamper-proof data enabled by BC may create a trustworthy database for using BDA in projecting demand and marketing tactics for luxury products or strategic items like vaccinations (Yong et al., 2020) during the COVID-19 pandemic. For instance, in the case of key products such as vaccines, governments may be more confident of future decisions by employing more reliable demand forecasting in order to distribute the proper quantities of vaccinations for different regions of a country. In order to accomplish this, they are able to depend on the reliable data gathered by BC and the analysis that was supplied by BDA.

In addition, with regard to luxury items, BC is able to supply trustworthy information about final customer, which may include the location, the final selling price, and other relevant details. As a result, such trustworthy information can make it easier to conduct a precise study by BDA in order to provide practitioners with assistance on probable places of actual selling for marketing goals. Other difficulties related to luxury goods pricing can be

improved as a result of digital technologies. Therefore, waste may be reduced by doing these tasks, as shown in the examples above.

Raw material and finished products warehouses have pivotal role as main processes in SC to link different parts range from suppliers, manufacturer, to retailers. Therefore, studying the optimum product allocation strategy in real time, by BDA and IoT may assist Lean initiatives to reduce transportation and Motion wastes in warehouses. Moreover, BC can employ for facilitating storage of certain items in warehouse. To this end, deteriorating items such as medicine and Food, can be audited and inspected by receiving and checking tamper proof data regarding the material origin or the expiration date from BC platforms. Therefore, BC is able to eliminate waste, such as Over Processing and waiting. In addition, this can result in fewer errors by giving quick and trustworthy data on the actual state of the warehouse inventory, such as the number of goods that have expired, the amount of inventory that is currently on hand, etc. BC ought to be integrated with IoT for the purpose of collecting data, CC for the purpose of sharing the information that has been acquired, and BDA for the purpose of analysing and proposing the best options by taking into consideration various factors in real time. The management of inventory and the number of errors in warehouses may both be improved.

Moreover, the application of BC and IoT might be advantageous for the improvement of remanufacturing and closed-loop SC in order to gather reliable and quick data on the item's remaining life cycle, expiration date, responsible manufacturer to return, etc. In this way, the effort required to Over Process data and information may be reduced, which is one step toward achieving a circular economy.

To reduce procurement Over Processing, the creation of BC applications in SC, by providing tamper-proof data regarding the reliability of suppliers, can result in a more trustworthy supplier selection process (Jain et al., 2020). In this respect, all the suppliers from the various echelons should be connected with BC systems, which could then be merged with the BDA system in order to analyse data and with the CC environment to exchange data among various suppliers. Defects may also be reduced as one of the wastes of Lean Manufacturing as a consequence of a more accurate and trustworthy approach for supplier selection, which leads to better quality materials from upstream suppliers.

(b) Supply chain associated issues

There is a significant amount of research focused on the influence of Lean and digital technologies on information sharing, as indicated in Figure (21). Studies have yet to investigate the impact that Lean Manufacturing and Industry 4.0 have on the other SC issues in order to find ways to boost efficiency. Scheduling, Risk management/assessment, and Revenue/cost sharing are a few good examples of these issues. Also, few efforts have been

made to integrate Lean concepts with digital technologies to increase sustainability. In this regard, CC, BDA, AM, and Industry 4.0 as a broad idea are analysed to increase the primary pillars of sustainability (Environmental, Economical, and Social). However, researchers only mention the environmental implications of each individual technology. They do not discuss the influence of each technology on the other dimensions of the Three Bottom line, namely economic and social ones. A significant number of studies examine the impact of Lean and digital technologies on performance assessment/measurement, although the technologies researched are restricted to CC, BDA, and IoT and these works are mostly focused on Industry 4.0 as a general notion.

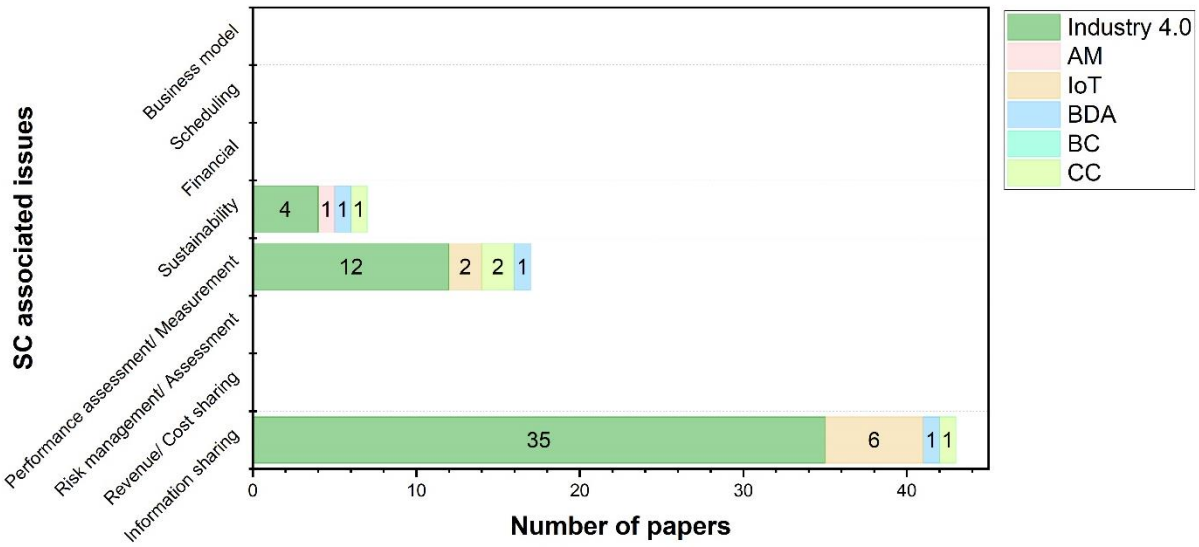


Figure 21 Distribution of Industry 4.0 technologies with Lean in each SC issues

Overall, Figure (21) shows that research articles on SC related issues are not evenly distributed. As a result, researchers should pay particular attention to the significance each technology plays in enhancing the SC organization and operations issues. It appears that, maybe as a result of the emergence and development of Lean DSC, academics are concentrating their efforts primarily on information sharing as one of the top objectives of digital technologies. However, the sharing of information is not the primary purpose served by all the digital technologies. For example, in the current body of research, AM is only discussed in relation to issues of environmental sustainability since it decreases the amount of waste created by transportation helping lessen the carbon emissions (Zanoni et al., 2019). Regarding this point, the influence that AM has on achieving Lean goals still has to be discovered in the other SC issues considered in the present SLR. For instance, AM can reduce lead times, hence minimizing the risks related to disturbances in supply, transportation, and inventory. Consequently, AM has the potential to significantly contribute to decreasing the wastes associated with waiting, transportation, and inventory.

The combination of CC, BC, and AM may also help to create new business models with less wastes by establishing distinctive customer service experiences. For example, due to the higher production speed of AM and its cost-effectiveness, AM has the potential to significantly raise the customisation of products. So, CC and BC have the ability to collaborate on real-time sharing of product information with AM to create more integrated SCs for adopting AM and defining new business models. As an outcome, waiting (for receiving copyrights and related licenses), transportation (for receiving raw materials from suppliers in traditional SC), and Over Processing waste (unnecessary communication for customizing the product according to the each customer order)are all decreased in the new business models.

Additionally, AM is able to alter customer-supplier relationship by decreasing the number of suppliers for the production and also reshaping SC structure by reducing SC tiers as SC members in business models. Therefore, it can lead to the reducing the Transportation and Over Processing waste for obtaining and transferring the materials from suppliers to the other SC tiers. Additionally, combining CC and AM can be beneficial for improving Information sharing issues and reducing related wastes. To this end, the sharing of information in real time through CC and the changing of production operations through AM can help decrease the amount of wasted inventory and Over Production by producing in the appropriate time according to the market needs. In addition, the integration of AM production with conventional one may alleviate scheduling challenges. In fact, AM procedures could be useful for producing customized products, satisfying unforeseen demand, minimizing inventory backlogs, and reducing production delays caused by maintenance. Therefore, this may result in a reduction in wasteful motion and waiting time.

Furthermore, building a system based on simultaneously implementing BDA, IoT, and CC can increase the transparency of SCs. As a result, they can share information in real time about the amount of inventory, customer demand, upstream and downstream suppliers, and transportation that can actually contribute to improve risk management and the planning of proactively responses to any possible disturbances (Haddud & Khare, 2018). In fact, this leads to a reduction in Over Production, Inventory, and waiting times.

One further idea is that the development of digital technologies such as BC can be helpful for decreasing the waste of Over Processing in financial transactions by giving trustworthy data and making the payments simpler and more secure (Venkatesh et al., 2020). The introduction of BC might also lead to greater cooperation and willingness among SC members to construct revenue/cost-sharing contracts. By using BC, the Revenue/ cost sharing contracts can be implemented as smart contracts which can be built and maintained without need to further input from the SC members after first

agreement. Therefore, BC can enhance saving time and resources in defining and executing Revenue/ Cost sharing contacts in SC. To be more precise, determining and executing the smart contract by BC can contribute to a reduction in the Over Processing that occurs in decision-making for practitioners involved in such contracts. There are less disagreements among SC members when they are able to accept contracts through BC. As a result, SC members have the ability to achieve stronger coordination and collaboration in revenue/cost-sharing contracts throughout the SC in order to improve their market share (De Giovanni, 2020).

(c) Applied methodologies

The Lean DSC is presently being addressed in literature by using a variety of approaches (Figure (22)). The survey/case study category emerges as a dominating one for investigating Lean concepts in combination with CC, BDA, IoT, and the notion of Industry 4.0 in general. In addition, it is important to highlight that, with the exception of the work done by (Torres et al., 2019) on AM, there are no publications applying literature reviews to address single digital technologies in connection with Lean Manufacturing. This is something that should be kept in mind as one of the possible directions for future research and paying more attention. Additionally, the use of conceptual frameworks as a way for discussing CC, IoT, and Industry 4.0 in general is becoming more and more common. Also, hypothesis testing is adopted to a considerable degree; nevertheless, it is not utilized to investigate any of the individual digital technologies apart from CC and BDA. Surprisingly, the application of simulation to study Lean DSC receives less attention than other methods. However, this is a promising way to highlight the prospective implications of Lean Manufacturing and Industry 4.0 technologies in a variety of different scenarios in order to aid researchers and practitioners in establishing appropriate implementation framework.

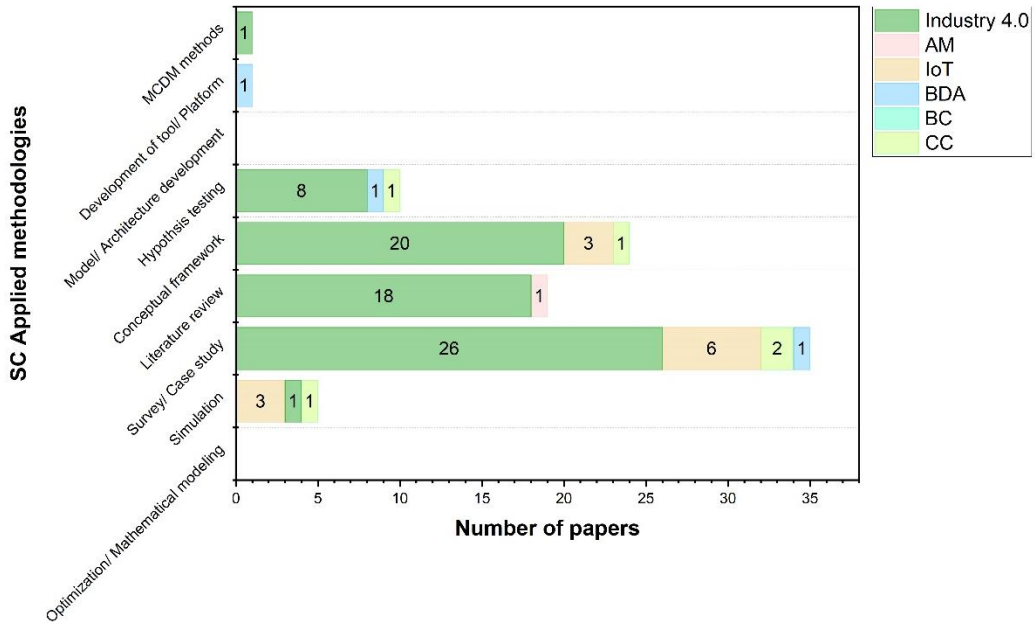


Figure 22 Distribution of Industry 4.0 technologies with Lean for SC applied methodologies

As already mentioned earlier in this section, the immaturity of Lean DSC as a new discipline is reflected in the substantial number of studies that are based on surveys and case studies. In fact, researchers are now conducting works in order to investigate the possible connections between the Lean concepts and digital technologies. In this context, one of the potential methodologies for completing analysis in surveys and case studies might be referred to as hypothesis testing. By using it, researchers can come up with original thoughts concerning the potential impacts and applications of Lean DSC and then evaluate those thoughts in a scientific way.

A number of studies present conceptual frameworks aiming at motivating practitioners to actually implement the Lean DSC concepts in a scientifically sound manner.

Figure (22) shows that the current literature does not present contributions relying on optimization models or architecture development approaches. To some extent, this may be due to the large amounts of data necessary to apply these methodologies, data that can only be acquired via real-world applications of Industry 4.0 technologies still not so spread in SC.

To this aim, simulation models may assist both academicians and practitioners in analysing various scenarios concerning the implementation of Lean DSC before investing in their implementation. As shown by the results of Figure (22), there is still potential for performing further SLR studies on the published contributions about specific digital technologies applied to SCs in conjunction with Lean principles. For practitioners and academics, this technique offers the most up-to-date state of knowledge on the subject, allowing them to adjust their SCs to reflect the most current evidence.

Finally, according to Figure (22), there is limited research on the Lean DSC by applying MCDM methods. Moreover, these studies just investigate the issue by considering Industry4.0 as a general viewpoint. Therefore, it

implies room for further research about every single Industry 4.0 technology to evaluate its usefulness in Lean DSC by applying MCDM tools and methods. In this regard, researchers may use MCDM models to identify the most critical aspects of implementing Lean DSC in different industries from the viewpoint of the main decision-makers. While practitioners may use MCDM models to assess their current condition and preparation for implementing Lean DSCs to reduce the non-value-added activities by applying Industry4.0 technologies.

(d) Combination of digital technologies

The combination of different digital technologies applied to SCM together with Lean Manufacturing is illustrated in detail in Figure (23). The digital technologies selected in step 1 in Section 3.4.2 are taken into consideration when determining the degree of concurrent application of each pair of them. As in Section 3.6.1, in Figure (23), the thickness of the lines between each pair of digital technologies indicates the number of reviewed papers that study the joint application of these technologies.

CC demonstrates the strongest connections with BDA (13 papers), IoT (14 papers), and AM (13 papers). In turn, the most common applications for AM are connected to CC (13 papers), BDA (11 papers), and IoT (10 papers).

AR is most frequently referenced together with CC and BDA (14 papers for each technology). In addition, the findings coming from reading the articles suggest that researchers are interested in making use of BDA, CC, and IoT together at the same time.

Figure (23) also shows that BC has no connection with the other Industry4.0 technology in the realm of Lean DSC. It implies that there is a need for more studies on BC integration with the other Industry4.0 technologies to achieve Lean DSC goals as discussed below.

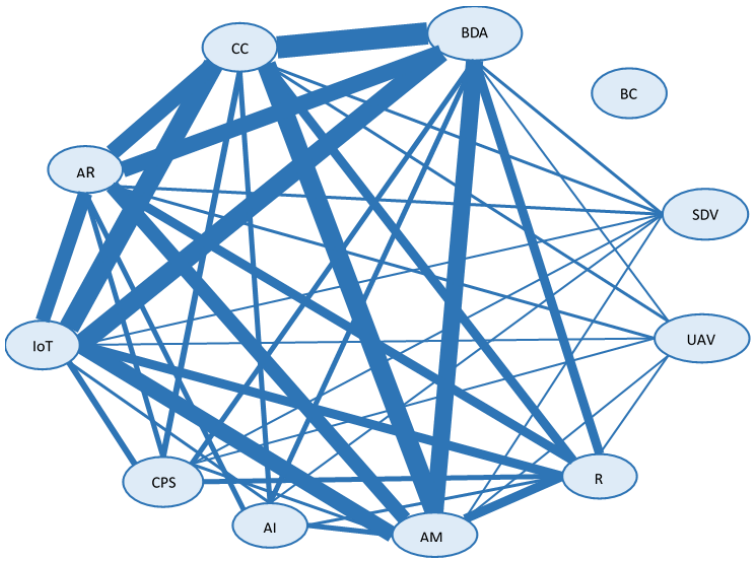


Figure 23 Assessing combinations of Industry 4.0 technologies for Lean DSC

On the contrary, BDA, IoT, and CC are the digital technologies that are employed most commonly in conjunction with one another. In fact, their combined implications, which include the provision of real-time data, make up the fundamental infrastructure for the exchange of information and decision making. The findings reported by (Dombrowski et al., 2017; Gallo et al., 2021) are also consistent with this observation. For example, merging these three technologies at the initial phase of constructing a DSC is already in accordance with Lean principles since it reduces the amount of work that is spent on Over Processing at various levels. IoT may be used to support the task of gathering real-time data with minimal effort, whereas CC can be applied to the task of quickly integrating all the relevant information. In addition, BDA may make the decision-making process easier by deriving knowledge from a variety of data sources.

In addition, it may be concluded from Figure (23) that AM should be linked to information-sharing systems in order to accomplish Lean goals. It means that it should have a strong link with BDA, CC, and IoT. In fact, adding AM to an integrated information system including CC, BDA, and IoT can accelerate its adoption in the SC. For instance, BDA can provide more accurate estimation of the demand to produce by AM and CC can be use as information sharing environment for communicating in real time with different SC members to acquire AM requirements like raw materials and licenses.

By now focusing on technologies that are rarely combined together, BC can help to build trust among the various SC members and encourage them to share information via CC. Furthermore, enhancing the trust of SC members to share information might lessen the necessity of auditing processes [62]. As a result, the Over Processing waste is reduced. As an added benefit, the combination of AM and BC may help alleviate some of the present obstacles to AM adoption, such as licensing and copyright regulations. In fact, BC is able to guarantee to designers that 3D printings and AM models are completely unique and safe according to the copywriting rules. Additionally, CC and SDV can work together to report any issues with the performance of SDVs in a timely manner. Because of this, there is less time spent waiting. AR may also be connected with CC to help maintain SDVs and reduce the amount of time and effort necessary. As a result, the combinations among technologies discussed above lead to an improvement in the Motion and Wait wastes.

As another illustration, the integration of UAVs in specialized applications, such as the distribution of light weight items or medical products, might enhance last-mile delivery by decreasing the amount of time spent waiting and in transportation. UAVs should thus be supported by CC, BC, and IoT in order to gather and transmit accurate real-time data on product delivery. Finally, the use of UAVs in the warehousing process may be beneficial in a number of ways, including improving inventory visibility and

minimizing unnecessary motion. In this regard, CC is able to aid in sharing the data gathered by UAVs in order to combine them with the other SC internal information systems and do an in-depth analysis, also by making use of BDA.

3.5.4 Critical analysis on findings about Lean DSC

The following two cross-analyses are undertaken in order to better understand the existing gaps and trends in the current state of the art about Lean DSC. The first study looks at the connections between the investigated SC issues and SC processes (Figure (24)). It may be used to identify the processes that are most frequently inspected with regard to each SC issue. A second analysis examines the use of various methods in addressing SC issues (Figure (24)). This can give a better picture of the possibilities of adopting less-studied approaches in the future to investigate a wide range of topics.

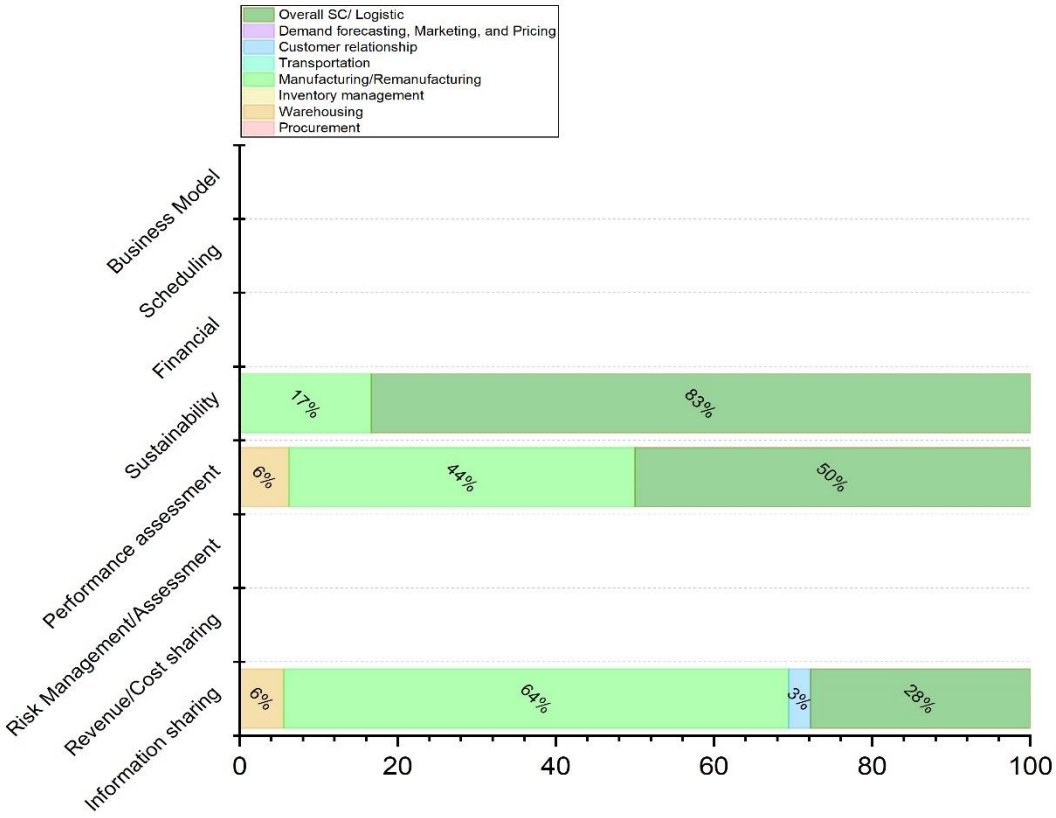


Figure 24 Analysis of SC issues in relation to SC processes in Lean DSC

As depicted in Figure (24), the mainly addressed issues in Lean DSC just focus on the overall SC. In fact, there are limited efforts to study individual SC processes from the point of view of the different issues. In this regard, Manufacturing is the single process most studied in relation to information sharing. It can be due to the fact that the Lean concepts were initially applied to manufacturing processes rather than to the other SC processes. Moreover, warehousing is one of the processes rarely addressed by literature when discussing how Lean could be applied to improve the considered SC issues

by Industry4.0 technologies. It is just studied in relation to the Information sharing and Performance assessment. However, for example, improving warehousing by applying digital technologies like AM can have a positive effect on sustainability issues. In fact, AM by producing customized products stored in warehouses close to customers can reduce the inventory and Transportation waste, allowing to be more in line with Lean goals.

Aside from the mentioned points, other single processes should be addressed in relation to the different SC issues. For instance, risk issues should be investigated in Procurement since it is one the main SC processes where risks might arise. In fact, applying digital technologies can reduce procurement risks. For example, a combined application of IoT, CC, and BDA can assist in dealing with the risks of delayed deliveries from suppliers. To this end, IoT can collect real time data about state of the orders for shipment from the supplier warehouse and share them through CC with retailers or manufacturers as the downstream SC members. Then, the data can be analyzed by BDA in order to provide a detail risk plan for the downstream SC members, so that it can supply the delayed materials from other suppliers or change the production plan accordingly.

As another example, inventory management can be affected by revenue/cost sharing contracts. BC, CC, and BDA can be applied to transfer and share the customer data to provide a reliable forecast for future revenue/ cost sharing contracts. Therefore, according to share data and the agreed conditions in the Revenue/ Cost sharing contracts SC members can have better control on the amount of the inventory in different levels.

In addition, information sharing might be studies in relation to the Demand forecasting, Marketing, and Pricing process. Indeed, digital technologies such as BDA and CC by providing and sharing better estimations of market requirements (e.g., demand and prices) can reduce the Over Processing efforts to make decisions about these parameters.

Figure (25) represents a critical analysis of the different SC issues in relation to the methodologies adopted by the investigated papers on Lean DSC. In this regard, Survey/ Case study is the dominant methodology applied to address all the issues taken into account by literature. Moreover, hypothesis testing is mainly applied to deepen sustainability and performance assessment issues. In fact, the application of Hypothesis testing to analyze information sharing is very limited. On the contrary, conceptual frameworks are one of the prevalent methods in information sharing. Among the issues studied in the Lean DSC, there is no literature review about performance assessment, although it might provide a clear insight about the benefits of digital technologies and their effects on achieving Lean goals in SC. As another room for future research, optimization/ mathematical modeling could be addressed to provide objective analyses about the potential impacts of Lean and digital technologies on SCs. In this regard, it is also worth mentioning that MCDM models might be considered in Lean DSC. These methods might

be applied to identify main benefits and barriers of integrating Lean and digital technologies in SCs from the point of view of different groups of practitioners. Also, MCDM methods might assist in prioritizing the most advantageous technologies according to the specific company situation in order to reduce Lean waste. However, as mentioned about DSC in section 3.6.2, due to the early stage of applying Industry 4.0 technologies to SCs, there are very limited applications of the other investigated methods to the different SC issues. Therefore, there are almost no works on studying specific issues by some other methods such as Development of tools/Platforms or Model/Architecture development in Lean DSC.

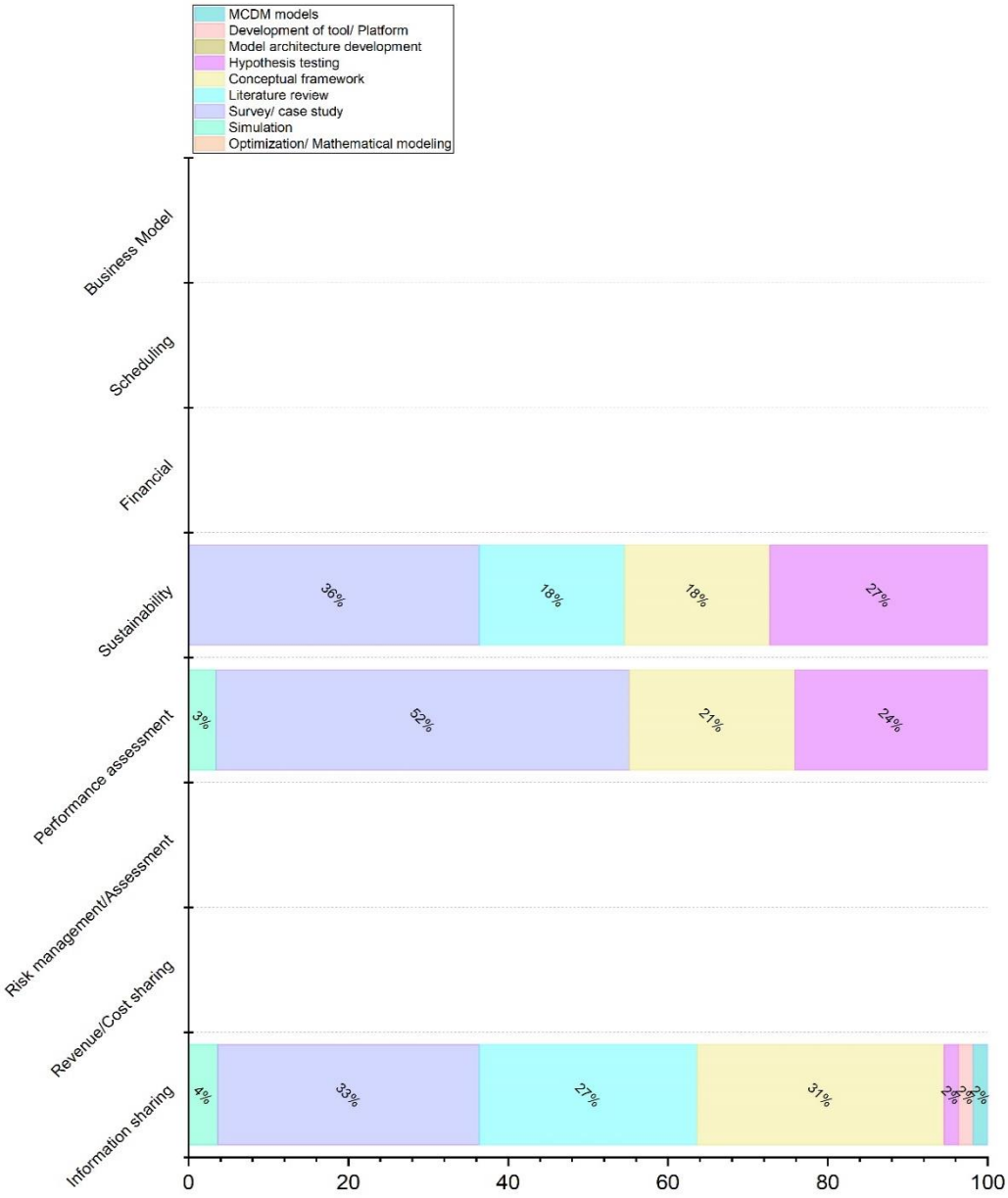


Figure 25 Analysis of SC issues in relation to the applied methodologies in Lean DSC

In conclusion, Table (4) describes the main identified gaps and trends in literature about Lean DSC, in order to provide a big picture for both academicians and practitioners in this field.

Totally, to mention some concluding points for comparing the two parts of these SLR, it seems that the Manufacturing is one of the most studied individual processes when dealing with both DSC and Lean DSC. Moreover, in both the parts sustainability issues have been referred as one of the highly studied topics. In addition, at this step of the development of the application of Industry 4.0 technologies to SCs, the most popular study methods applied are surveys and case studies. Furthermore, CC, BDA, and IoT have been identified as the most prevalent technologies implemented in combination with the other ones. It can imply the pivotal role of applying these technologies as the main pillars of constructing both DSC and Lean DSC.

Aside from the previous points, the main gaps in the SLR parts are described in the following. In the both the parts the obtained results reveal a lack of research on individual SC processes, and mainly Procurement, Transportation, and Warehousing. Also, there is a lack of research about specific SC issues, such as Revenue/Cost-sharing, Risk management/Assessment, Scheduling, Business modeling, and Finance. Moreover, there are very few works applying MCDM methods, Development tools/Platform, and Simulation. It can arise from the need of these methods to use a large quantity of data or in-depth perceptions about Industry4.0 technologies and their effects on SC which are not completely available so far. Besides, SDV, UAV, R, and AI should be more integrated in SCs in future by more development and implementation of the other technologies. For instance, for integrating UAV (such as Drones) in the SC, companies need to have reliable information systems to share information by CC or in some cases to analyze the collected information by BDA. It is important to point out that BC has been seamlessly incorporated with other technologies in DSC. However, the findings from the SLR part on Lean DSC reveal that, due to the early stages of its development, BC needs further investigation on how to combine it with other technologies in accordance with the Lean principles.

Table 4 Identified trends and gaps from Lean DSC SLR

Perspectives	Trends	Gaps
Supply chain processes	• Manufacturing is the most analyzed process, both when Industry 4.0 as a general concept is addressed and when single digital technologies are debated. • IoT and Lean principles are studied in a wider range of SC processes than the other digital technologies.	• Few papers consider the effects of Lean and each Industry 4.0 technology on single SC processes, in particular Inventory Management and Customer Relationship. • None of the previous researches study the Lean DSC applied to Procurement, Transportation, Demand Forecasting, Marketing, and Pricing. • No papers study BC, AM, and CC in combination with Lean principles in single processes.
Supply chain associated issues	• Papers about Lean DSC mainly focus on the influence of digital technologies on information sharing. • IoT is the most frequently considered individual technology to be studied together with Lean principles in order to address SC issues. • Sustainability and performance assessment/measurement are among the emerging issues to be addressed in Lean DSC.	• A limited number of studies analyze the impacts of Lean and each single Industry 4.0 technology on SC operational and organizational issues. • Scarce investigation of the relevant advantages of applying Lean and digital solutions to revenue/cost-sharing, risk management/assessment, scheduling, business modeling, and finance in SCs. • No work addressing the relationship between IoT and sustainability issues in the realm of Lean DSC. • AM is just discussed in relation to sustainability and needs to be further developed in the other SC issues considered in the present research.
Applied methodologies	• Surveys and case studies are the most applied methodologies to Lean DSC. • Most of the works applying the literature review approach address Industry 4.0 as a general concept. • IoT is the most prevalent digital technology studied by simulation approaches.	• No papers apply optimization and architecture development to Lean DSC. • Literature reviews rarely analyze single digital technologies and no works focus on CC, IoT, BDA, BC. • There are few applications of MCDM methods, as well as digital platforms to Lean DSC management.
Combination of digital technologies	• IoT, BDA, CC, and AM are frequently applied to SCs together. • CC is the digital technology most often combined with the other ones.	• BC needs to be combined with the other digital technologies in Lean DSC. • SDV, UAV, R, and AI have poor connections with the other digital technologies in the Lean SCM field.

3.6 Conclusion and identifying the gaps addressed by the present research

According to the results obtained from the previous Sections 3.6.2 and 3.6.4, the present section focuses on warehouses as a part of the current research gaps in the field of Lean and Industry4.0 technologies applied to SCs. Warehouses are essential components of modern SC because of their buffering function against fluctuations in supply and demand (Gu et al., 2007). However, as mentioned above, quite few studies consider the Lean perspective to eliminate wastes as non-value-added activities in warehouses (Gu et al., 2010; B. Shah & Khanzode, 2017). In fact, most of the previous research investigates Lean at the operational level in the manufacturing process and neglects its benefits on the whole SC. Nonetheless, due to the immediate connection of warehouse activities with the other SC processes, such as Source and Deliver, any warehouse improvement can also directly enhance the performance of the other SC parts.

Moreover, applying digital technologies to SCs is still in its infant stage (Mahdavisharif et al., 2022). However, there are huge possibilities in using them also in warehouse to reduce waste. The use of BDA, for instance, can boost both the efficiency of storage and the productivity of picking by analyzing storage and receiving orders data to optimize the decisions according to the defined criteria. Additionally, utilizing IoT to collect real-time data and track shipments might help reduce the amount of time spent waiting for products in the warehouse. Moreover, using IoT in warehousing has the potential to have a substantial impact since it can be used to track several warehouse operations in real time and reduce the need for human error (Mostafa et al., 2019). In fact, Industry 4.0 technologies are able to support warehouse operations, including picking and transporting items, as well as conveying the associated information. Drones, just to mention another digital technology, have the capability of picking items from warehouses and delivering them to border areas (Yudhistyra et al., 2020).

The discussion up to this point has shown that it is essential to investigate the effects of Industry 4.0 technologies and Lean principles on warehouses in connection with Source and Deliver processes. Therefore, it is critical to figure out how Industry4.0 should be integrated in a Lean approach in the SC processes of a company linked to warehouses. In fact, this issue has been mentioned as one the main aim of the present research in RQ1 and RQ2.

To this end, constructing a framework can result in obtaining the outcomes that can be more directly implemented compared to applying other popular methods such as surveys. Indeed, survey as an investigation method gives rise to high level and general results about the ways to real implementation of the obtained results. Therefore, the outcome from survey is not immediately exploitable for real world companies.

However, according to the performed SLR, in building frameworks for the DSC, researchers mainly provide conceptual frameworks that are based on the previous literature to describe the benefits of digital technologies. In this regard, (Büyüközkan & Göçer, 2018) construct a framework based on the benefits and

challenges of the DSC out of a SLR. In this field other contributions address the barriers in adopting Industry 4.0 technologies in SCM. For example, (Kouhizadeh et al., 2021) conduct a research to identify and prioritize the barriers in the BC application. They consider the Technology, Organization, and Environment (TOE) and the Force Field theories as the main pillars for constructing their framework. Additionally, some proposed frameworks take a descriptive attitude. In this regard, (Treiblmaier, 2018) figures out the possible impacts of BC on SCs by developing a descriptive framework based on four different theories, namely Principal Agent Theory (PAT), Transaction Cost Analysis (TCA), Resource Based View (RBV), and Network Theory (NT). Nonetheless, conceptual frameworks are still too high level to assist practitioners in constructing applicable roadmaps for DSC.

(Büyüközkan & Göçer, 2018) mention the lack of frameworks constructed according to real case studies as one of the main shortcomings of the present academic research. In aiming to achieve a practical framework for DSC deployment, some of the later works investigate case studies (Tan et al., 2020). (Kouhizadeh et al., 2021) identify the barriers for BC adoption through a qualitative case study moving steps from evidence out of previous literature and then relying on experts' judgments by selected academicians and practitioners. They did not focus on showing BC benefits for alleviating real issues in case studies. Moreover, (Sternberg et al., 2021) conduct a case study for constructing a framework for identifying pros and cons of the BC adoption in SC. To this end, they develop discussions with employees of selected companies. Therefore, they also do not provide a framework for real implementation of Industry 4.0 technologies in SCs. In addition, some of the previous studies, after constructing a framework based on literature, test it in different case studies (Zaki et al., 2019). Nevertheless, their investigation is not enough in depth since they just usually rely on some interviews with managers.

As a result, the missing point here is constructing and organizing a framework according to the real observations from the SC processes of companies.

In addition, the majority of the works just develop frameworks for a limited number of single digital technologies (Büyüközkan & Göçer, 2018). (Kouhizadeh et al., 2021; Sternberg et al., 2021) refer to SC frameworks just by considering BC as the applicable technology, without taking into account the facilitating role of the other technologies to overcome the barriers in the BC adoption. For instance, (Sternberg et al., 2021) mention the time and effort needed to scan and /type as one of the main negative factors influencing the BC adoption. Nevertheless, this can be alleviated by obtaining the input information to be sent by IoT devices that need less effort compared to the conventional methods like using barcode readers (Mostafa et al., 2019).

Last but not least, the majority of the previously mentioned research does not evaluate the effects of Lean Manufacturing on developing the frameworks (Büyüközkan & Göçer, 2018). There are some works in this realm; however, most of the frameworks are organized based on just the manufacturing process rather than the other SC processes (Mahdavisharif et al., 2022). Furthermore, they address Lean tools in connection with different Industry 4.0 technologies (Ciano et al.,

2021). Nonetheless, the missing point is focusing on the primary goal of Lean Manufacturing, namely removing non-value-added activities from different SC processes. Thus, it becomes essential to concentrate on investigating the processes by the lens of removing wastes as non-value-added activities through the application of Industry 4.0 technologies.

Therefore, the final goal of this research to construct a tool for designing strategies in order to remove wastes in internal SC processes connected to the warehouse by considering the benefits of Industry 4.0. This is accomplished through an adaptable framework integrating the Lean approach and a number of different digital technologies, built based on real SC processes and by using MCDM methods. In fact, using MCDM methods can offer a decision support system to make the proposed framework for waste identification and removal in a practical way. In this regard, integrating MCDM method into the proposed theoretical framework out of the real case studies can provide a practical decision support tool for the practitioners for defining their main path for reducing waste by implementing Industy4.0 technologies based on their specific circumstances.

Chapter 4

Developing a new framework for Lean DSC

The main objective of this chapter is to develop a reference framework for applying digital technologies within a Lean Manufacturing approach to either reduce or eliminate wastes in the main processes of an internal SC, namely procurement and delivery as the logistics processes in relation to the warehouse. The framework, whose structure is built based on past research, will be tested through case studies in the next chapters (chapters 5 to 8).

In the present chapter the fundamental elements and techniques for building the framework are outlined in great detail. Additionally, by presenting evidence from earlier publications, the primary rationales for choosing the underpinning tools and methodologies are argued.

Based on (Harrison et al., 2011), the main steps for constructing this framework are as follows and will be discussed in the next sections :

1. Developing process mapping
2. Waste identification with Lean principles
3. Investigating waste root causes
4. Suggesting improvement solutions based on digital technologies.

4.1 Developing process mapping

In accordance with (Gunawan et al., 2019), process mapping is a method for documenting the present state of the processes of a system based on the interconnections between activities, people, data, and objects .

As a direct result of using this method, flow charts that illustrate the sequence in which the various parts of the process must be performed will be generated (Wincewicz-Bosy et al., 2022). By applying the mentioned method, it might be easier to improve and restructure company processes (Gunawan et al., 2019). As a result, it can be helpful in establishing a visual overview of the current process and make it much simpler to identify activities that do not add value, with the goal of either eliminating or reducing them. As a matter of fact, an in-depth process map is essential for gaining a comprehensive understanding of the procedure and pinpointing areas in need of more investigation (Gutierrez-Gutierrez et al., 2016).

Another possible method instead of process mapping can be applying Value Stream Mapping (VSM). However, there is a substantial difference between these

two methods laying in their level of focus. To be more specific, the methodology of process mapping is applicable without focusing on specific products in the company and its main goal is analyzing different steps of company processes in general. VSM, on the other hand, concentrates its attention almost entirely on a particular product and its associated processes to scrutinize. To sum up, despite the difference in the two methods, the goal, which is to reduce waste whenever possible, almost always stays the same (Ariffien et al., 2021). In fact, process mapping might be considered as the first step in implementing VSM. To be more specific, VSM is made up of three distinct parts: a process map (Process Mapping), a timeline map (Timeline), and an information flow map (Information Flow) (Ariffien et al., 2021). Therefore, since VSM is mostly time-based (Gutierrez-Gutierrez et al., 2016) for studying a specific product, in the current work process mapping is applied, in order to provide a more comprehensive picture of SC processes in companies without focusing on time and specific products.

When constructing a process mapping, one of the main prerequisites is identifying the different activities in each process. To this end, the Supply Chain Operation Reference (SCOR) model can facilitate identifying the main activities in a standard structure. This model facilitates constructing process mapping in order to make it more adaptable as a generalizable model for different case studies. In fact, SCOR is a well-known model among both academicians and practitioners in the field of SC (Millet et al., 2009). The SCOR model conducts an analysis of the SC on each of the following four levels, namely Major processes, Process categories, Process elements, Improvement tools/activities (Figure (26) (APICS, 2017)).

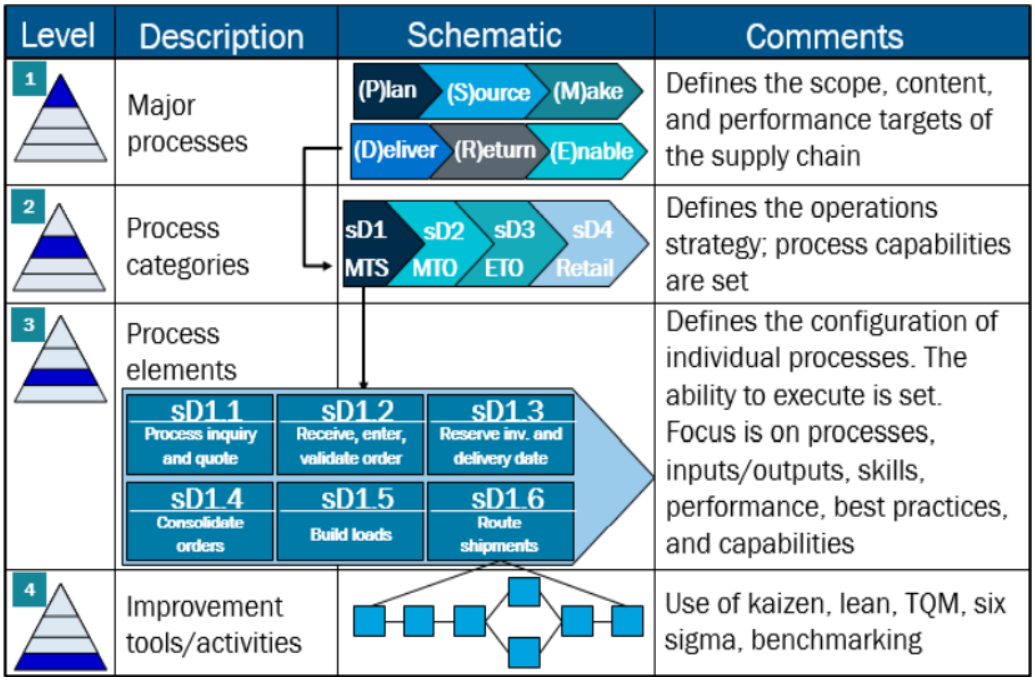


Figure 26 Different levels of SCOR model(APICS, 2017)

At the basic level of the model, the SC scope is described as being composed of the following six major processes: Plan, Source, Make, Deliver, Return, and Enable (APICS, 2017). A brief explanation of these processes are mentioned in Table (5).

Table 5 Description of processes in SCOR model

SCOR process	Description
Plan	The Plan is a component of the SC process for organizing operations, which includes defining the requirements for activities, collecting information about resource availability, and balancing them in order to respond properly to demands (APICS, 2017).
Source	The Source process includes activities such as placing orders for products, scheduling their delivery, and receiving them from suppliers. In addition, the Source process comprises validation, storage of incoming products, and supplier invoice acceptance (APICS, 2017).
Make	The Make procedure encompasses all company actions involved with material transformations at various stages. It encompasses not just "production" or "manufacturing," but also assembly, chemical processing, repair, remanufacturing, refurbishing, recycling, and maintenance, among the others (APICS, 2017).
Deliver	All the steps taken to make, update, and fulfill orders placed by customers could be found in the Deliver process. Orders are received, verified, created, scheduled for delivery, picked, packed, and sent, and finally invoiced to the consumer as part of the Deliver process (APICS, 2017).
Return	The Return process is the set of activities that occur during the reversal flow of a product. The return process consists of assessing the need to return, deciding on a disposition, scheduling the return and shipment, and receiving the returned products (APICS, 2017).
Enable	The Enabling processes detail what must be done for the effective SCM. Business rule management, data management, resource management, facility management, contract management, supply chain network management, regulatory compliance management, risk management, and supply chain procurement are all examples of Enable processes (APICS, 2017).

At the second level, the operations strategy, which may be "Make to Stock," "Make to Order," "Engineer to Order," and "Retail," is defined. The definition of each operations strategy is provided in Table (6).

Table 6 Description of operations strategy in SCOR model

Operations strategy	Description
Make to Stock	The process of manufacturing or creating a product or service in order to add value to a deliverable. Make to Stock items are those that can be prepared in advance of receiving a customer order and are typically manufactured to a predetermined timetable in accordance with a demand prediction. Therefore, the intention is to send them as finished products based on customer demand (APICS, 2017).
Make to Order	When a product has a high price and many customization options, the Make to Order method is the best option. The high cost of holding raw materials, work in progress, and finished goods for high-tech products like automobiles, computers, and medical equipment inspired this strategy. To fulfill a customer's request to their exact specifications, a "Make to Order" approach is implemented (APICS, 2017).
Engineer to Order	Producing finished products to the exact requirements of customer is known as "Engineer to Order." In this strategy more time is needed to design and manufacture to meet the customer's special needs (APICS, 2017).
Retail	Deliver Retail products refers to the processes used to acquire, stock, and sell finished goods at a local shop. A retail store is a storefront with a point of sale (POS) system, whether staffed by humans or machines. At the store level, merchandising refers to the act of storing and refilling products in allocated storage areas to boost sales (APICS, 2017).

At the third level, the configuration of each process is identified by concentrating on its inputs and outputs. In fact, third level involves more in-depth analysis. Supply chain planning, material sourcing, product fabrication, shipment, customer support, and returns processing are all examples of third level processes. These first three levels of the SCOR model are not industry specific.

In order to reach the fourth level, namely Improvement tools/activities, companies must adapt the previous levels to their actual circumstances in order to accomplish the improvements that are stated in the final level of the SCOR model (APICS, 2017). In fact, details on the appropriate order of activities inside a process would be described in the fourth level. Therefore, fourth level procedures are usually unique to a given industry, products, geographic region, or technological infrastructure. Every business that decides to use SCOR to enhance its SC will need to take the model at least to Level 4.

Figure (27) depicts the levels and the associated items of the SCOR model adopted for constructing process mapping in the present work according to the main assumptions described in the following.

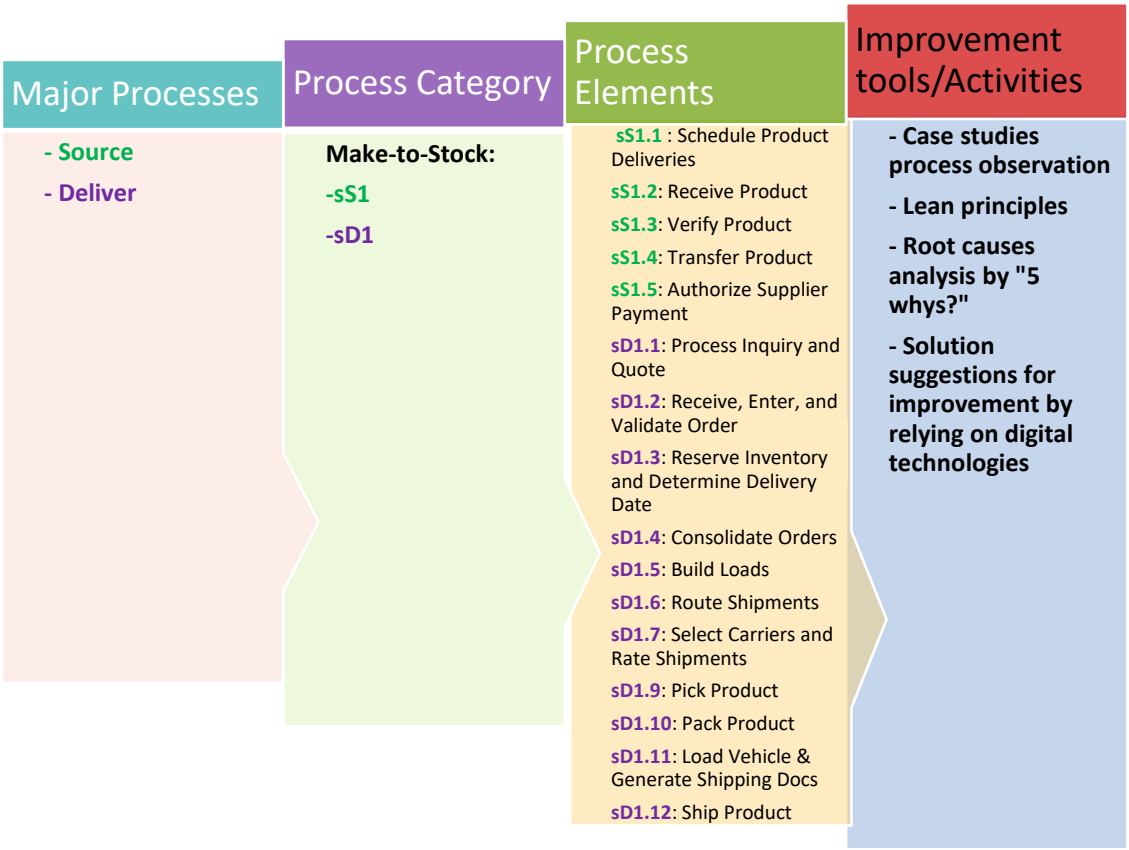


Figure 27 Main levels and elements of SCOR model for process mapping

As discussed in Section 3.7 the main focus of this study is the processes connected to warehouses in the internal SC of a company. To this end, the standard SCOR processes Source and Deliver are considered thanks to fact that they have direct relations with the raw materials and finished products warehouses (see Figure (28)). Moreover, a Make-to-Stock strategy is addressed here as the reference process category, since it represents one of the most applied SC strategies in manufacturing companies (Kaminsky & Kaya, 2009). Therefore, this characteristic contributes to making it easier to adjust the proposed framework to real case studies. Afterward, the appropriate process elements for both Source and Deliver processes are selected according to the (APICS, 2017). To this end, in the Source process for Make-to-Stock (sS1), all the mentioned elements are addressed according to the (APICS, 2017) since these elements are totally inside the main scope of this research about warehousing in SCM. Also, for the Deliver process of the Make-to-Stock (sD1) all the associated elements, are selected, except those are out of the scope of this research about warehousing. For instance, sD1.13 (Receive and Verify) and sD1.14 (Install Product) have not been considered in the present work since they do not have a direct relation to the warehouse logistics activities in Deliver process.

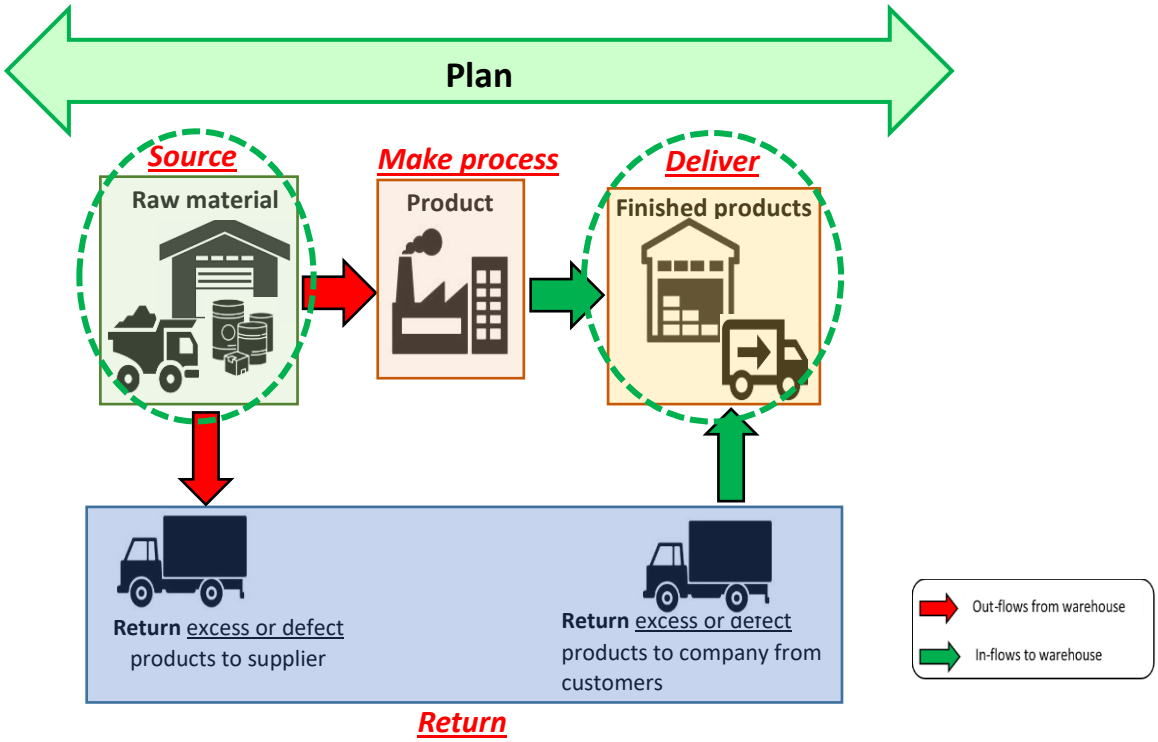


Figure 28 Major processes of SCOR model in relation to warehouses

In the next step, for developing the fourth level of the SCOR model any of the case studies deeply investigated in both Bachelor and Master of Science to extract the main sequence for detail activities for selected elements in third level. The mentioned works cover a wide range of detailed mappings and analyses of procurement, warehouse, and delivery processes of companies in different sectors, including for example Automotive and Food (Colamaio Claudia, 2018; Fanto' Federico, 2018; Fontana Federico, 2018; Lucca Elisa, 2018; Oliva Francesca, 2020; Tafuri Corrado, 2020). According to an in-depth investigation of them, the proposed framework has been designed according to the following steps:

1. Selecting the main manufacturing industries as the main scope of the present research and excluding the service industries
2. Selecting the related Master and Bachelor thesis containing the process mapping according to the real case studies
3. Carefully investigating different Source and Deliver process for each thesis.
4. Considering the most common activities as mentioned in the majority of investigated theses.
5. Developing new framework based on the SCOR model and most common activities for each Source and Deliver process.

This framework has been revised many times with a panel of three academic SC experts to be sure about addressing all the relevant activities in enough detail for each element in both Source and Deliver processes. Moreover, here the cross functional approach has been adopted for developing the flowcharts. Therefore,

activities are organized in different columns according to process elements, also associated departments are depicted for each process in the different rows. As a result, Figures (30) and (31) depict the outcomes of process mapping for Source and Deliver processes respectively. As mentioned before and also according to Figure (26), all of the levels have been developed by following the SCOR model () as the main resource. It is clear until third level also in figure (27). However, as discussed before for developing the fourth level for exploring the details of sequence for each activity we used the case studies in Master and Bachelor theses. As a result, It is possible to use the developed framework as a starting point for further customization in the following stage with respect to each case study.

Moreover, Figure (29) Depicts the legend for guiding the readers about different symbols and madules that have been used for drawing the framework.

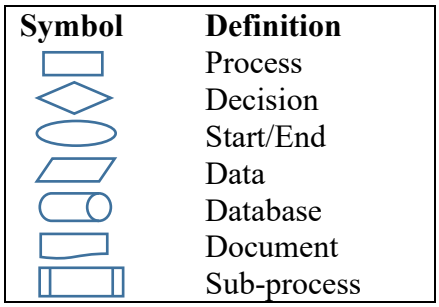


Figure 29 Definition of different shapes used in developing process mappings

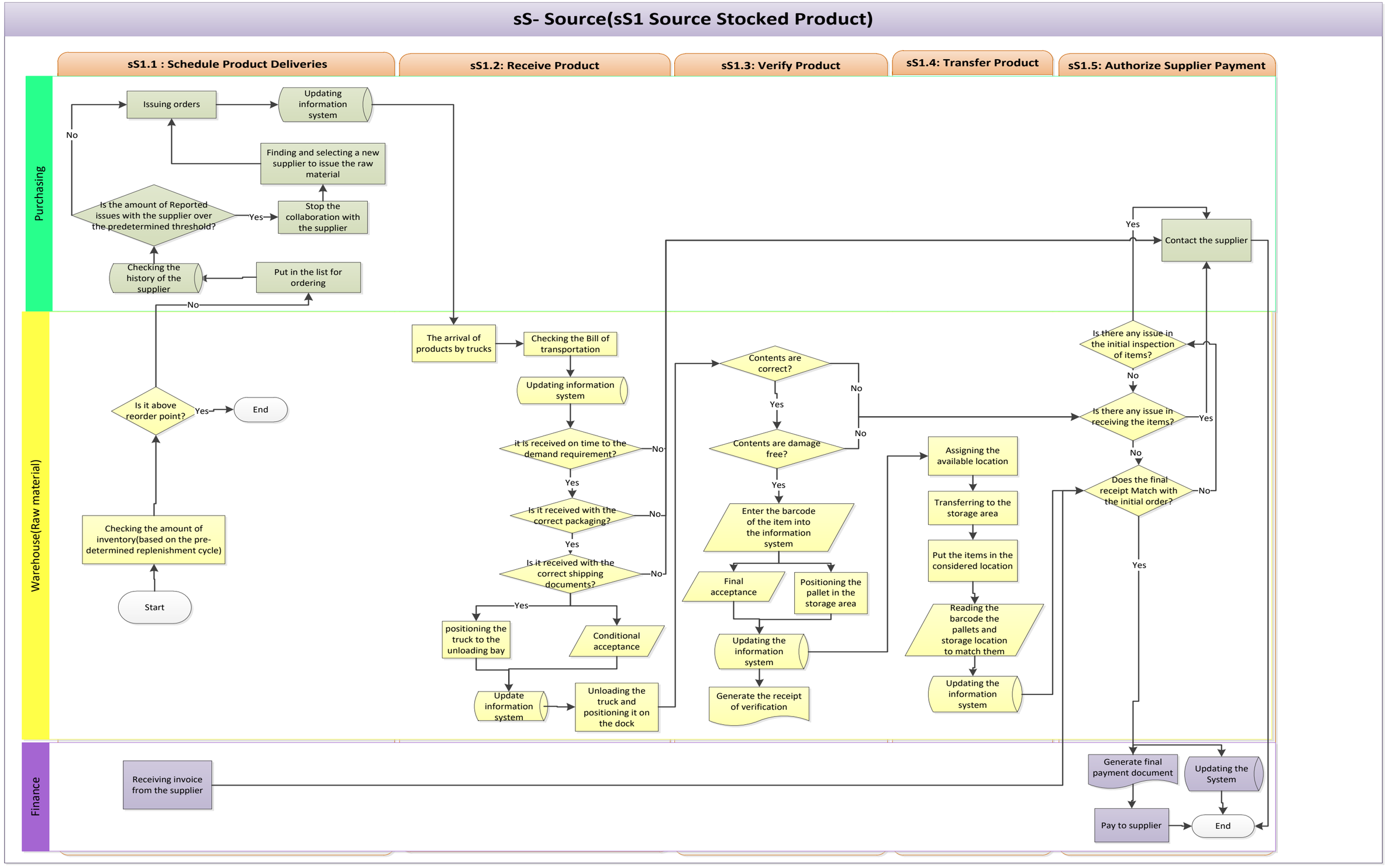


Figure 30 Process mapping of Source process

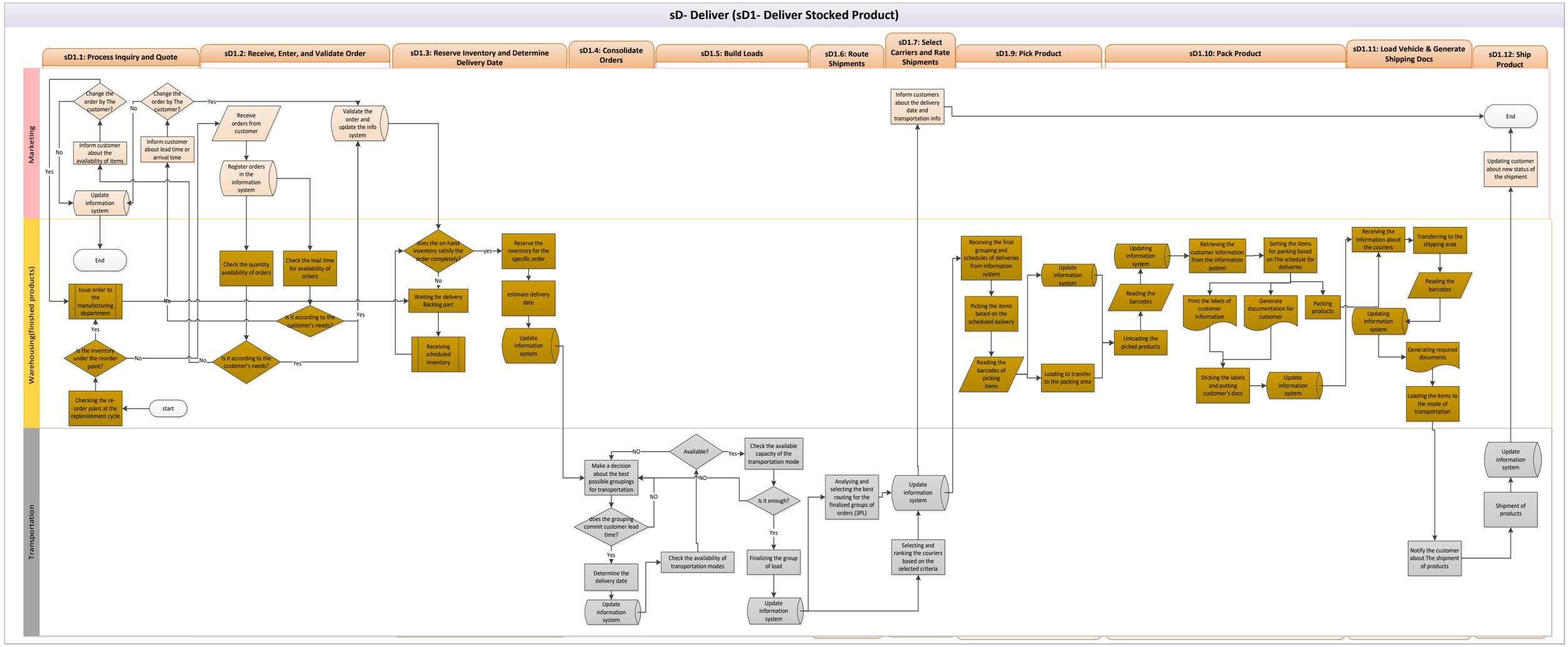


Figure 31 Process mapping of Deliver process

4.2 Waste identification with Lean principles

After obtaining a detailed process mapping as described in Section 4.1, the activities should be analyzed in order to identify the wastes that do not add value to the considered SC processes. In fact, (Gutierrez-Gutierrez et al., 2016) mention that process mapping can assist companies in identifying potential areas for improvement. To this end, Lean principles can be helpful (Ariffien et al., 2021).

Figure (32) presents a short definition of each waste type tailored to the SC processes addressed in this work. Additionally, it describes some possible associated consequences.

The outcomes of the process mapping in the previous part of the framework development are scrutinized in order to identify the potential non-value-added activities in relation to each waste. In his

Regarding, Tables (7) and (8) describe the definition of the activities containing one or more than one type of the wastes in Source and Deliver processes. Afterward, according to the literature references (Arunagiri & Gnanavelbabu, 2014; Novack & Simco, 1991; Tahboub et al., 2019) the potential wastes related to the previously identified activities have been described in Tables (9) and (10). It is worth mentioning that each activity can include more than one type of waste according to the Lean principles. As previously stated, initiatives in this area have been outlined based on prior case studies in the academy. Furthermore, in the first stage, the related wastes of various activities were recognized deductively based on the author's understanding. Following that, at the weekly meeting of the author and related supervisors, each of the recommended wastes was addressed in further depth to assess with SCM specialists in the academy, considering their extensive expertise in conducting various case studies in this sector.



Figure 32 Lean waste description and possible consequences

Tables (7-10) only show a portion of the framework as an example of how the framework should be created. However, the comprehensive implementation of the framework requires the inclusion of real-world case studies from the industry. As a result, the established framework in this chapter will be considered the primary source of inspiration for the practical frameworks in the next chapter, which will be customized.

Table 7 Definition of Source process activities prone to Lean wastes

	Definition of activities	sS- Source(sS1 Source Stocked Product)
	Activity	**Explanation**
Procurement	**Issuing orders**	Choosing and contacting the supplier to order the required quantity of inventory. It is also the responsibility of procurement staff to negotiate with suppliers on several aspects such as pricing and product delivery time.
	Checking the history of the supplier	The process of reviewing and evaluating a supplier's performance in the organization based on predefined criteria
	Finding and selecting new supplier to issue the raw material	The process of looking for new suppliers in order to place orders for raw materials for manufacturing
	Contact with supplier about received products	When problems are identified with items that have already been received, the procurement team is responsible for determining the best way to get in touch with the supplier and negotiate a resolution before making any final decisions.
Warehouse (raw material)	**Checking the amount of inventory**	The action of keeping track of and calculating stock levels. This method also includes assessing the remaining shelf life and other physical parameters for each item. Warehouse staff can use this information to decide whether or not to place an order for replenishment of inventory for the following period.
	Checking the Bill of transportation	This task involves identifying the kind and number of products received based on the transportation documents. Before unloading the shipment into the warehouse, it must be compared to the issued orders to guarantee that the proper products are received.
	Conditional acceptance	After reviewing the basic specifications, such as the bill of transportation, this is the action that allows the truck to be positioned at the unloading bay.
	Generate the receipt of verification	Generating and submitting the supplier's verification receipt for receiving the correct products.
	Assigning the available location	Assessment of the most appropriate location within the warehouse area for the storage of the items that have been received.
	Reading the barcode of the pallets and storage location to match them	Before placing the pallet in its ultimate place for storage, it is necessary to first read the barcode of the pallet and the storage site.
Financial	**Recieving invoice from supplier**	Receiving a copy of the invoice sent by the supplier for the goods that have been delivered to the warehouse.
	Generate final payment document	Issuing the final receipt that should be paid to the supplier in accordance with the agreed contract.
	Pay to supplier	Sending the money to the supplier in accordance with the specifications and the timeframe that were previously agreed upon.

Table 8 Definition of Deliver process activities prone to Lean wastes

	Definition of activities	sD- Deliver (sD1- Deliver Stocked Product)
	Activity	**Explanation**
Marketing	**Inform customer about availability of items or changing the arrival time**	Communication between the marketing department and the consumer regarding any potential changes in order availability or delivery. schedule.
	Register orders in the information system	The process of registering the received orders from the customers to the information system
	Inform customers about the delivery date and transportation information	The activity of communicating with the consumer regarding the product's arrival date
	Updating customer about new status of the shipment	Provide the customer with timely updates on the shipment's current status or any adjustments.
warehouse	**Issue order to manufacturing department**	Contact the manufacturing department to determine the quantity of inventory required to replenish the finished product warehouse.
	Waiting for delivery backlog part	In the situation that there are insufficient available items to fulfill customer orders, the warehouse of finished products must wait the arrival of new products.
	Generate documentations for customer	Documentation must be provided in accordance with the terms of the agreement with the customer and shipped alongside the items.
Transportation	**Make decision about best possible groupings for transportation**	Determining the grouping of shipments to the various consumers
	Analysing and selecting the best routing for the finalized groups of orders (3PL)	Transportation planning refers to the processes involved in selecting the best route to deliver a product to a customer (s)
	Selecting and ranking the couriers based on the selected criteria	The process of assessing potential couriers to deliver a product to a consumer (s)
	Notify the customer about shipment of products	Provide the customer with up-to-date information on the shipment's status or any modifications.

Table 9 Identified activities and related wastes for Source process

	Identifying related wastes for each activity	sS- Source(sS1 Source Stocked Product)						
	Activity	Motion	inventory	Over processing	Over production	transportation	wait	defects
Procurement	**Issuing orders**					To communicate with the warehouse and finalize the quantity of order, the procurement personnel must make some physical efforts, such as going directly to discuss or conducting a meeting.	Waiting waste occurs when the procurement department's personnel is waiting for a response from the associated supplier in to complete the purchase.	
	Checking the history of the supplier			Checking the performance of suppliers on a regular basis and collecting all relevant information for the inquiry may be a time-consuming operation for procurement staff.			If some new orders for raw materials are received during the performance review, they should wait to approve and allocate to the new or prior supplier after the evaluation is completed.	Due to insufficient, inaccurate, or unavailable data to conduct the inquiry, the process of evaluating the performance of suppliers may result in incorrect decisions.
	Finding and selecting new supplier to issue the raw material			Finding new suppliers and building trusting relationships with them takes effort. It may also take some time to acquire data on these new suppliers in order to evaluate them.				The process of acquiring information on prospective suppliers may result in decisions based on unreliable information. This may lead to defects in the company's future production.
	Contact with supplier about received products	Procurement staff should visit suppliers or make other direct attempts to get the requisite return authorization from management if there are problems with the received inventory.		It takes time for the procurement personnel to call the supplier and fix the difficulties each time.				
Warehouse (raw material)	**Checking the amount of inventory**	The related operations for monitoring the inventory status need physical effort from warehouse staff to count and check.		Inventory counts, physical checks, and other similar operations performed by warehouse personnel might result in unnecessary extra work with no value to the customer.				The activity of counting and inspecting inventories might cause some product damage.
	Checking the Bill of transportation	Warehouse personnel must stop the truck at the unloading site in order to get the transportation bill. Then, compare the documentation with the orders that have been issued. Therefore, completing this activity requires gathering and reviewing the paperwork.		Staff reviewing and evaluating paperwork in the manual procedure is a repetitive operation for each arriving truck.		The warehouse personnel must collect the necessary documentation from the procurement department.	The warehouse employees should wait for the truck to stopped in the proper location before asking the driver for the bill of lading. The items should also be held until they are eventually accepted as delivered by the company.	The process of evaluating and comparing papers may result in workers accepting incorrect items. (This can be caused by human mistake during the inspection process or by insufficient documentation from the supplier or procurement department.)
	Conditional acceptance			This step may need additional time to accept the received items with no added value for the consumer.			After unloading, the products should be inspected again and delivered as accepted.	
	Generate the receipt of verification.						The documentation cannot be delivered until all preceding steps have completed and confirmed the product conditions.	
	Assigning the available location	The warehouse employees should walk around the warehouse looking for potential places and evaluating them to determine the optimal location. The employees must put physical effort during this procedure.						
	Reading the barcode of the pallets and storage location to match them	The warehouse personnel must move in order to scan and match these two barcodes.		Reading each barcode one by one for each box takes time for the warehouse personnel.			Before reaching the final destination, each pallet should wait for the warehouse employees to match the barcodes.	
Financial	**Recieving invoice from supplier**						If the procedure is not quick and efficient, the finance staff will have to wait a long time to obtain the associated invoice from the supplier.	
	Generate final payment document			There is unnecessary communication with multiple stages of the product verification process to complete the payment paperwork.		Collecting the appropriate paperwork to complete the payment necessitates meeting with other workers to collect them and determining the amount that should be paid based on the condition of the goods obtained.	This document should be validated by all of the preceding steps and describe the payment-related concerns that should be included in the payment document. Therefore, time is required to gather all confirmations.	
	Pay to supplier			Before making payments to the supplier, it must review all necessary documentation.			This job should be held until the responsible person in the finance department approves the payment at the specified or appropriate period.	

Table 10 Potential identified activities and related Lean wastes for Deliver process

	Identifying related wastes for each activity			sD- Deliver (sD1- Deliver Stocked Product)				
	Activity	Motion	inventory	Over processing	Over production	transportation	wait	defects
Marketing	**Inform customer about availability of items or changing the arrival time**			The time-consuming procedure of informing the consumer of any potential modifications to the order			For every order, the request coming from the marketing department should be approved by the warehouse. As a result, the marketing department needs to wait for the warehouse to provide the definitive information about the time frame and product availability before informing the customer and completing the order for each customer.	
	Register orders in the info system			After finishing the orders, the personnel must manually enter each of the customer orders into the system one by one.				The process of entering consumer orders into the information system is susceptible to human mistake. Consequently, this might lead to errors in the final order amount, type, delivery time, or other customer information provided by the marketing department's personnel.
	Inform customers about the delivery date and transportation info			Marketing employees should have interacted with other departments such as warehouse and transportation to inform the customer about the most recent status of the order delivery.				
	Updating customer about new status of the shipment			Marketing employees should have interacted with other departments such as warehouse and transportation to inform the customer about the most recent status of the order delivery.				
Warehouse (Finished products)	**Issue order to manufacturing department**			Communication with the manufacturing department to request more inventory to fill the warehouse of finished items takes time.				
	Waiting for delivery Backlog part						To fulfill the customer's order, the warehouse should wait for the items to arrive from the manufacturing department.	
	Generate documentations for customer			Staff should prepare and print all relevant documentation for each order delivery based on the needs of the customer, which may be a repetitive operation.				
Transportation	**Make decision about best possible groupings for transportation**			It is a time-consuming process to choose the appropriate groupings for each of the arriving orders to ship.				
	Analysing and selecting the best routing for the finalized groups of orders (3PL)			The time-consuming procedure for each delivery of analyzing potential routes and making the optimal selection for each delivery based on its unique needs			Customer orders should be held until the final transportation plan for delivery is received.	
	Selecting and ranking the couriers based on the selected criteria							Selecting the incorrect carrier for product delivery may result in product problems during shipment to the customer's delivery destination.
	Notify the customer about shipment of products						If the system does not utilize real-time information, the customer must wait for the goods to be delivered or for any possible modifications to the delivery of orders.	

4.3 Investigating waste root causes

One of the main aims of the framework here under development is improving the current state of the studied SC processes. Thus, after identifying wastes contributing to non-value-added activities, the next step in the proposed framework is recognizing the root causes for these wastes.

To this end, the 5Whys analysis is a useful Lean tool for exploring the chain of reasons for a problem leading to find its primary causes (Amiri Ara et al., 2022). Inquiries that begin with "why" are repeated multiple times as part of the 5Whys, with the next question formulated based on the response to the previous one. The series of inquiries is aimed to get to the root reason for a certain issue (Myszewski, 2013). In general, the underlying premise of this strategy is that the construction of a series of questions will encourage problem-oriented thinking by stimulating the human mind to engage in the investigation of an issue (Myszewski, 2013).

The 5Whys approach is applied to each waste identified in the previous step of the framework in order to explore its possible root causes separately.

Table (11) presents some examples of the 5Whys application to the wastes previously identified in Section 4.2. These examples clarify the method for conducting the sequence of the questions as well as the implementation of the present step of the framework. Hence, the final identified root cause can be obtained by answering the Whys. The main point here is finding the reasonable root for the problem and there is not any specific rule in the number of iterations for asking Whys. In fact, “5” is just referred to the recommended number of Whys for doing this procedure in general. Therefore, there are no strict rules to ask “why” exactly 5 times. It could be dependent on the precision of the answer to each “why” and other factors, such as who is answering the questions, based on what source of knowledge, and the complexity and level of details in defining the associated activity and answers. As a result of applying the 5Whys method, the following Table (11) shows the identified root causes highlighted in red color.

Table 11 Examples of applying 5Whys in Deliver process to find root causes of wastes

	Activity	Generate documentations for customer	Make decision about best possible groupings for transportation
Over Processing	***Waste description***	*Staff should prepare and print all of the related documents for each order delivery based on the customer need, which could be a repetitive task*	*It is a time-consuming procedure to figure out the best groups for each of the arrival orders to ship.*
	1st why?	Because the company information management system does not allow customers to access share area with company for requesting online documentation	Because this task should be done by the related person based on its experience and proficiency
	2nd why?	Because there is no secure and reliable way to share information with customers	Because there is no automatic tool for making best decision based on the available data
	3rd why?		Because the related data is not stored in appropriate way to access timely and reliable from info system.

4.4 Suggesting improvement solutions based on digital technologies

The main motivation for identifying the root causes of wastes is either removing or reducing it by proposing pertinent solutions. The present framework aims to integrate digital technologies in the Lean approach. Therefore, according to the obtained results out of the root cause analysis, the Industry 4.0 technologies that could be potentially applied are suggested in this step in order to alleviate waste.

To such an end, the advantages and disadvantages of each Industry 4.0 technology are addressed in relation to the nature of the analyzed activity and the associated waste, based on the outcomes of the comprehensive SLR conducted in Chapter 3. In fact, the author aims to identify the most effective digital technology, based on the thorough SRL analysis, to mitigate each waste by determining the ultimate root causes for each activity and their related waste. As previously stated in section 3.5.1, combining several Industry 4.0 technologies might be more useful than using a single technology. As a result, the author considers this benefit whenever it appears to be appropriate and useful to alleviate the associated wastes when suggesting Industry4.0 technologies.

To clarify the adopted procedure, Table (12) presents the two examples introduced in Section 4.3 with the associated suggested improvements according to the application of Industry 4.0 technologies.

Table 12 Example of suggested solutions for waste reduction of Deliver process based on Industry 4.0 technologies

	Why?	Generate documentations for customer	Make decision about best possible groupings for transportation
Over Processing	***Waste description***	*Staff should prepare and print all of the related documents for each order delivery based on the customer need, which could be a repetitive task*	*It is a time consuming procedure to figure out the best groups for each of the arrival orders to ship.*
	1st why?	Because the company information management system does not allow customers to access share area with company for requesting online documentation	Because this task should be done by the related person based on its experience and proficiency
	2nd why?	Because there is no secure and reliable way to share information with customers	Because there is no automatic tool for making best decision based on the available data
	Suggested technologies	CC, BC	BDA
	Benefits of **CC** for alleviating the waste and how it works	CC is able to provide an integrated system for sharing the relevant information with customers in a timely manner (Núñez-Merino et al., 2020). In this regard, the customers of the company are able to review and access all of the documents that have been agreed upon (Sahin et al., 2017)	
	Benefits of **BC** for alleviating the waste and how it works	BC can streamline the distribution and storage of documents regarding deliveries by making the information they provide and the related paperwork easily accessible to all the parties (Tsiulin et al., 2020)	
	Benefits of **BDA** for alleviating the waste and how it works		Grouping products based on all relevant criteria, including lead time, price and distance, is made easier by a BDA algorithm that provides probable delivery dates automatically. Because of this, there is no need for logistics workers to perform this activity on a daily basis (Yudhistyra et al., 2020).

Chapter 5

Applying the framework

The primary purpose of this chapter is to apply the framework proposed in chapter 4 to specific case studies. As a result, the content of this chapter presents a sketch of the suggested framework's structure in order to illustrate how different companies should customize it depending on their SC for implementation in real-world case studies. Hence, this chapter describes two practical cases drawn from the Automotive and Food industries. In the first part of this chapter (section 5.1), the rationale behind selecting these two industries to employ as case studies have been described. The framework is then applied by following the same technique outlined in Chapter 4, and final customized recommendations for improvement are made by suggesting technologies from Industry 4.0 for each case study.

5.1 Selecting sectors

Two companies, one in the Automotive industry and one in the Food industry, are selected as case studies to provide a complete application of the framework presented in Chapter 4. The following paragraphs will elaborate on why the Automotive and Food industries were selected as prime sectors for more investigation.

5.1.1 Automotive industry

Numerous jobs are generated by the Automotive industry, making it as one of the major sectors in the global economy (Münch et al., 2022). By the recent reports from European Commission, Automotive industries are responsible for around 7% of European Union (EU) Gross Domestic Product (GDP) [1] . Moreover, the Automotive industry is characterized by a dynamic nature, which is given by the intense competition and changing demands of its customers (Siems et al., 2021). In this regard, product offerings in the Automotive industry include a wide range of features (Siems et al., 2021) to increase and keep the market share of production companies. Hence, Automotive companies in order to increase their adaptability in the face of fluctuating market and to mitigate the impact of demand variations are increasingly contracting out "non-core" procedures to third-party suppliers (Keller Richter et al., 2016), although some recent insourcing attempts in this regard. It leads to shaping the Automotive industry as one of the most complex multi-tier SC

[1] https://single-market-economy.ec.europa.eu/sectors/automotive-industry_en

structures, and global geographical locations all over the world (Bennett & Klug, 2012). Hence, in complex SCs like Automotive, where suppliers provide 70-80% of the value added, it is not enough to only restructure internal processes by focusing on individual companies (Bennett & Klug, 2012). In fact, Lean Manufacturing, which has its roots in the TPS in Japan and is widely researched and applied in the Automotive sector, usually focused on internal processes of an individual company. However, Automotive companies in order to maintain and increase their competitive edge, should work toward establishing and maintaining long-term, mutually beneficial relationships with their suppliers (Habidin & Yusof, 2013). It suggests the need of adopting the Lean idea not only to improve an Automotive firm's internal processes, but also to widen and apply the concept to all the SC operations.

On the other hand, from the invention of the assembly line to the advent of the electric automobiles, the Automotive sector has experienced a number of notable breakthroughs throughout its history (Wankhede & Vinodh, 2022). Moreover, the Automotive industry is one of the most advanced industries in terms of embracing new technologies. Therefore, the implementation of Industry 4.0 brought about a significant increase in the number of opportunities available to this industrial sector in relation to production innovation (Wankhede & Vinodh, 2022) and also relationship among SC members. However, many Automotive companies have not investigated these game-changing improvements to the same extent as they might have (Wankhede & Vinodh, 2022).

5.1.2 Food industry

Food has a crucial role in the functioning of modern economies and society. In this regard, according to a European Commission report the Food industry obtained the first rank in producing jobs and value-added compared to the other manufacturing sectors in the EU. Over the past decade, exports of Food and drink from the EU have doubled to over €90 Billion, adding about €30 Billion to the region's export earnings [2]. Customers' demand in the Food market is always evolving. In this regard, the Food SC defines as a network of enterprises that collaborate to ensure the smooth and efficient movement of materials and information between each link in the chain, from farm to fork, so that consumers receive the highest quality Food at the most affordable price (Beske et al., 2014). In fact, to confirm that Food reaches consumers, a wide range of companies must collaborate, and this process has a substantial impact on the global economy and sustainable development (Palazzo & Vollero, 2021). Therefore, it implies the importance of enhancement of capabilities in this sector to quickly adjust plans for highest resource utilization (Beske et al., 2014). This can be achieved by removing non-value-added activities through the current activities in Food SC.

On the other hand, in the past few years, the Food industry in EU has been confronted with a decline in its competitiveness in comparison to other Food manufacturers throughout the world. This reduction may mostly be attributed to a

[2] https://ec.europa.eu/growth/sectors/food_en

slower development in labor productivity and value added. In fact, the performance of the EU Food SCs has been faced with several challenges that are related to a lack of visibility, B2B partnerships, a lack of attraction for competent employees, and low market integration across the various nations in EU[3].

From what has been stated so far, it is clear that Food companies, especially those located in the EU, need to prioritize the removal of non-value-added activities and overcome challenges associated with SC integration and enhanced visibility to achieve competitiveness. Therefore, the adoption of Lean concepts and the use of Industry 4.0 technologies in Food SCs presents a promising opportunity for resolving these issues.

5.2 Automotive company case study

The first case study is selected from the Automotive industry. That is a company located in the south of Spain in Jaèn as a city of Andalucia (Figure (33)). Due to confidentiality issues, it is not possible to disclose the name of the company. This company is a second-tier manufacturer for different automotive brands in the first tier such as Renault, Iveco, Volkswagen, Fiat etc. They fabricate metal automotive components such as structural components of a car such as chassis, body products in white, side doors, rear doors, etc. As a result of the company's involvement in every stage of the production process, its operations contain the whole value chain. The entire process, from press and die design through production and completion. Some of basic information about this automotive company has been provided in Table (13).

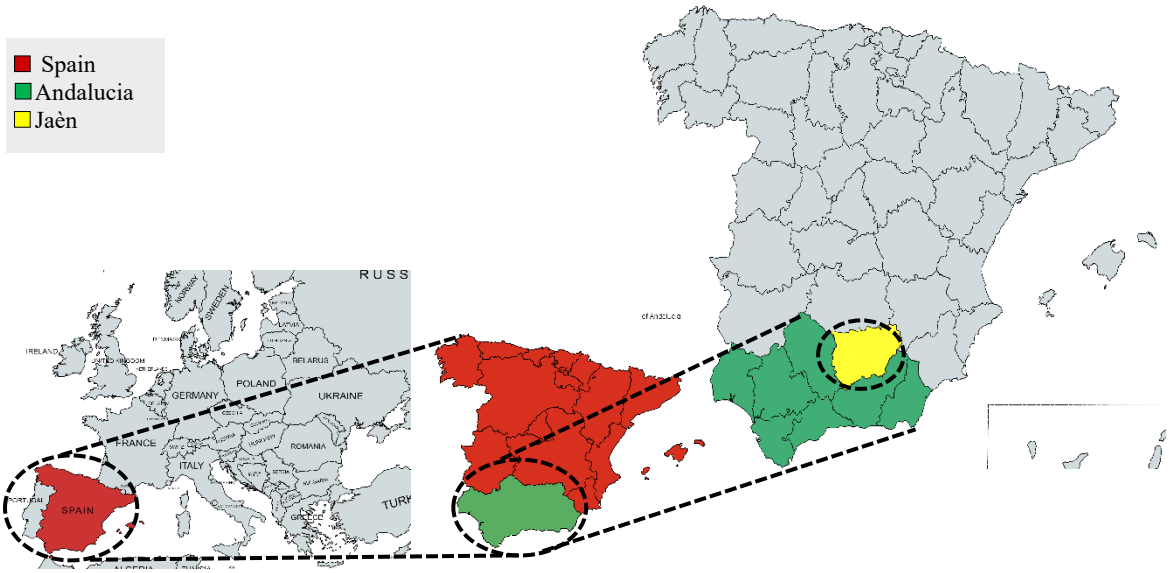


Figure 33 Geographical location of two case studies

[3] https://single-market-economy.ec.europa.eu/sectors/food-and-drink-industry_en

Table 13 Information of Automotive company

Information about Automotive company	
Establishment year	1999
Number of employees in different parts (production and non-production)	156
Total value of production (per year)	39.000.000,00€
Number of Suppliers	100
Number of B2B customers	62
Push or pull system of production	PULL
Average lead time for B2B customers	5 days
Factory area	27500 m2

5.2.1 Applying logistics process mapping in the Automotive company

Field observations from the Automotive company have been performed at this step to apply the process mapping approach discussed in section 4.1. To achieve such goal, more than 15 visits and 75 hours were spent on-site to gain an in-depth and thorough understanding of Source and Deliver processes in the company by direct observation and conversation with the relevant workers and managers. In addition, Figure (34) describes different steps for conducting this part in a more structured way to summarize it. The remaining components of the framework are depicted as boxes without detailed instructions, which will be expanded upon in the future sections.

To this end, in the first step a general visit has been held with one of the main managers of the Automotive company to introduce the project's primary goals and scope, as well as become familiar with the company processes.

Moreover, after this meeting the related employees for conducting the next interviews to receive more detailed information about each part of the focused process have been selected. Thus, as the first step to create the flowchart depicted in Figure (35) The following employees of the Source process and management team have been contacted individually for the purpose of having in-depth discussions on the various stages of Source process:

- Procurement manager
- Quality manager
- Logistics manager
- Scheduling manager
- Warehouse staff
- Financial Manager

Similarly, in developing Figure (36) For Deliver process of the Automotive company the following managers and staff have been contacted:

- Logistics manager
- Warehouse staff
- Marketing manager
- Logistics staff

In order to fine-tune process mapping, the next step is to provide each involved worker with a printed copy of the theoretical process mapping described in section

4.1. In this step, the employee receives a brief introduction to the project's goals and scope, outlining the basics role of interviewer, the expected contributions from interviews, the workflow's methods, and the next actions in the case study. Therefore, aside from the real process observation, with the help of relevant staff, the basic process mapping as outlined in chapter 4 was subsequently modified to the specific activities of the Automotive company across the whole Source and Deliver processes.

Each worker was questioned to answer inquiries about his or her duties and the extent of work. Managers and employees at all interviews were recorded so that pertinent details could be also extracted after the interviews. It is worth noting that the duration of each interview could vary according to the complexity of the specific part of the process and the availability of the employees during the working time range from 30 to 1 hour and a half.

As a result, following each interview, the visitor updated the process mapping based on the data acquired from discussions and direct observation of the processes. In this regard, the process elements shown in Figure (27) are still taken into account. However, if it became apparent via conversations with staff that some elements of the process were not so pertinent to the company's activities, they were deleted. Also, the engaged departments have been considered according to the real workflow for each process in this company. Hence, the detailed activities inside each process element are totally adapted according to the real observations from processes and interviews.

In addition, the process mapping underwent several iterations of refining to correct all the possible inaccuracies in the interpretation of data collected through interviews and direct observations. For this purpose, the interviewer conducted follow-up interviews with relevant staff members following each interview to confirm the truthfulness of the revised process mapping and make any necessary revision.

After adapting the basic process mapping described in section 4.1 (See Figures (30) and (31)), a new flowchart has been built for the company's Source and Deliver process. As a result, the following process mappings have been created to outline the source and Deliver process of the Automotive company in Figures (35) and (36) respectively.

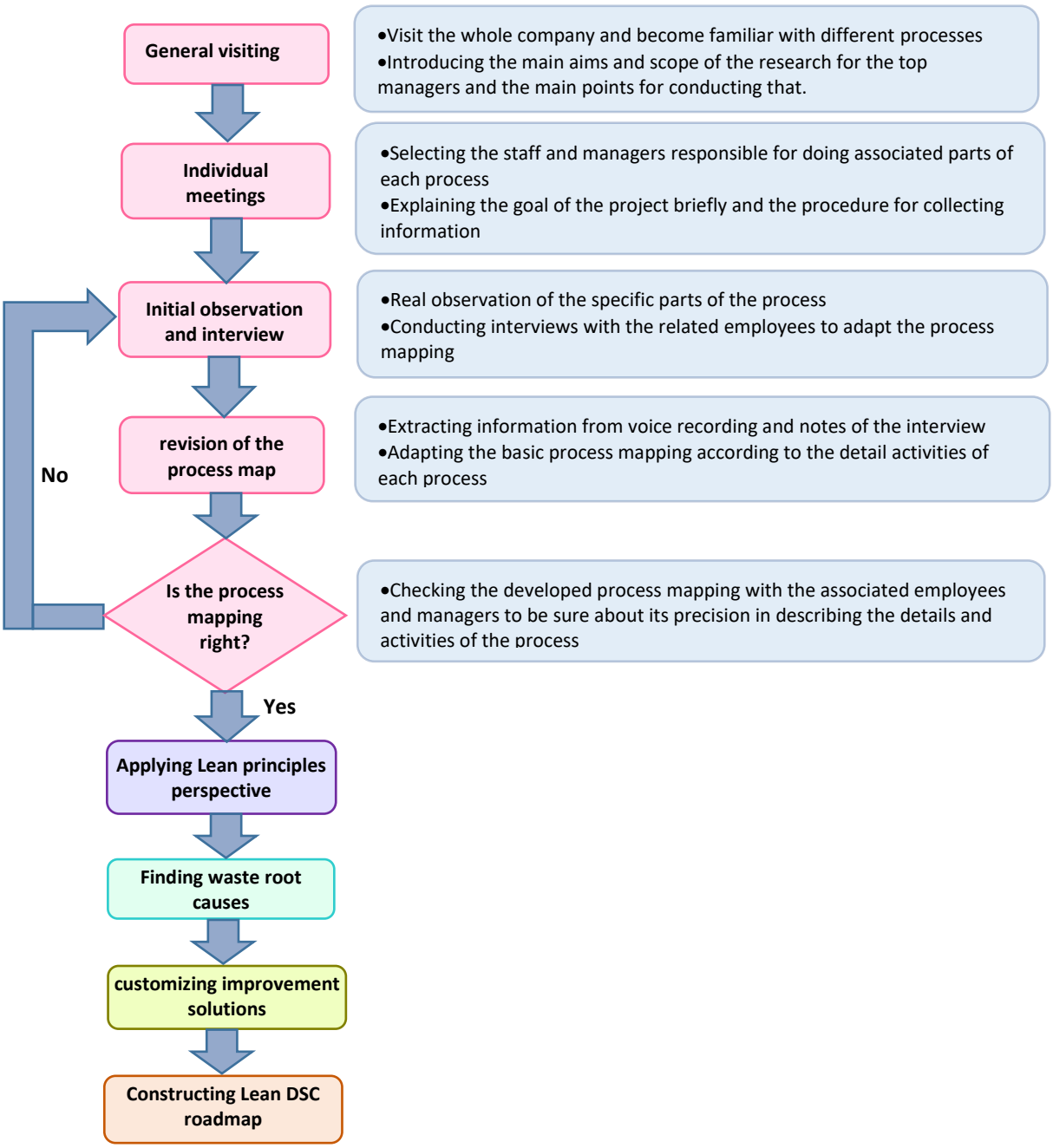


Figure 34 Graphical abstract of "Applying process mapping for logistics processes" for constructing Lean DSC framework of case studies

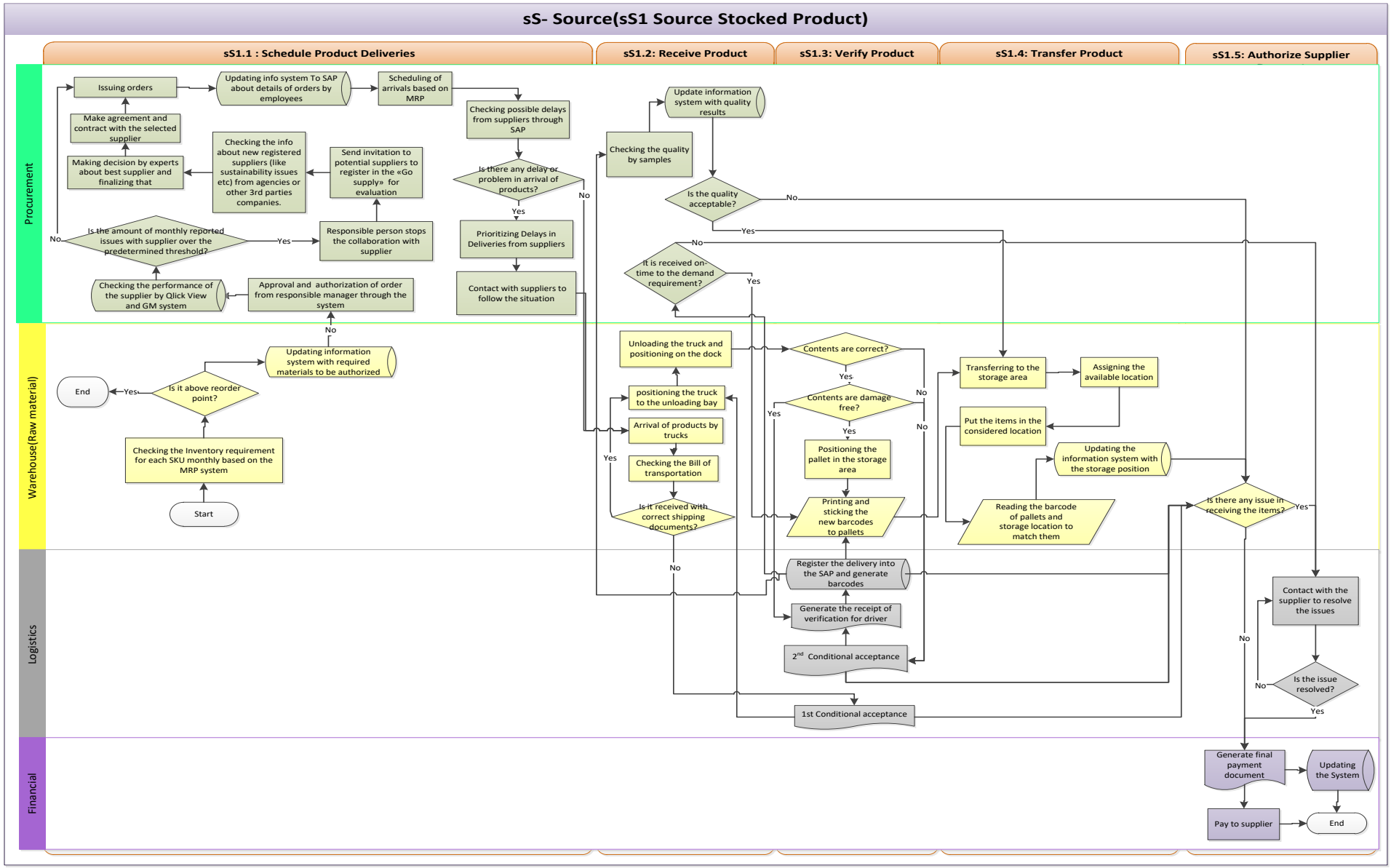


Figure 35 Source process mapping of Automotive company

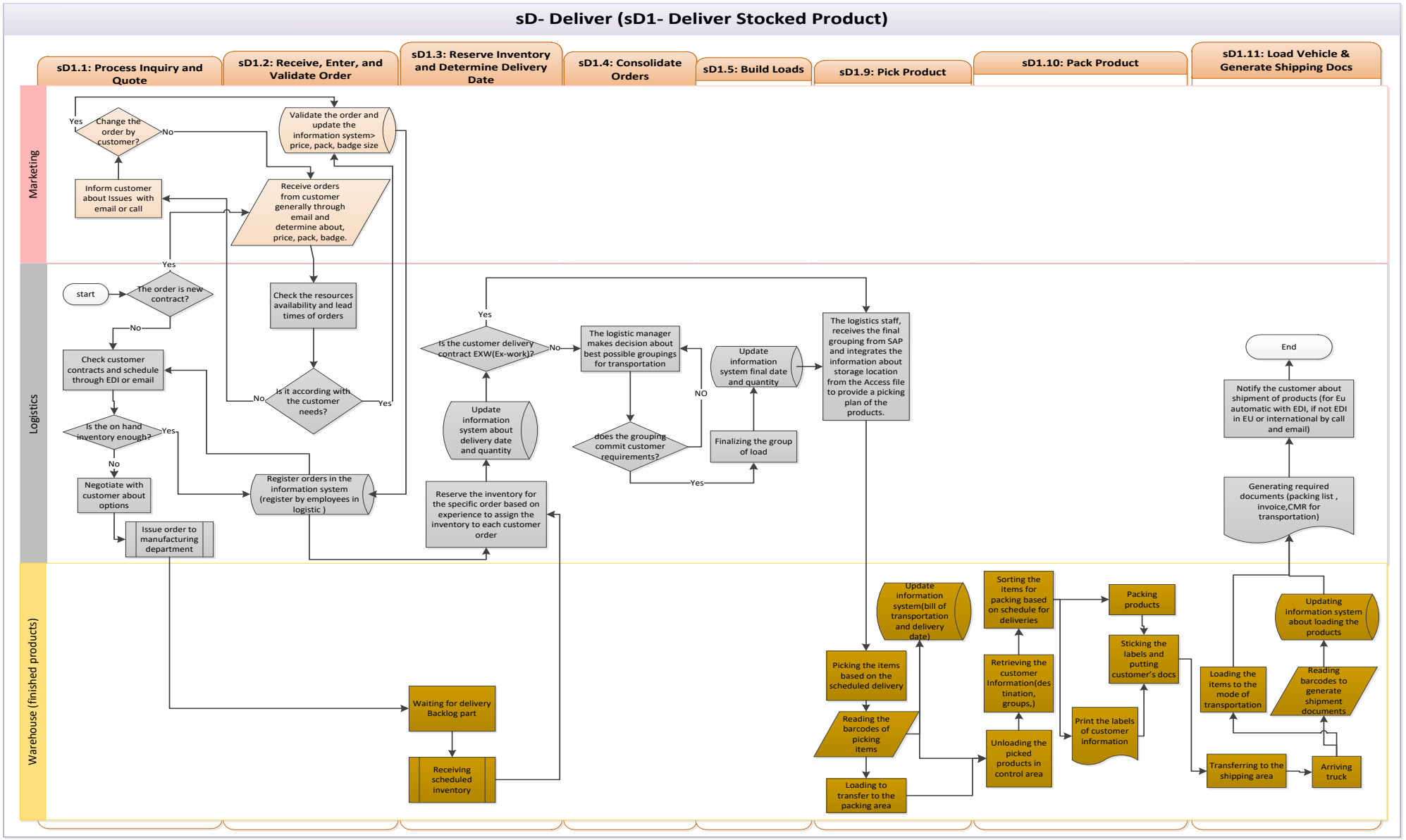


Figure 36 Deliver process mapping of Automotive company

5.2.2 Applying Lean principles perspective for Automotive company

Following the completion of the process mapping for the Automotive company in the phase before this one, the possible wastes should be identified in accordance with the Lean concepts and the seven different forms of waste as described in section 4.2. Towards this goal, the visitor attempted to compile a rough list of the potential wastes associated with each activity carried out within the company while participating in the interviews for process mapping and process observation. It is important to point out that for preparing this initial draft for list of wastes, she had sufficient understanding about the Lean concept and the seven different categories of waste in the past.

As a result, following the completion of the process mapping and the finalization of the current status of the Source and Delivery processes in accordance with the precise stages shown in Figure (37), the preliminary draft of the potential wastes has been presented to the relevant personnel (the same employees as for developing process mapping). In addition, a brief explanation has been given to the related employees in the case that they were unaware of the Lean concept and its seven categories of waste.

As a result, the current round of interviews involved a more in-depth discussion with the person responsible regarding each waste discovered in relation to various activities in the company's process mapping. More precisely, relevant employees have been engaged in discussions about the present status of the process mapping for each activity, with a concentration on the activity's actual condition and the wastes that arise from it. In this case, the discussion between the interviewer and the interviewee could be extremely useful since it can provide the employees a new and different perspective on the wastes they may not have considered previously when doing the activities as routine and everyday responsibilities. Just as in the previous round, all interviews have been recorded for the reasons that have been already covered.

Following each interview, the list of identified wastes has been adapted according to the required revisions out the discussion with related employees. Multiple passes were made through the updated waste list to ensure accuracy and ensure that all waste categories associated with each process activity were accounted for. The following is a complete list of all discovered wastes in the Automotive company's Source and Deliver process, as shown in Tables (15) and (16).

To improve readability, for Source and Deliver processes different categories of wastes have been represented by distinct colors in rows. Furthermore, for the sake of simplicity, each waste category is represented in the first column of the tables by acronyms labeled "Waste Symbol." The meaning of these acronyms for the Source and Delivery processes is depicted in Table (14). Furthermore, as illustrated in Figures (38) and (39), activities linked with one or more than one form of Lean waste have been shown by blue in process mappings for each process. In addition, these activities are also briefly introduced in the second column of Tables (15) and (16). Moreover, a more extensive description of these activities is provided

in the third column of Tables (15) and (16). In order to provide more information to clarify the next stages the last columns of Tables (15) and (16), a brief overview of each waste is also mentioned.

Table 14 Definition of acronyms for Lean wastes in Source and Deliver processes

Symbol	Definition
S-MT	Source Motion waste
S-OPD	Source Over Production waste
S-OPR	Source Over Processing waste
S-WT	Source Wait waste
S-TR	Source Transportation waste
S-IV	Source Inventory waste
S-DF	Source Defect waste
D-MT	Deliver Motion waste
D-OPD	Deliver Over Production waste
D-OPR	Deliver Over Processing waste
D-WT	Deliver Wait waste
D-TR	Deliver Transportation waste
D-IV	Deliver Inventory waste
D-DF	Deliver Defect Waste

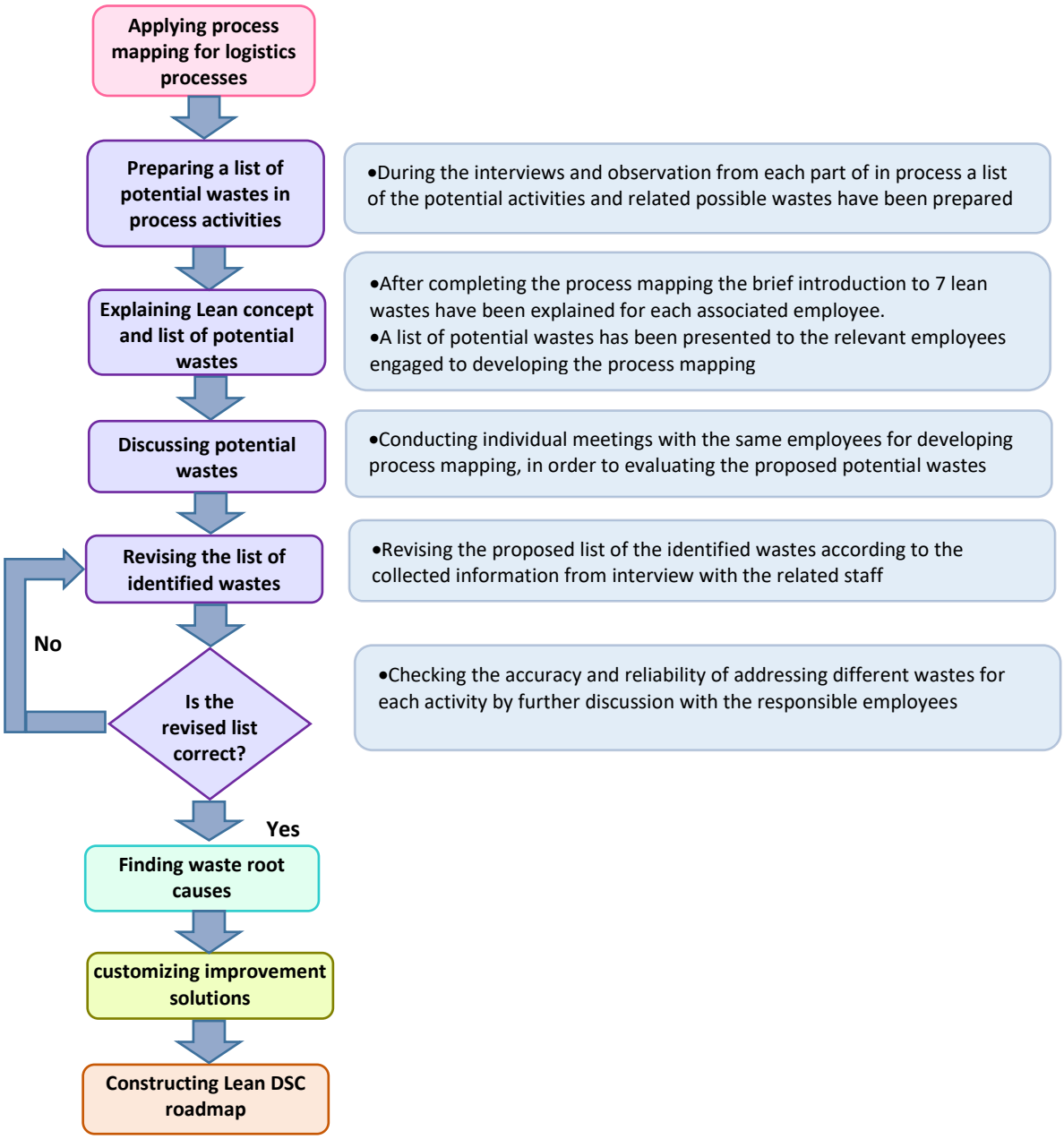


Figure 37 Graphical abstract of "Applying Lean principles perspective" for constructing Lean DSC framework of case studies

Table 15 Definition of identified wastes in Source process of Automotive company

Waste Symbol	Activity	Definition of waste related to the activity	Waste summary
S-MT1	**Generate the receipt of verification**	To print, stamp, and scan reception documents, logistics staff should go around to complete this task. Therefore, this activity contains unnecessary motions for logistics staff for providing this document to other parties	Going around to finalize the reception documents.
S-MT2	**Reading the barcode of pallets and storage location to match them**	The warehouse staff need to have some unnecessary motions to read both barcode for updating the information system.	Unnecessary motions to read and update information about barcodes of pallets.
S-OPR1	**Responsible person stops the collaboration with supplier (with "go supply" inform about supplier's state)**	It could be a time-consuming task for procurement staff to check the performance and history of issues with supplier each time before contract and make decision about the supplier and communicate with supplier about stopping the collaboration.	Collecting and integrating the available information about performance form different sources every time an issue arises with the supplier.
S-OPR2	**Checking the information about new registered suppliers (like sustainability issues etc.) from agencies or other companies.**	It can take time for procurement staff to check the information and data about the previous performance of the new suppliers. They need to contact with the 3rd parties like agencies to collect data. In some cases, they should also communicate with the other companies those have been previously work with this supplier.	Collecting information about the previous performance of new registered suppliers each time before new contracts.
S-OPR3	**Making decision by experts about best supplier and finalizing**	This is time consuming task for the procurement staff to make decision about the best supplier for new contract by checking different criteria.	Integrating criteria before every new contract to select the best supplier
S-OPR4	**Prioritizing delays in deliveries from suppliers**	It is a time-consuming task for the procurement staff to evaluate different delays from suppliers each week. In fact, they should make decision about delays and prioritize the delays by considering their criticalities and effect to the production plan.	Everyday data integration to prioritize delays from different suppliers
S-OPR5	**Contact with suppliers to follow the situation**	This is a time consuming task for the procurement staff to contact with each supplier to follow the reason of the delays in delivery and try to find the solution for that by negotiation with supplier.	Every day contacting with supplier about delays to resolve
S-OPR6	**Generate the receipt of verification**	It is a time consuming task for logistics staff without no value added for the customer. For each arrived truck after unloading the driver should come to the logistic office and ask for stamping the delivery documents as a proof for driver and supplier.	Providing the paper receipt of the delivery for receiving containers from each supplier every day.
S-DF1	**Checking the information about new registered suppliers (like sustainability issues etc) from agencies or other companies.**	Wrong information about the new supplier can lead to select the inappropriate suppliers and can give rise to make some defects in the production due to the unreliable or low quality materials from supplier.	Collecting wrong or unreliable information about supplier.

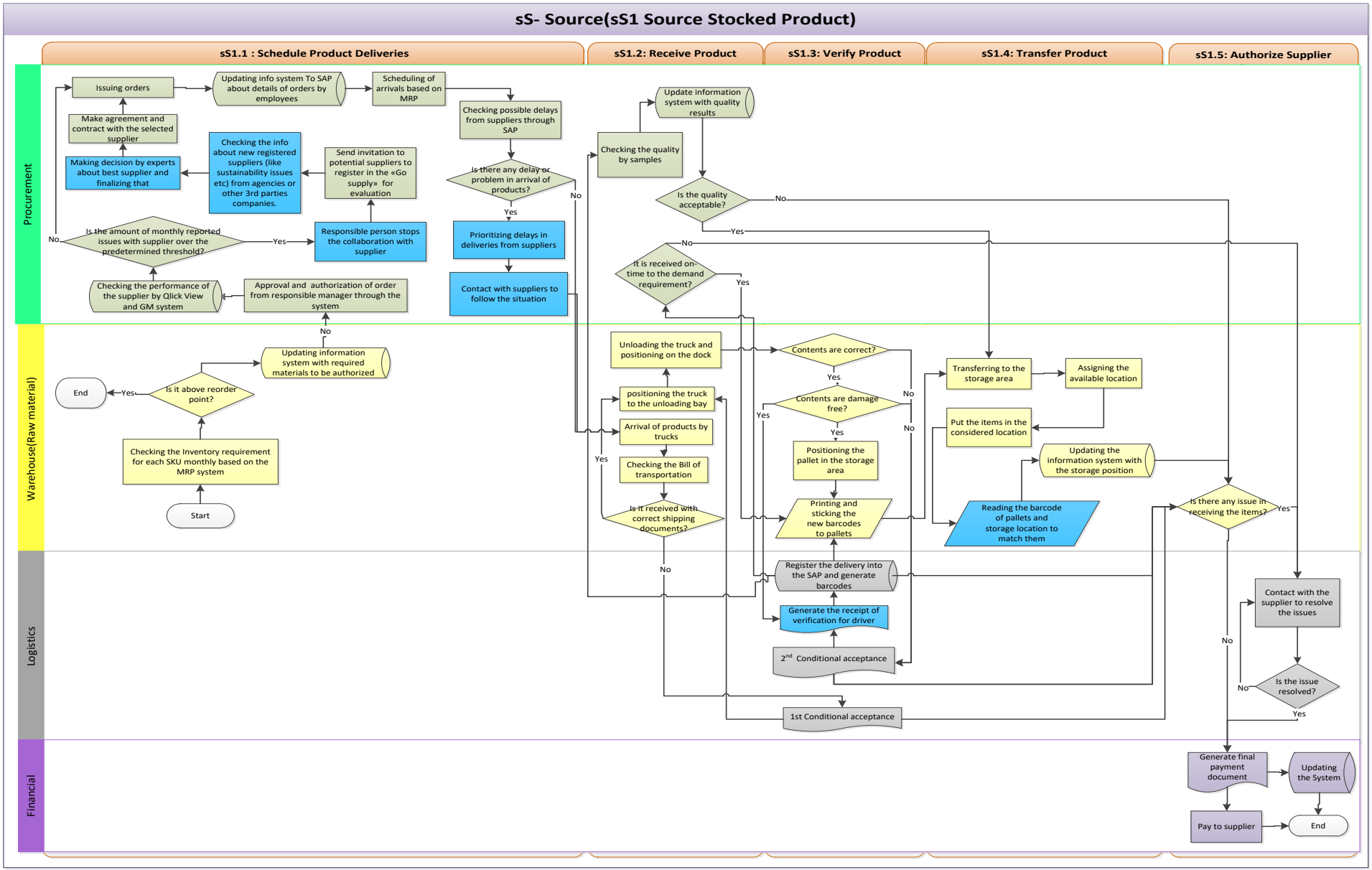


Figure 38 Source process mapping with Non-value added activities for Automotive company

Table 16 Definition of identified wastes in Deliver process of Automotive company

Waste Symbol	Activity	Definition of waste related to the activity	Waste summary
D-MT1	**Generating required documents (packing list , invoice, CMR for transportation)**	The logistics staff should move around to print, stamp, scan the related documents for the shipment. Also, they should communicate with warehouse staff and drivers to validate and collect these documents.	Going around long way to complete shipment and delivery documents.
D-MT2	**Reading the barcodes of picking items**	The warehouse staff need to move around to read the barcode of the pallets and containers to pick up them.	Unnecessary motions for reading the barcodes of pallets for picking up.
D-OPR1	**Check the resources availability and lead times of orders**	The process of checking the lead time and available resources is a time-consuming task for logistic staff before finalizing the new contracts from marketing department.	Before each contract checking the resource availability.
D-OPR2	**Check customer contracts and schedule through EDI or email**	The logistic employees should check the new received changes from customers and implement them into the production and logistics plan according to the customer needs.	Checking the customers' orders for production plan every day.
D-OPR3	**Issue order to manufacturing department**	In the case of any change to the customers' demand which is not according to the initial contract the logistic staff should change the production and logistic plan to answer the customer needs.	Updating the changes received from customers every day.
D-OPR4	**The logistic manager makes decision about best possible groupings for transportation**	It is a time-consuming task for logistic staff to decide about the best group for transportation to deliver the products to B2B customers. Also, they should consider different requirements from customers like delivery date, agreed lead times, etc.	For every shipment making decision about best grouping of deliveries to different customers.
D-OPR5	**The logistics staff, Receives the final grouping from SAP and integrates the information about storage location from the Access file to provide a picking plan of the products.**	To be sure about the final group and deliveries to the customer before giving the plan to the warehouse staff, logistic employees should check and integrate all the information from different software (SAP and Access) to provide the final plan to pick up the products.	Every day for each picks up from warehouse the information should be integrated for providing a picking plan
D-OPR6	**Generating required documents (packing list , invoice, CMR for transportation)**	This is time consuming task for logistic employees since after loading the items they should print and stamp all the related documents for transportation. Moreover, after delivery the products to the customer they should receive the stamped verification of delivery from driver. Then, they should also scan and keep this verification to the system and manage all related documents at least for 5 years after issuing.	Providing and organizing the shipment and delivery documents in paper form for each shipment to the customers every day.
D-OPR7	**Notify the customer about shipment of products (for Eu automatic with EDI, if not EDI in EU or international by call and email)**	It takes time for logistic employees to make a call or send email to the customer from non EU companies or without EDI as information system to inform them about the shipment of the products.	Sending information of shipment and delivery to customer after each shipment to the customers.
D-OPR8	**Picking the items based on the scheduled delivery**	The picking of items from the warehouse can be a time-consuming task for warehouse staff. when they go to the associated place to pick	Every time Looking for picking the right products for delivery.

		up the item, but they cannot find the product there according to the information from logistic staff and information system.	
D-WT1	**The logistics staff, receives the final grouping from SAP and integrates the information about storage location from the Access file to provide a picking plan of the products.**	In the time of checking and integrating the new plan from information system by logistics staff, the warehouse staff should wait to receive the new plans from logistic office to pick up the products for delivery.	Waiting for receiving the new pick-up plan
D-WT2	**Generating required documents (packing list, invoice, CMR for transportation)**	The products should wait to print, stamp and scan these documents by logistic staff after loading to the truck and before transportation to the customer destination.	Waiting for completing delivery documents.
D-WT3	**Picking the items based on the scheduled delivery**	The products should wait to complete the picking of all items to go to the next step for loading and delivery. Also, warehouse employees should wait to receive new plan and updated information from logistic staff.	Waiting for completing picking items to shipment.
D-TR1	**Picking the items based on the scheduled delivery**	If warehouse staff cannot find and pick up the product based on the received information, they should go to logistic office to receive the new updated plan and related information.	Moving among different departments to receive the updated picking plan.

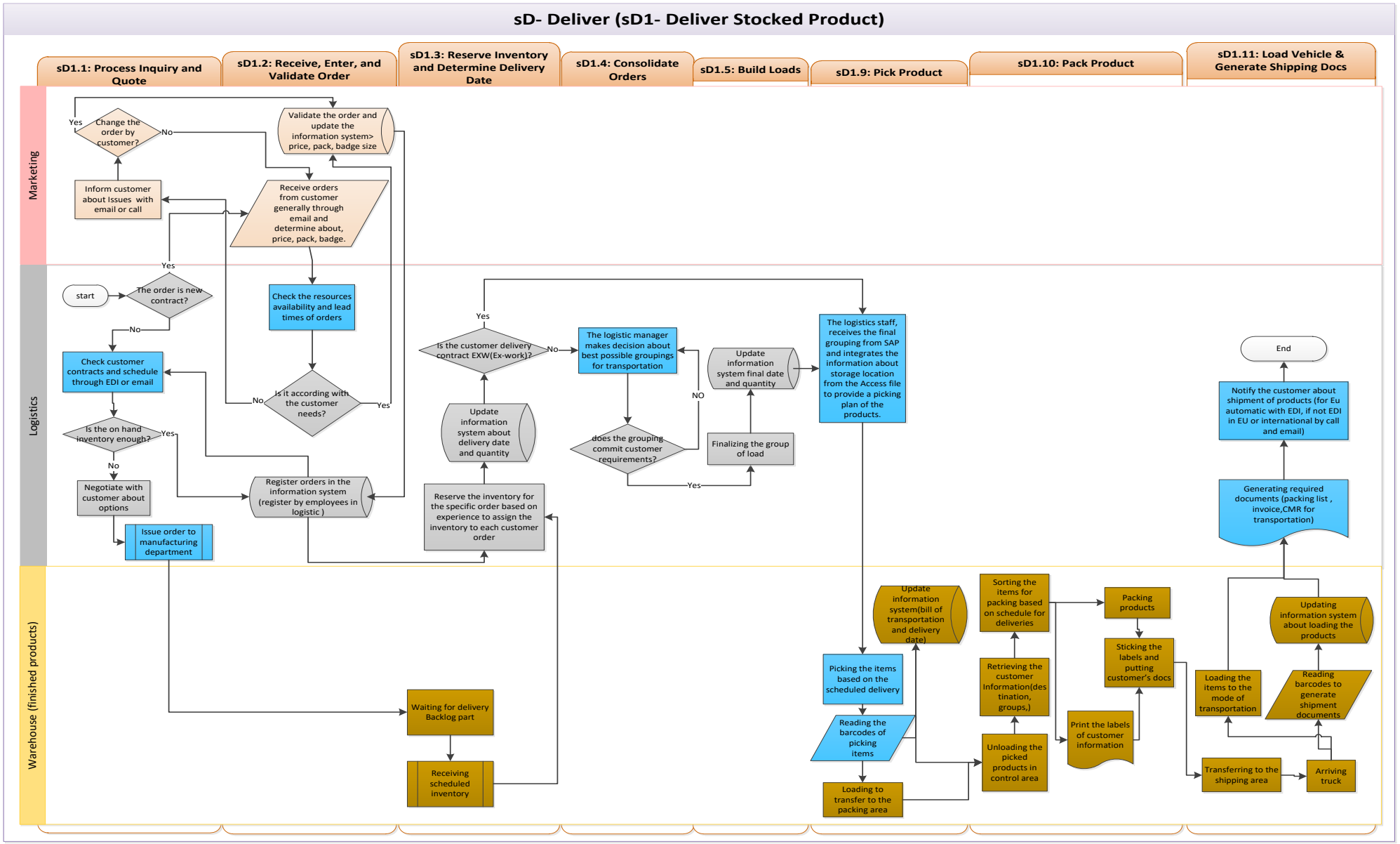


Figure 39 Deliver process mapping with Non-value added activities for Automotive company

After completing the final draft of the process map for the automotive company's Source and Deliver process (see Figures (38) and (39)), Figure (40) compares the amounts of the different types of wastes discovered in these processes. Figure (40) shows that the Deliver process accounts for more than 60% of the total wastes in the Automotive company. It suggests the company should think about how to enhance the Deliver process with its downstream SC members. However, the company should still explore improving wastes associated with each activity for the Source process, as the quantity of recognized waste associated with this section is not negligible (about 40%).

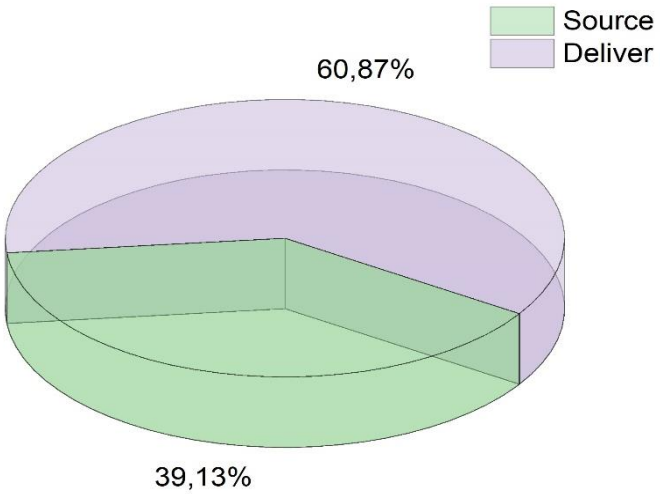


Figure 40 Comparing amount of Source and Deliver wastes for Automotive company

Furthermore, Figure (41) shows the amount of each type of waste generated in each process individually. Thus, the major portion of wastes in both processes are connected to Over Processing as the principal waste in the Automotive company. Furthermore, the amount of Motion as waste is greater in the Source activities than in the Deliver process. It implies that the physical efforts required by workers in the source process are greater than those necessary in the Deliver process. However, when both wastes related to Motion and Transportation (as unnecessary movements of staff and items between different parts of the company) in the Deliver process are considered (14% and 7% of total waste, respectively), the total amount appears to be equal to the amount of Motion waste in the Source process (22%). As a result, from such perspectives, the quantity of wasteful movement and physical effort of staff is the same for both the Source and Deliver processes.

In addition, the Deliver process includes several activities with Wait as waste. After Over Processing, this waste is the second most prevalent waste in the Deliver process (21%). It might be connected to the poor structure of the Deliver process in the Automotive company, which can result in several Wait wastes in different stages of the Deliver process.

Aside from Over Process and Motion, another type of waste is associated with the Defect in the Source process. It is closely linked to the importance of activities in the Source process and their direct impact on defective goods and low-quality items in production.

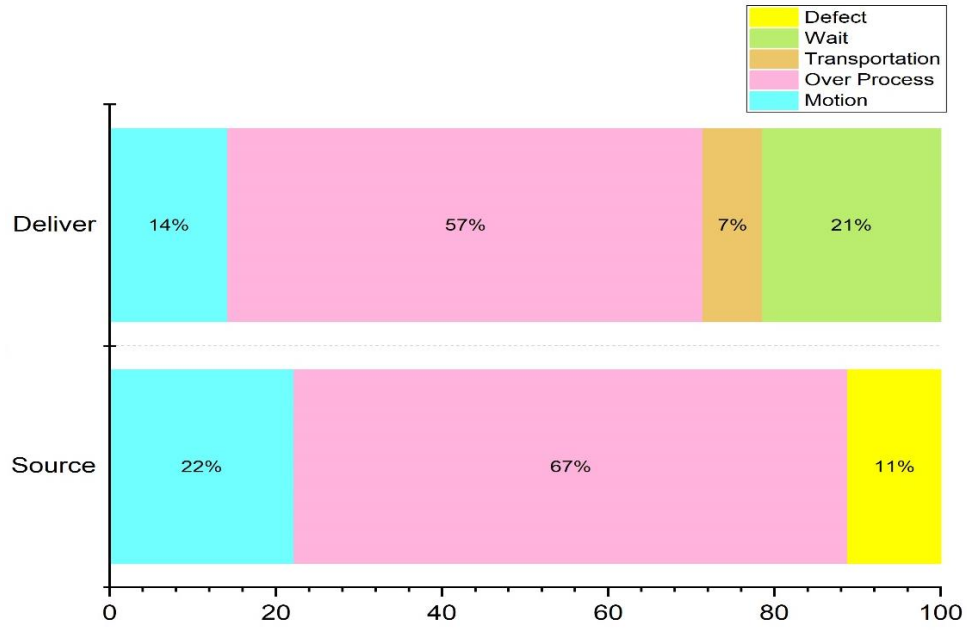


Figure 41 Comparing number of different types of wastes in Source and Deliver for Automotive company

5.2.3 Finding waste root causes for Automotive company

In the previous phase, we determined the associated wastes for each activity in the Source process and the Deliver process. The "5 why?" approach is used to investigate the origins of each waste identified in the preceding stage (See Figure (42)). Therefore, only employees who carry out the responsibilities related to the waste identified in the previous stage have been interviewed (see Figures (38) and (39)). In light of this, the following employees have been considered for "5why?" participation in the Source process:

- Procurement manager
- Logistic manager
- Logistic staff
- Scheduling staff
- Warehouse staff

Furthermore, the following group of employees has been taken into account in the Automotive company's Deliver process in order to obtain the root causes analysis:

- Logistic manager
- Logistic staff
- Warehouse staff

In this regard, at the start of this round of interviews, each interviewee was presented with a brief explanation of the "5why" approach and related steps for achieving that. As a result, it is clear that by organizing the interviews, the most critical root causes of each waste are expected to be identified. Furthermore, as in the prior phases, each employee was questioned about the waste related to their tasks and daily activities. All the interviews have been recorded in the same manner as before in sections 5.2.1 and 5.2.2.

The finished Excel sheet, which is used to classify the various kinds of waste, has been given to the person being interviewed. In addition, the interviewer

tries to retain both the activity and the specific waste during the interview with the associated employee. Therefore, they make an attempt to deliver a reasonable respond to the "why" question in a recursive manner, and by creating more debate over the activity and the waste that is linked with it.

The current phase is repeated until a satisfactory answer for the "why" as the major underlying causes of the concentrated waste was obtained. Mainly the final root causes for the majority of the wastes have been identified after two iterations of the “5why”. It means that in many cases after answering to the why in second time the main root is discovered. Finally, the final response is double-checked with the interviewee before moving on to the next detected waste or concluding the interview. This procedure is followed for all waste listed in Tables (15) and (16). As a conclusion, Table (17) represents a piece of the Automotive company's "5why" root cause analysis for Deliver process. More details of analysis is also available in appendix A. Also, whole analysis is available by asking from author by email.

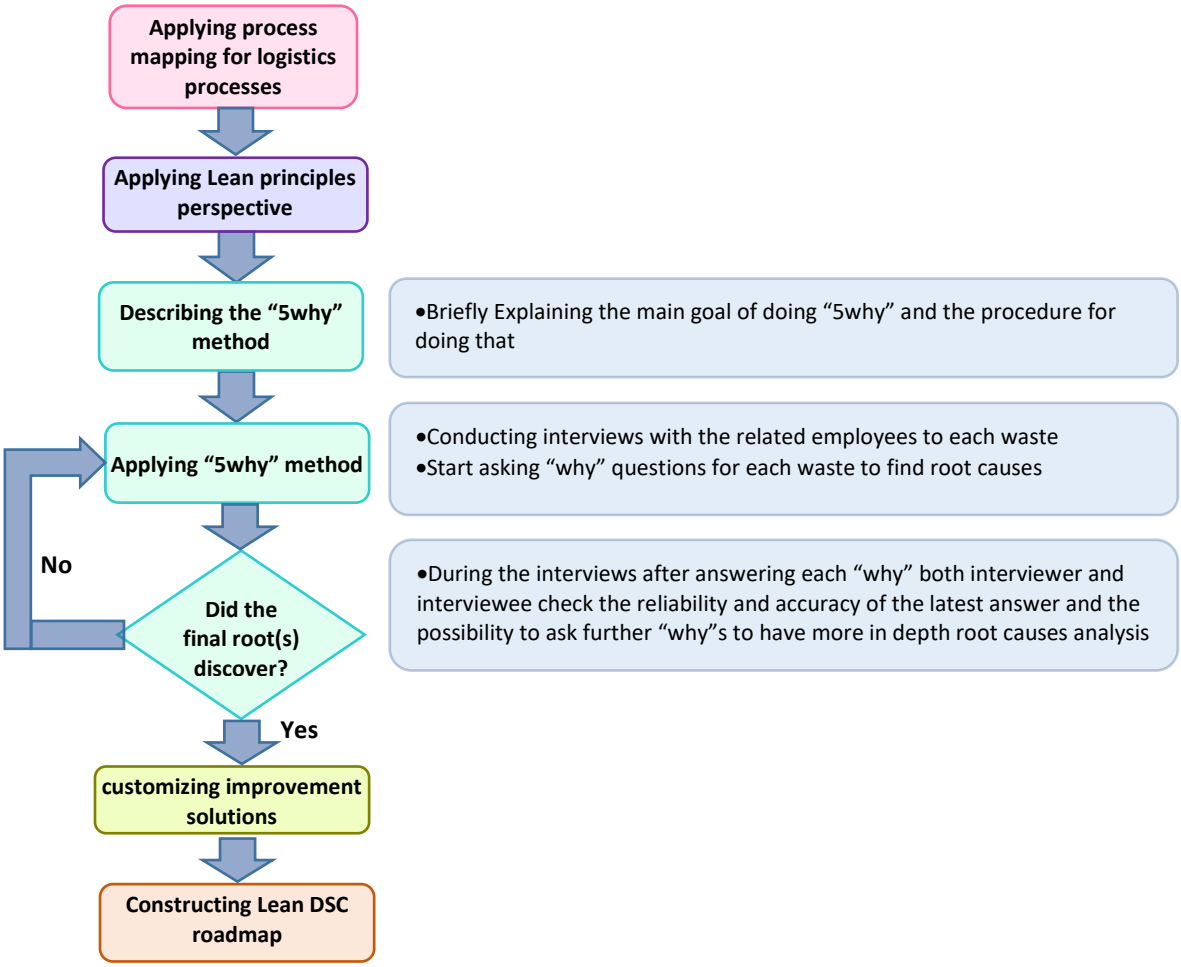


Figure 42 Graphical abstract of “Finding waste root causes” for constructing Lean DSC framework of case studies

Table 17 Example of applying 5why method in Deliver process of Automotive company

	why?	Generating required documents (packing list, invoice, CMR for transportation) [D-OPR6]	Make decision about best possible groupings for transportation [D-OPR4]
Over Processing	***Waste description***	*This is time consuming task for logistic employees since after loading the items they should print and stamp all the related documents for transportation. Moreover, after delivery the products to the customer they should receive the stamped verification of delivery from driver. Then, they should also scan and keep this verification to the system and manage all related documents at least for 5 years after issuing.*	*It is a time-consuming task for logistic staff to decide about the best group for transportation to deliver the products to B2B customers. Also, they should consider different requirements from customers like delivery date, agreed lead times, etc.*
	1st why?	Because the employees should do same steps for providing these documents for each shipment and keep the track of these documents for 5 years before discarding them to resolve any possible conflicts during this period.	Because this is a daily task for the logistic staff, and they should consider many criteria and parameters to make the best decision.
	2nd why?	Because the system for sending and keeping the proof of shipment and related documents is not automatic and shared among different parties (company, driver, customer).	Because there is not any automatic tool or system to assist the logistics staff for making the best decision with less effort and by considering all criteria and related parameters at the same time.

5.2.4 Customizing improvement solutions for Automotive company

The following step, which comes after determining the causes of the waste, is to offer solutions by aiding the technologies that are part of Industry 4.0. Figure (43) shows the details of different parts of this step. In this regard, establishing a list of suitable technologies before beginning interviews with employees may be advantageous in accelerating the approach and finding more effective options for reducing the identified wastes. To that purpose, the solutions will consider the specific characteristics of each activity as well as the underlying causes of the waste.

Therefore, based on the information gathered in chapter 3, the author developed a list of possible technologies for tackling each waste. In fact, she integrated the SLR findings with the data and insights gathered from the numerous interviews as well as the real observation of the processes inside the company. In light of the aforementioned data and sources, a preliminary version of the relevant technologies has been prepared uniquely for each waste in Tables (18) as an example.

The next step is to have interviews about the list of possible technologies with the relevant staff to assess whether they are accurate and applicable to minimizing the identified wastes. In addition, these interviews can pave the way for the follow-up actions necessary to adopt these technologies in the day-to-day operations of the company. In fact, when workers understand the core ideas and practical advantages of Industry4.0 technologies, they are more likely to embrace them to improve their productivity. Moreover, since they are involved continuously and interactively in the process of developing this framework for Lean DSC, they may feel more responsibility for future stages in the implementation of this framework.

As a result, at the start of each interview with associated worker, a quick introduction to the various Industry4.0 has been delivered to them via a PowerPoint file. This presentation lasts around 15 minutes and begins with a general explanation

of the technologies while mainly focusing on the benefits of those that will apply to wastes associated with the employee's everyday activities. Following the brief presentation and answering any employee questions or concerns about the technologies and their benefits, further in-depth discussions were held with them.

Therefore, after reviewing the identified root causes, potential technologies are presented for each referenced waste to the employee. The advantages of a certain technology regarding each type of waste are highlighted to the staff member during these interviews. The interviewer subsequently inquired about the respondent's thoughts on the proposed waste-reduction technology. Actually, to conclude the list the discussion has been continued until clarifying any remaining issues of disagreement or uncertainty regarding these suggestions.

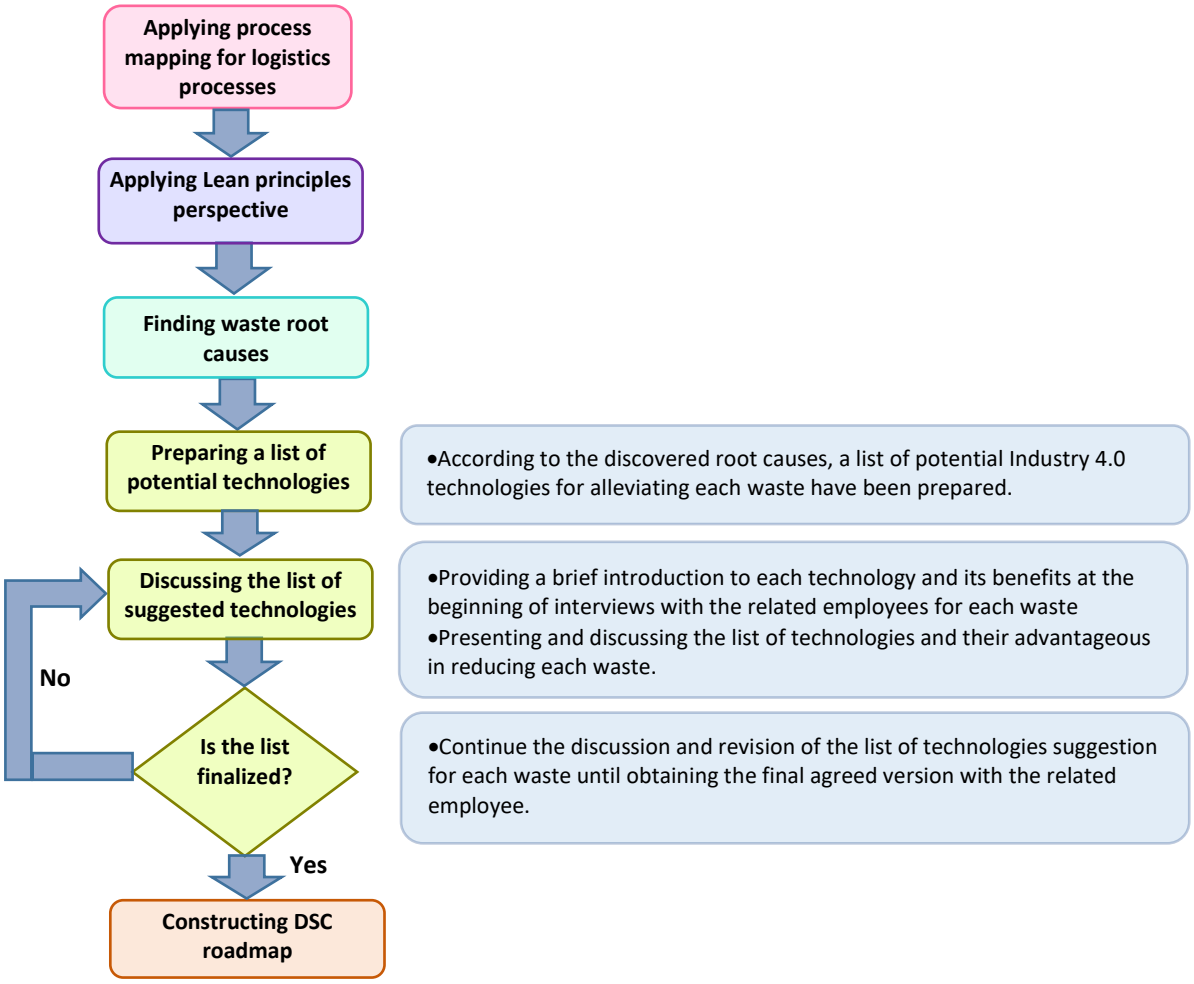


Figure 43 Graphical abstract of "customizing improvement solutions" for constructing Lean DSC framework of case studies

Table 18 Example of suggesting Industry 4.0 technologies for Deliver process of Automotive company

	why?	Generating required documents (packing list, invoice, CMR for transportation) [D-OPR6]	Make decision about best possible groupings for transportation [D-OPR4]
Over Processing	***Waste description***	*This is time consuming task for logistic employees since after loading the items they should print and stamp all the related documents for transportation. Moreover, after delivery the products to the customer they should receive the stamped verification of delivery from driver. Then, they should also scan and keep this verification to the system and manage all related documents at least for 5 years after issuing.*	*It is a time-consuming task for logistic staff to decide about the best group for transportation to deliver the products to B2B customers. Also, they should consider different requirements from customers like delivery date, agreed lead times, etc.*
	1st why?	Because the employees should do same steps for providing these documents for each shipment and keep the track of these documents for 5 years before discarding them to resolve any possible conflicts during this period.	Because this is a daily task for the logistic staff and they should consider many criteria and parameters to make the best decision.
	2nd why?	Because the system for sending and keeping the proof of shipment and related documents is not automatic and shared among different parties (company, driver, customer).	Because there is not any automatic tool or system to assist the logistics staff for making the best decision with less effort and by considering all criteria and related parameters at the same time.
	suggested technologies	IoT, BC, CC	BDA
	benefits of **BDA** for alleviating the waste and how it works		BDA algorithm can assist the decision-makers to make the best decision for grouping the items by considering all related parameters like lead time, price, distance, etc, and also, they can provide the possible delivery dates automatically. Therefore, there is no need to do this repetitive task from logistics staff daily.
	benefits of **IoT** for alleviating the waste and how it works	IoT and RFID tags can use to reduce the process time to insert the related data about products. In fact, all data can be updated through different steps of the picking and loading the items by RFID scanner to store them for validating and generating related documents by BC and sharing by CC.	
	benefits of **CC** for alleviating the waste and how it works	Combining the CC with BC can make it possible for all related parties to access the real-time shared data by connecting to the CC from everywhere. They just need to have the right authentication for access to the documents and information on BC with private keys that have been provided to them. Therefore, here applying CC can give access to and share data from BC with authorized chain members.	
	benefits of **BC** for alleviating the waste and how it works	BC by providing trustful to access all parties to the related information about shipment and documentation can remove all the related steps for sending, and simplify the process of keeping these documents. In this way, after finishing product loading the related documents have been published by initiating the related smart contacts conditions. Then, all parties can access the related documents with the private key. Also, all the information and documents have been kept in the related digital blocks without time limitations on the distributed ledgers. Moreover, since the system is tamper-proof and validates the documents with many nodes in the network, all parties can be sure about the originality of the information and documents, from fraud and manipulation.	

5.3 Food company

The second case study is from the Food industry, and it was chosen for the reasons given in Section 5.1.2. This company is in the industry of producing olive oil. See Figure (33) for a location map of this firm's headquarters in Jaèn, Andalusia, Spain. Olives are used in a wide range of the company's products, but its flagship product is extra-virgin olive oil. The olives grown by local farmers are the primary source of raw materials for the company's products (suppliers). Since the oil should be extracted as soon as the olives are harvested, the company's main period of production is from September to January, when the olives are collected. As a result, the majority of the remaining time in the year is spent by the firm concentrating on bottling the extracted olive oils in accordance with the orders and requests that have been received from the market, both actual and estimated. As a result, this firm mostly uses a hybrid Push-Pull approach as its business model.

In fact, the corporation follows the Push method, an estimate of market demand based on collected data, when it begins harvesting in September and accepts farmers for being suppliers. However, once the olive oils have been extracted, they are stored in large containers until the firm receives orders from the end customers, at which point the Pull system comes in and the olive oils are bottled as the finished products. Due to the restricted amount of time available to gather the raw material during specified season, the olive oil industry might benefit from utilizing this hybrid Push-Pull method. As a small business, minimizing the expenses associated with storing finished products until they can be shipped to customers is also important.

The company appears to be one of the finest in its industry based on a visit to the production site and a review of its website on the internet, as well as a comparison with other businesses in the same industry. In point of fact, the manufacturing process and the extraction of the olives have reached an adequate level of maturity and automation. However, there are several flaws that need to be fixed in SC-related processes and in integrating various parts of the company to act as a unified system. Thus, the primary goal of this research is to enhance the company's SC relationships and logistical activities across the Source and Deliver processes through the use of Lean DSC.

For this purpose, Table (19) shows some of the most basic points about the company. Following this introduction, you will find details on how the key phases of the framework were adapted for this specific company to create the final version of the Lean DSC framework.

Table 19 Information of Food company

Information about PICUALIA (Food Industry)	
Establishment year	2009
Number of employees in different parts (production and non-production)	13
Amount of production	4 million Kg olive oil per year
Number of Suppliers	1000 local farmers from Jaen
Number of B2B customers	200 (35 percent international)
Push or pull system of production	Hybrid Push-Pull
Average lead time for B2B customers	44 hours
Factory area	15000 M2

5.3.1 Applying process mapping for logistics processes of Food company

For doing the process mapping exactly the same procedure is followed as described in section 5.2.1 for the automotive company (see Figure (34)). According to that, after doing the general visiting of the company and by considering the specific characteristic of the Food company the following employees have been selected during the meeting for the next interviews. For the Source process of the Food company the employees are:

- Marketing manager
- Procurement manager
- Quality control staff
- Warehouse manager
- Production manager
- Financial manager

For the deliver process of the Food company the following employees have been interviewed:

- Marketing manager
- Logistics manager
- Warehouse manger

Moreover, it is worth noting that in conducting this case study more than 30 hours have been spent to the real observation of the processes and also around 10 meetings have been conducted with the related employees. Thanks to the smaller size of the company compared to the previous case study (Automotive company) it is possible to conduct the framework in fewer meetings. Accordingly, the following Figures (44) and (45) have been developed as the current process mapping for the Food company in the Source and Deliver process.

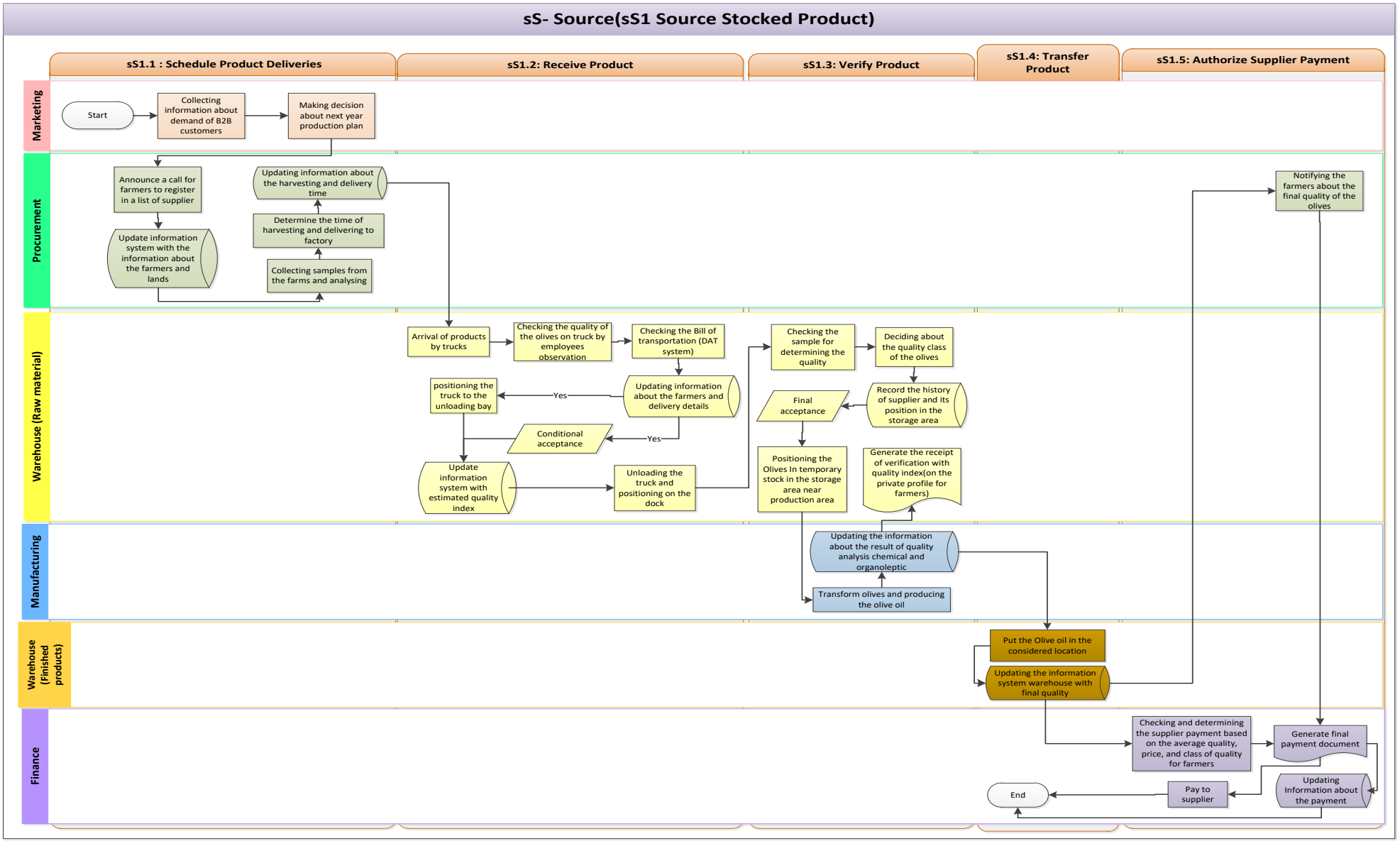


Figure 44 Source process mapping of Food company

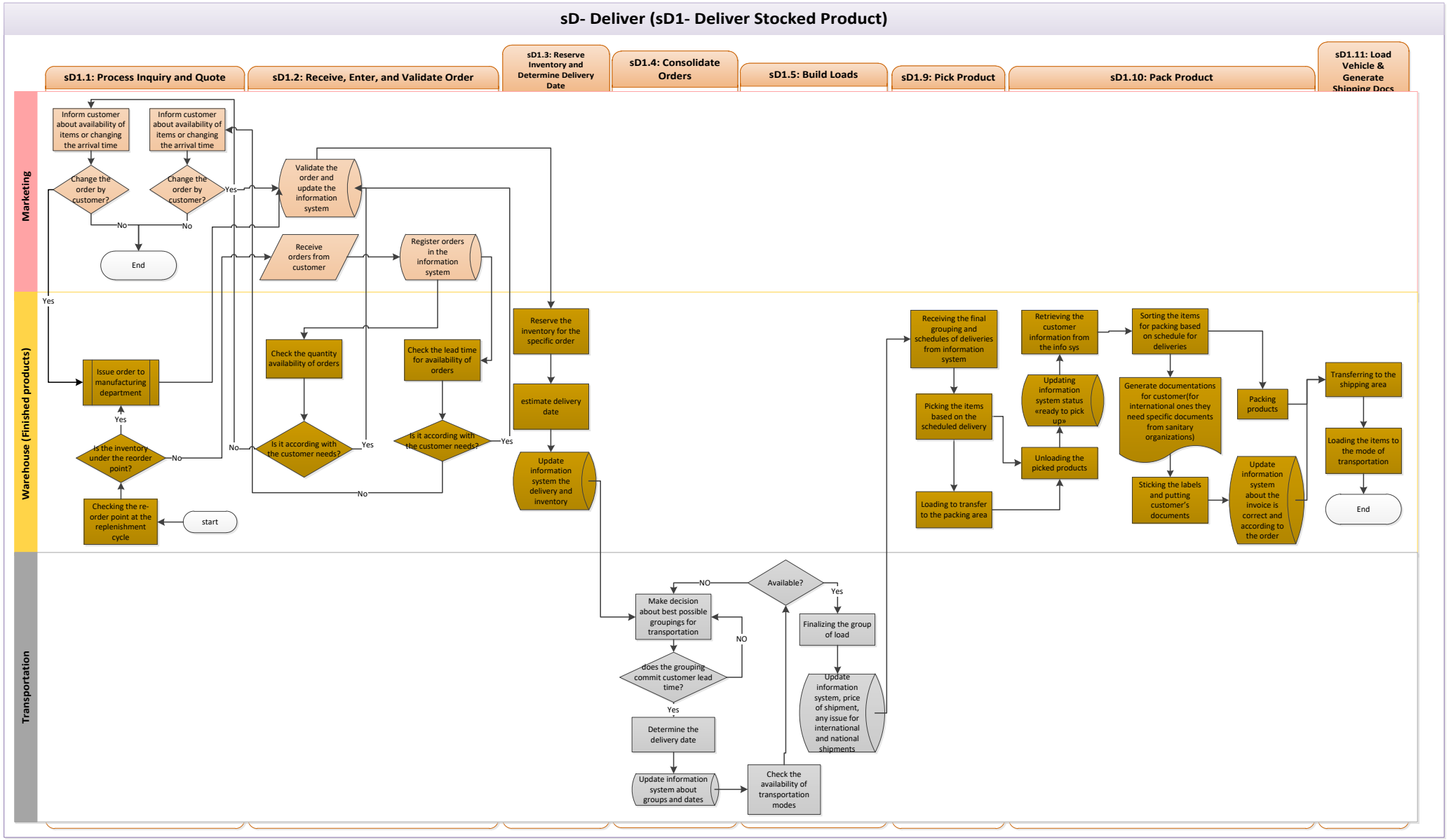


Figure 45 Deliver process mapping of Food company

5.3.2 Applying Lean principles perspective for Food company

For applying Lean principles in the Food company, the same procedure is followed for identifying the waste in Source and Deliver process. The result of this procedure is shown in the following Tables (20) and (21) with presenting the symbols of each waste and the related descriptions. Moreover, Figures (46) and (47) depict the process mapping for each process by highlighting the activities associated with one or more than one identified waste.

Table 20 Definition of identified wastes in Source process of Food company

Waste Symbol	Activity	Definition of waste related to the activity	Waste summary
S-OPD1	**Making decision about next year production plan**	It can lead to wrong estimation and producing the finished products more than the real market demand.	Producing more than what demanded according to wrong initial estimation
S-OPR1	**Making decision about next year production plan**	This can be a time consuming task for the marketing dep to collect data and decide about the amount of the demand for production planning based on the market information.	Doing repetitive task to make decision for next year production by Collecting and integrating all data about demand from different resources and potential B2B customers
S-OPR2	**Notifying the farmers about the quality of the olives**	It is a time-consuming task for the procurement staff to contact with the supplier and inform them about the quality of their olives.	Contact suppliers every time to inform them about olives quality
S-OPR3	**Conditional acceptance of olives**	This step can take long time for accepting the received products without any value added for the customer.	Analyzing quality parameters after conditional acceptance of olives for each arrived truck
S-OPR4	**Update system with the information about the farmers and lands**	This is time consuming task to follow the treatments from each farmer, validating that, and inserting in the information system for recording the data	Following, inserting, and keeping the track of each treatment for each farm
S-OPR5	**Collecting samples from the farm and analyzing**	It is a time-consuming task for the company and employees for collecting samples weekly from all farms in the time of harvesting	Weekly collecting and analyzing samples from all farms in the season of harvesting
S-WT1	**Checking the quality of the olives on truck by employee's observation**	The received olives should wait to evaluate the quality for directing to the right production line by the receiving area employees before unloading the olives.	Waiting each truck of olives to have an initial evaluation by observers
S-WT2	**Pay to supplier**	The financial department should wait a relevant amount of time to integrate and approve the related information in the system before proceeding the payment to the supplier.	Waiting for integration of selling information in the company system before the payment to the farmers
S-WT3	**Conditional acceptance**	The olives should wait a relevant amount of time for final acceptance after quality investigation before being delivered to the production lines.	Waiting received olives for the results of the other analysis about quality of them
S-TR1	**Collecting the information about demand and estimating size of market**	It needs to move employees around (e.g., to have meetings) to collect the related information from different sources and dep like marketing, production.	Going around to collect related information from different sources for estimating demand
S-TR2	**Checking the quality of the olives on truck**	Doing this activity needs to the movement of the employees around the truck to	Going around the truck for checking the received olives on

	by employees observation	inspect the quality of the received olives.	truck
S-TR3	**Update information system with the information about the farmers and land**	This activity needs to do efforts by employees to contact with both farmers and treatment centers to get the information the company needs to know about the treatments carried out during the cultivation of olives.	Going around to contact and visit the farmer and treatment centers to collect necessary information about applied treatments
S-TR4	**Collecting samples from the farm and analyzing**	This activity needs physical efforts and movements from employees to go to each farm and collect the related samples weekly.	Going to the farms and collecting samples for determining the time of harvesting every week
S-DF1	**Checking the quality of the olives on truck by employee's observation**	The process of investigation of the olives quality can lead to some defect in the production process since it depends to the observer and can affect by human errors and wrong estimation of the olives quality.	Human errors to determine right quality and directing to the right line for dropping the olives
S-DF2	**Determine the time of harvesting and delivering to factory**	This process can give rise to wrong estimation about the time of harvesting due to some human errors in time of collecting or analyzing samples	Possible errors for estimating the time for harvesting and its effect on the quality of final product

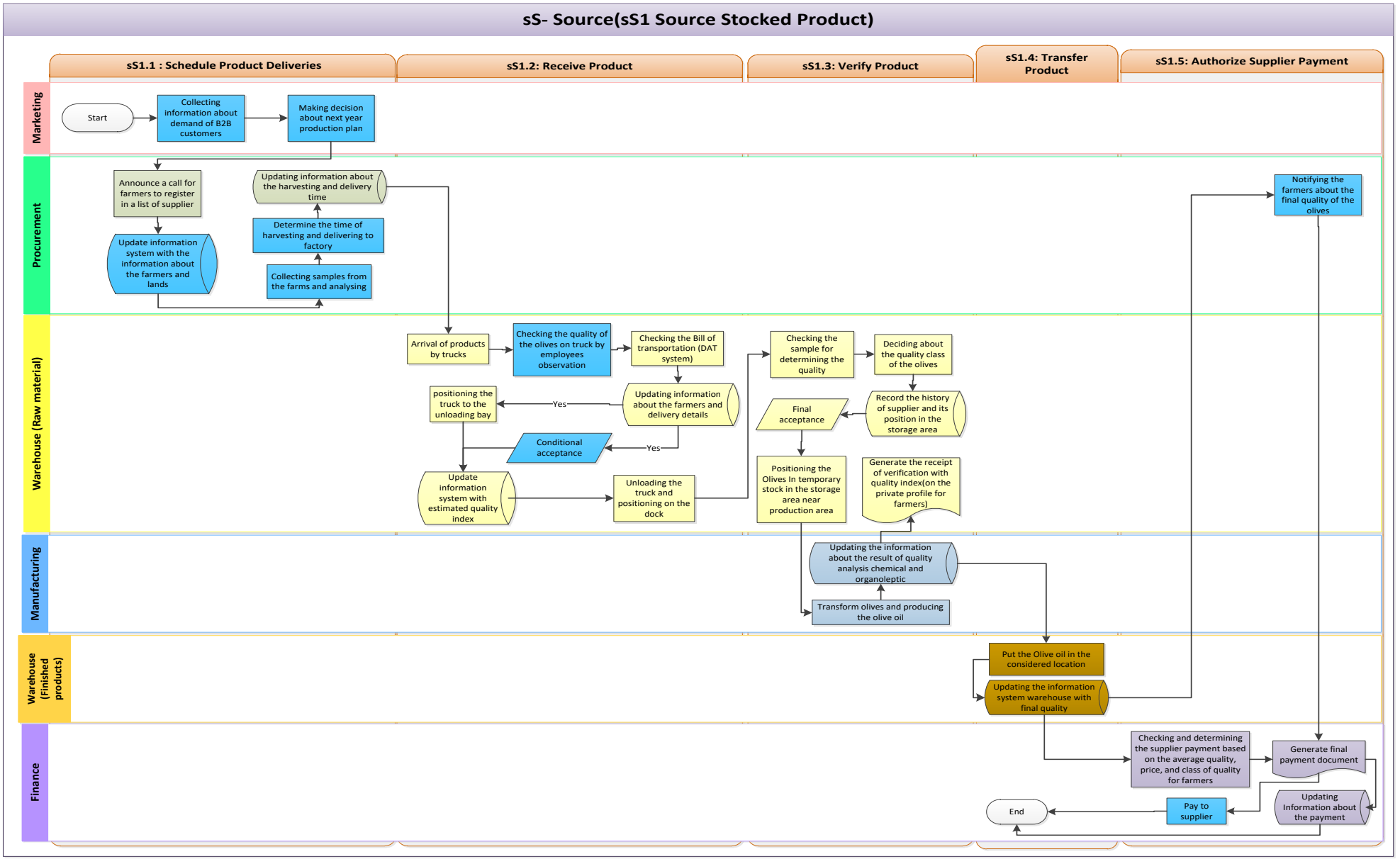


Figure 46 Source process mapping with Non-value added activities for Food company

Table 21 Definition of identified wastes in Deliver process of Food company

Waste Symbol	Activity	Definition of waste related to the activity	Waste summary
D-OPR1	**Inform customer about availability of items or changing the arrival time**	Time consuming process to contact with the customer about any possible changes in the order.	For each change in the customer order the marketing staff need to inform the customer about the availability of the requested products
D-OPR2	**Register orders in the information system**	It is time consuming process to insert each of the customer orders in the system one by one by the employees after finalizing the orders.	For each customer and each order, the information about the order should register to the company information system
D-OPR3	**Issue order to production department**	It is time consuming for the finished product warehouse staff to communicate with the production department to order for bottling new quantity of oils to replenish the warehouse	Communicate each time to order new bottle of products to the production department
D-OPR4	**Generate documentations for customer**	Staff should prepare and print all of the related documents for each order delivery based on the customer needs, which is a repetitive task.	Printing and preparing all shipment documents for each customer and each delivery
D-OPR5	**Make decision about best possible groupings for transportation**	It is a time consuming procedure to figure out the best groups for each of the arrived orders to ship.	Spending time to searching and defining the best possible shipment group for delivery to customers
D-WT1	**Inform customer about availability of items or changing the arrival time**	Warehouse should approve the request from the marketing department for each order. Therefore, for each order marketing dep should wait for the final information about time and product availability from warehouse to inform customer and finalize the order.	Waiting to receive the updated information about the inventory availability from warehouse department
S-DF1	**Register orders in the information system**	The process of inserting customers' orders into the information system can lead to some human errors for registering them. Therefore, that can make some defects in the final order quantity, type, delivery time, or other customer information by the marketing department staff.	Possible issues and errors to insert and register orders to the information system of the company by the company staffs.

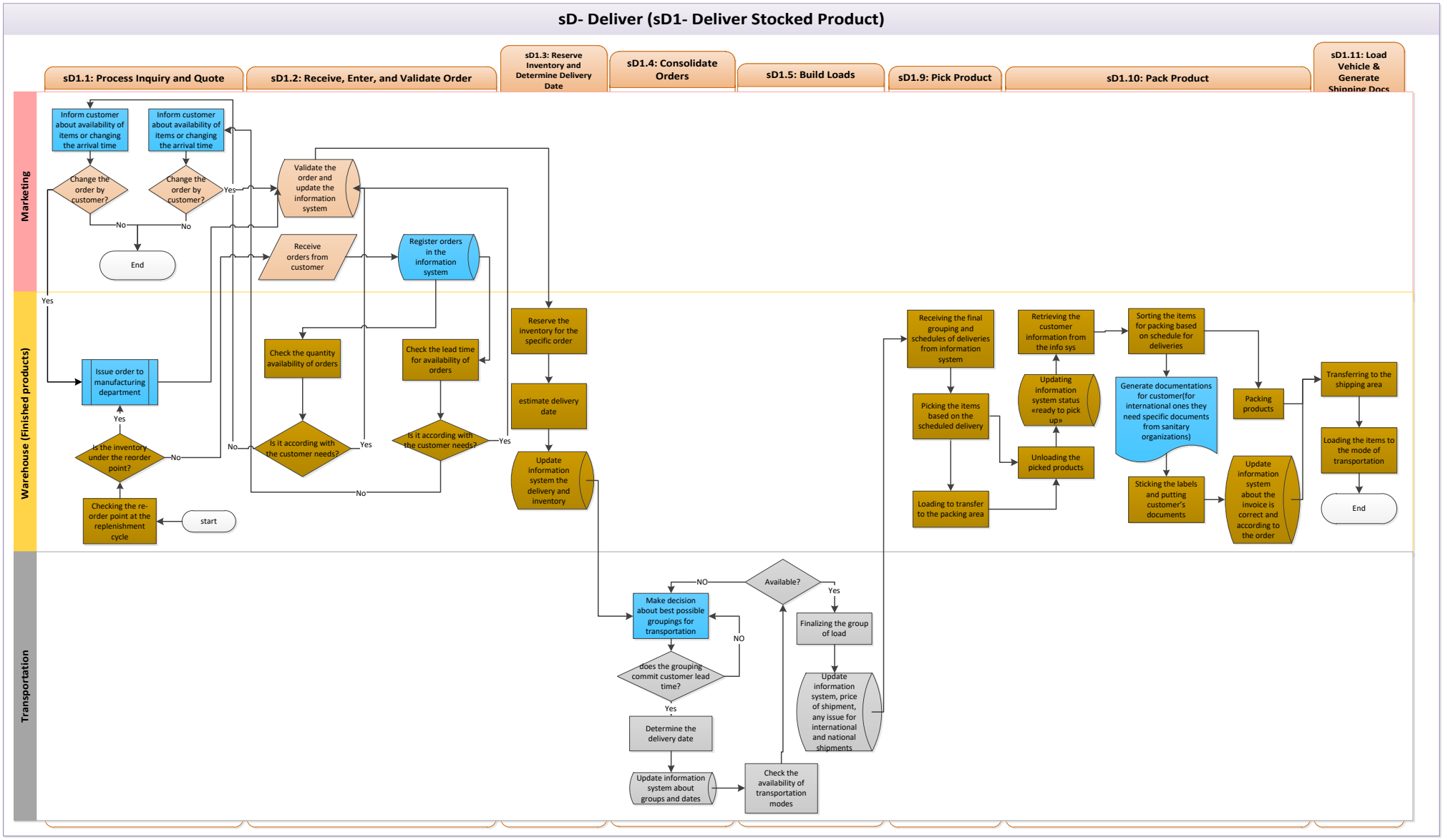


Figure 47 Deliver process mapping with Non-value added activities for Food company

Furthermore, Figure (48) is a description of the proportion of various wastes as non-value added activities for Source and Deliver process of the food company. It is determined by the outcomes of the process mapping based on the current situation of the Food company. The results show that the Source process accounts for the greatest portion of waste (around 69%) for this Food company. This may result from the specific industry to which the business belongs. Due to the presence of numerous parameters outside human control, businesses that rely heavily on agriculture as a supply of raw materials inevitably generate a variety of wastes in sourcing process. As a result, the investigated Food company in this research should prioritize wastes in source process as the primary objective for the improvement roadmap. Yet over 32% of all wastes are associated with Deliver, so that process deserves attention as well.

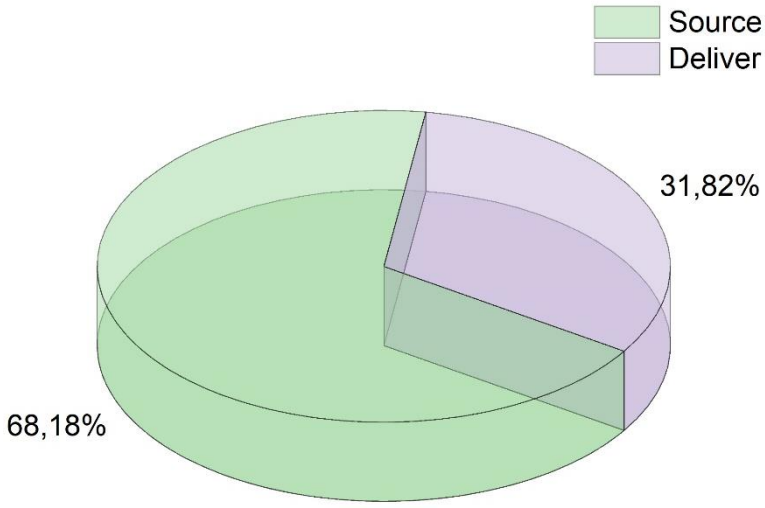


Figure 48 Comparing amount of Source and Deliver wastes for Food company

Moreover, as can be seen in Figure (49), the Food company's waste is generated mostly through the Source process, rather than the Deliver process. According to the proportion of discovered wastes, Transportation wastes (27%) in the Food company's Source process could be equally significant as Over Processing (33%) waste in the same process. However, in the Deliver process, most of the waste is due to Over Processing (71%) when compared to other wastes in the same process. To be more precise, the Deliver procedure is more straightforward and more standard than the Source process since its parameters are more certain, and it does not rely on the agricultural process. As a result, a minor percentage of the detected wastes came from other categories of waste, such as Wait and Defect.

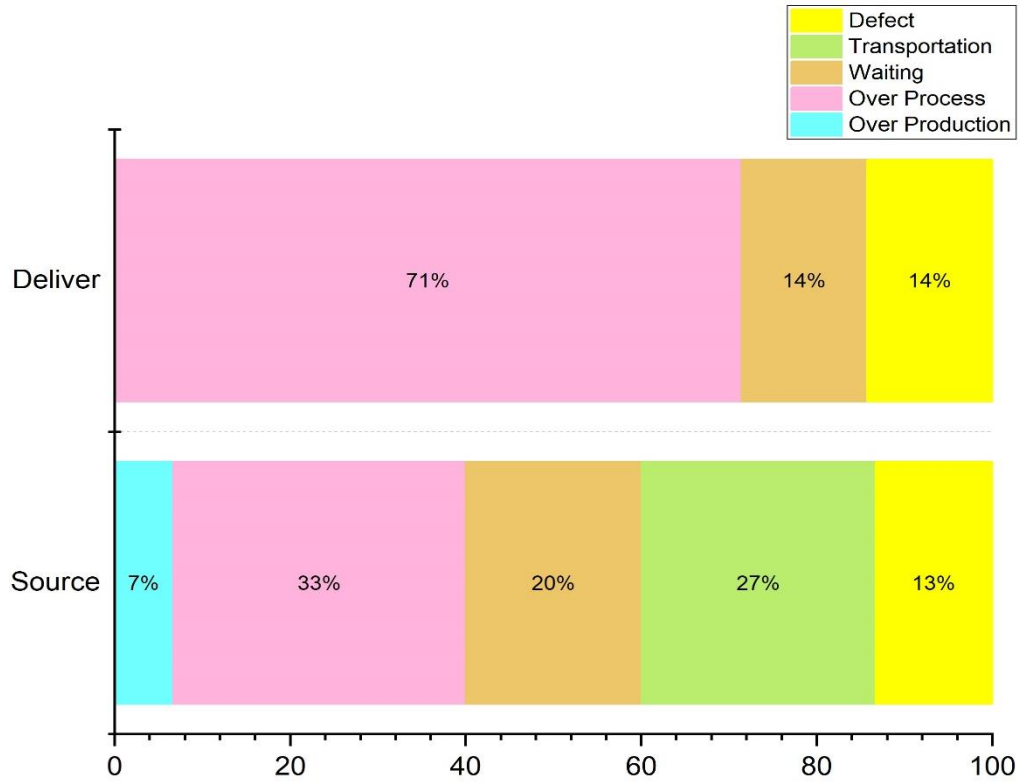


Figure 49 Comparing number of different types of wastes in Source and Deliver for Food company

5.3.3 Finding waste root causes for Food company

According to the detailed steps that have been described in Figure (42) also the main root causes for each identified waste is obtained for the wastes in the Food company. The following Table (22) just represents a part of the full root causes analysis for the Source process of this company. The full version of the analysis for each process have been attached in the appendix A.

Table 22 Example of applying 5why method in Source process of Food company

	why?	Update information system with the information about the farmers and land [S-OPR4]	Collecting samples from the farm and analyzing [S-OPR5]
Over Processing	***Waste description***	*This is time consuming task to follow the treatments from each farmer, validating that, and inserting in the information system for recording the data*	*It is a time consuming task for the company and employees for collecting samples weekly from all farms in the time of harvesting*
	1st why?	Because the related employee should negotiate with farmers and after validating the specific treatments insert them one by one to the information system.	Because need to estimate the best time for harvesting the olives for each farm to have the best olive oil quality
	2nd why?	There is not a reliable and real time system among company, farmers and suppliers(shopping centers for treatments to the farmers)	Because the company just rely on the results of samples to estimate the harvesting time

5.3.4 Customizing improvement solutions for Food company

As described in Figure (43), the list of the suggested Industry4.0 technologies has been prepared for each of the identified wastes in the Food company. Therefore, Table (23) just shows a part of this step and full version of the suggestion for each waste is available in appendix A.

Table 23 Example of suggesting Industry 4.0 technologies for Source process of Food company

	why?	Update information system with the information about the farmers and land [S-OPR4]	Collecting samples from the farm and analysing [S-OPR5]
Over Processing	***Waste description***	This is time consuming task to follow the treatments from each farmer, validating that, and inserting in the information system for recording the data	It is a time consuming task for the company and employees for collecting samples weekly from all farms in the time of harvesting
	1st why?	Because the related employee should negotiate with farmers and after validating the specific treatments insert them one by one to the information system.	Because need to estimate the best time for harvesting the olives for each farm to have the best olive oil quality
	2nd why?	There is not a reliable and real time system among company, farmers and suppliers(shopping centers for treatments to the farmers)	Because the company just rely on the results of samples to estimate the harvesting time
	suggested technologies	CC, BC	Drones, BDA
	benefits of **CC** for alleviating the waste and how it works	CC can connect the centers for selling the treatments to the farmers directly to the company to inform company about the type of treatment they buy and the advice instructions for applying that to the olives trees.	
	benefits of **Drone** for alleviating the waste and how it works		Drones can remove the efforts of company and employees to collect the samples from each farm. Since by flying above the farms it can collect the data and take related pictures to analyze that by BDA.
	benefits of **BDA** for alleviating the waste and how it works		BDA as in combination with Drones can remove the efforts for collecting the samples and analyzing them. Since BDA can make a powerful tool for predicting the time of harvest based on the previous data and collected image and image processing algorithms.
	benefits of **BC** for alleviating the waste and how it works	BC can make reliable environment to have a trustful relationship with treatment centers and company. In this way, nobody can change the related information and this information can keep in reliable way to use for other purposes by company like providing the quality certificate to its customers.	

Chapter 6

Computational preliminaries for constructing Lean DSC framework

This chapter's goal is to present the overarching concept driving the selection of approaches and theories for implementing the computational portion of the Lean DSC framework. Therefore, section 6.1 explains why the author chose to build the Lean DSC framework on the primary principle of Multi Criteria Decision Making (MCDM). The benefits of utilizing Grey numbers as the central theory to address the subjectivity inherent in MCDM are then outlined in section 6.2. Section 6.3 then discusses how FUCOM, as the preferred MCDM approach, stacks up against its competitors.

6.1 Multi Criteria Decision Making

The MCDM approach is mostly utilized for the purpose of providing solutions by referring to the real requirements that are stated by decision makers (Anysz et al., 2020). In this regard, MCDM approaches can be seen among the most popular and powerful tools for evaluating options and recommending the most appropriate action based on the data availability (Akbari et al., 2021). Therefore, MCDM methods can be used to assess the significance of different types of wastes in the present study and paving the way for their elimination or reduction with construction of a Lean DSC framework.

In this regard, there are two primary distinctive techniques in providing solutions in MCDM methods, namely: objective methods and subjective methods. In the objective methods there is no need to collect information and preferences from Decision Makers (DM) as experts. Therefore, in the objective methods the importance (weights) of options is obtained according to the specific computational methods (Cao et al., 2019) by minimizing the interactions with experts. Variation Coefficient, Shannon entropy, Criteria Importance Through Intercriteria Correlation (CRITIC), and Ideal Point are some of the most common methods as objective methods in MCDM (Zhu & Liu, 2021).

On the contrary, in subjective methods, DMs express their judgments on a set of options, and they are asked to give their opinion on the importance of each option. Hence, subjective approaches heavily rely on pairwise comparisons in order to gain

the judgment of specialists (Pamučar et al., 2018). For instance, Best-Worst Method (BWM), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHE), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are few of the subjective MCDM methods (Zakeri et al., 2022). In fact, using such a subjective method and enhancing interaction with experts as DMs can increase employee participation in establishing the final Lean DSC framework. The more employees engage in defining the final solution, the more likely they follow it in the implementation phase.

Furthermore, subjective MCDM approaches mainly collect the DMs preferences based on a linguistic scale. As a result, determining a linguistic scale to collect expert judgments on each pairwise comparison is required. It is worth mentioning that due to the subjectivity of these methods if multiple experts state the same preferences on a set of options it cannot guarantee the same weights for the options (Cao et al., 2019). As a result, it is necessary to determine an effective technique to deal with this uncertainty in the context of subjective judgments in MCDM methods and address it. A number of different theories, including Fuzzy theory and Grey theory have been developed to assist with this kind of uncertainty.

To sum up, Grey theory is discussed as the basic answer to dealing with the indicated uncertainty in section 6.2, and the key benefits of using it are described. Finally, in section 6.3, FUCOM is introduced and compared to the other methods as the major subjective MCDM approach for ranking the identified wastes to build the Lean DSC framework.

6.2 Grey theory

Grey theory is a generalized form of fuzzy theory (Bai & Sarkis, 2014; Li et al., 2007). In fact, Grey theory was born from Grey set to solve the problem related to the uncertainty and incomplete information in discrete data (Keller Richter et al., 2016; Li et al., 2007; Lin et al., 2008; Oztaysi, 2014).

According to Grey theory, systems can be divided into three different categories based on the availability of information. Therefore, if the information about a system is fully available and known by the decision-maker or observer it is called a white system. On the other hand, if the information is unknown the system is categorized as a black system. Accordingly, when there is a system with partially known and partially unknown available information, the system has been called a Grey system (Li et al., 2007).

In this regard, Grey numbers can be used for describing the information related to the Grey system. The main privilege of using Grey theory compared with the Fuzzy sets theory is the higher flexibility of Grey theory (Li et al., 2007). In fact, in Grey numbers there is an interval with known upper and lower bounds; however; unlike the Fuzzy numbers the exact distribution of the interval is unknown (Li et al., 2007; Oztaysi, 2014). Therefore, it brings about higher flexibility and more precision in expressing human judgment. In fact, Grey numbers can assist decision-makers by integrating subjective judgments out of a small amount of data to obtain valuable information (Keller Richter et al., 2016).

There are many real situations when the information about the system items is neither deterministic nor totally unknown (Liu et al., 2011). In this regard, decisions related to the importance of wastes identified by Lean principles can be also identified as partially known systems to be modeled by Grey numbers. As a matter of fact, the identified wastes are related to the different processes and departments, and they have relatively partially unknown influences on the other departments and their performances. For instance, the effect of a delay in procurement of raw materials has partially unknown effect in relation to delivery date of the finished products to the customer. Therefore, due to the such unknown relationships and effects between different identified wastes, the evaluation of the system by experts requires to deal with these uncertainties and complexities in an appropriate way (Lin et al., 2008). As a result, it makes it difficult to express the importance of the identified wastes by exact numbers as a deterministic judgment (Li et al., 2007). Thus, in the present study using Grey numbers as intervals for expressing experts' judgments can lead to more precise judgments. This implies the significance of using Grey numbers to collect the experts' judgment about the waste to construct a more reliable and realistic Lean DSC framework. In the following the main preliminaries about the Grey numbers have been described (Oztaysi, 2014).

Definition 1. An interval Grey number $\otimes a = [\underline{a}, \overline{a}]$ is defined as an interval with known lower $\underline{a}$ and upper $\overline{a}$ bounds, but unknown distribution information. That is,

$$\otimes a = [\underline{a}, \overline{a}] = [a' \in a \,|\underline{a} \leq a' \leq \overline{a}], \quad (1)$$

Where $\underline{a}$ and $\overline{a}$ are the minimum possible value and the maximum possible value respectively. Obviously, if $\underline{a} = \overline{a}$ then the interval Grey number $\otimes a$ is reduced to a real crisp number.

Definition 2. Given two intervals Grey numbers $\otimes a = [\underline{a}, \overline{a}]$ and $\otimes b = [\underline{b}, \overline{b}]$, the basic mathematics operations that can be perform on them can be defined by the following relationships:

$$\otimes a + \otimes b = [\underline{a} + \underline{b}, \overline{a} + \overline{b}] \quad (2)$$

$$\otimes a - \otimes b = [\underline{a} - \overline{b}, \overline{a} - \underline{b}] \quad (3)$$

$$\otimes a \times \otimes b = [\min(\underline{a}\,\underline{b}, \underline{a}\,\overline{b}, \overline{a}\,\underline{b}, \overline{a}\overline{b}), \max(\underline{a}\,\underline{b}, \underline{a}\,\overline{b}, \overline{a}\,\underline{b}, \overline{a}\overline{b})] \quad (4)$$

$$\otimes a \div \otimes b = [\min\left(\tfrac{a}{\underline{b}}, \tfrac{a}{\overline{b}}, \tfrac{\overline{a}}{\underline{b}}, \tfrac{\overline{a}}{\overline{b}}\right), \max(\tfrac{a}{\underline{b}}, \tfrac{a}{\overline{b}}, \tfrac{\overline{a}}{\underline{b}}, \tfrac{\overline{a}}{\overline{b}})] \quad (5)$$

Definition 3. Consider k belongs to the set of real numbers, $k \in \mathbb{R}$. The operation of multiplying and dividing the interval Grey number $\otimes a$ by k is done by the following equations:

$$k \times \otimes a = k \times [\underline{a}, \overline{a}] = \begin{Bmatrix} If\ k \geq 0, then\ k \times \otimes a = [k\underline{a},\ k\overline{a}] \\ If\ k < 0,\ then\ k \times \otimes a = [k\overline{a},\ k\underline{a}] \end{Bmatrix} \quad (6)$$

$$\otimes a \times \frac{1}{k} = \begin{cases} If\ k \geq 0, then\ \frac{1}{k} \times [\underline{a}, \overline{a}] = [\frac{a}{k}, \frac{\overline{a}}{k}] \\ If\ k < 0\ , then\ \frac{1}{k} \times [\underline{a}, \overline{a}] = [\frac{\overline{a}}{k}, \frac{a}{k}] \end{cases} \quad (7)$$

Definition 4. The whitening value of a Grey number $\otimes a$, is defined as a deterministic number with its value lying between the upper and lower bounds of $\otimes a$:

$$\underline{a} \leq \widetilde{\otimes} a \leq \overline{a} \quad (8)$$

Where $\widetilde{\otimes} a$ is a whitening value of $\otimes a$. This relation can be expressed as:

$$\widetilde{\otimes} a = \underline{a} + \alpha\ (\overline{a} - \underline{a}) \quad (9)$$

Where α is a Grey coefficient. When 0< α <1, i.e.$\alpha \in (0,1)$, $\widetilde{\otimes} a$ will change between its upper and lower bounds, $\widetilde{\otimes} a \in (\underline{a}, \overline{a})$; when $\alpha = 0$, $\widetilde{\otimes} a$ will reach its lower bound, i.e. $\widetilde{\otimes} a = \underline{a}$; when $\alpha = 1$, $\widetilde{\otimes} a$ will reach upper bound, i.e. $\widetilde{\otimes} a = \overline{a}$.

Suppose Grey number $\otimes a = [\underline{a}, \overline{a}]$, where $\underline{a} < \overline{a}$, in the case of lack of the distribution information of the value of Grey number $\otimes a$, if a Grey number $\otimes a$ is continues, then $\otimes \hat{a} = \frac{1}{2}(\underline{a} + \overline{a})$ is called the kernel of Grey number $\otimes a = [\underline{a}, \overline{a}]$. To reaching this value, the α value is considered equals to $\frac{1}{2}$ in formula 9. In this study, the formula 9 using $\alpha = \frac{1}{2}$, is employed for whitening the Grey numbers.

In the present research, the linguistic scale is applied to collect the experts' perspective about importance of identified wastes in Source and Deliver processes. In this regard, a 9-point linguistic scale is used to acquire experts' judgments with great accuracy. Afterwards, due to the vagueness and uncertainty related to the experts' judgments by the linguistic scale, the transition of the vagueness related to that scale is modeled by applying Grey theory. Table (24) shows the linguistic scale and related Grey numbers for the present work. According to (Lin et al., 2008), the length of each grey interval can indicate the level of uncertainty from experts (DMs) in selecting the relevant linguistic variable. As a result, a wider interval is assigned to the grey intervals associated with "Weak Important" (WI) and "Extremely Important" (EI). It can cover the higher uncertainty related to the very strong and very weak evaluations of options from experts.

Table 24 The linguistic variable and its related Grey number

Linguistic Scale	Grey interval numbers
Equal Important (EqI)	[1,1]
Weak Important (WI)	[1,2.5]
Little Important (LI)	[2.5,3.5]
Moderate Important (MI)	[3.5,4.5]
Moderate Plus Important (MpI)	[4.5,5.5]
Strong Important (SI)	[5.5,6.5]
Strong Plus Important (SpI)	[6.5,7.5]
Very Strong Important (VsI)	[7.5,8.5]
Extremely Important (ExI)	[8.5,10]

6.3 FUCOM method

FUCOM is a new Multi Criteria Decision Making(MCDM) method invented by (Pamučar et al., 2018). This method enables the decision makers to make the judgments based on the less pairwise comparisons among alternatives than the other MCDM methods previously mentioned. In fact, the accuracy of the MCDM methods for obtaining the weights of alternatives can be directly affected by the amount of the pairwise comparison. The more pairwise comparison leads to the less accuracy of the weight calculation (Pamučar et al., 2018; Popović et al., 2022). To this end, the FUCOM method just needs $(n-1)$ comparisons among n alternatives. For instance, other MCDM method like Analytic Hierarchy Process (AHP) and Best-Worst Method (BWM) need $n(n-1)/2$ and $(2n-3)$ pairwise comparison among different alternatives respectively (Pamučar et al., 2018).

Moreover, one of the other important factors in comparing different MCDM methods is the final consistency of the obtained weights to provide more reliable results by less subjectivity among pairwise comparisons. However, other MCDM methods like Decision-making Trial and Evaluation Laboratory (DEMATEL) and Step-Wise Weight Assessment Ratio Analysis (SWARA) cannot provide any index or way to calculate the consistency of the results (Pamučar et al., 2018). In this regard, the BWM is one of the MCDM methods in recent years with less pairwise comparison and providing a way to express the consistency of judgments. Nonetheless, in the BWM still due to the higher number of pairwise comparison compared with the FUCOM, the range for the consistency of results can range between zero and one. On the other hand, the value of the Deviation From Consistency(DFC) index in FUCOM is varied in the acceptable range $[0,0.025\ ]$. Therefore, the final consistency obtained by FUCOM is higher than the BWM due to the less pairwise comparison needed (Popović et al., 2022).

Totally, the following benefits can be summed up as the primary benefits of the FUCOM approach, according to (Pamučar et al., 2018):

- Finding optimal weight coefficients and being able to validate them based on the consistency of the outcomes is possible thanks to FUCOM.
- Decision-makers can prioritize a number of criteria in analyzing phenomena in light of current circumstances by using FUCOM's straightforward mathematical modeling to determine optimal values for weight coefficients.
- The final values of the weights of criteria determined by FUCOM are optimized with respect to minimizing both the amount of subjectivity involved and the effect of inconsistencies in expert preferences.
- Only the n-1 comparison of criteria is required.
- The model is adaptable, so it may be used with a variety of scales that represent various aspects of the preferences of experts.

Since its initial presentation by (Pamučar et al., 2018) in 2018, FUCOM has been employed in a wide range of research topics in recent years. The articles that applied the FUCOM as part of their solutions are classified in Table (25). This table categorizes all publications into twelve major subjects.

Among these studies on using FUCOM in various areas (See Table (25)), numerous papers have used this approach in the field of SC. In this regard, (Zavadskas et al., 2018) select AGVs using FUCOM for warehouse automation. Also, (Fazlollahtabar, Smailbašic, et al., 2019; Mahmutagić et al., 2021) apply FUCOM to find the most efficient forklift types in the warehouse, or purchase new ones for warehouse logistical processes. Furthermore, FUCOM is utilized in the manufacturing process to prioritize the discovered failure modes and associated risks (Dhalmahapatra et al., 2022; Yousefi et al., 2021). Similarly, FUCOM may employ to make SC more resilient by evaluating resilience strategies and associated risks (Baig et al., 2022; Sharma et al., 2021). In addition, there are some FUCOM efforts on determining the optimal location of the SC infrastructures such as logistics platforms (Ayadi et al., 2021) and logistics centers (Yazdani et al., 2020). Additionally, the FUCOM technique demonstrates the capacity to be used for inventory categorization and management as part of SC processes (Erceg et al., 2019; Vukasović et al., 2021). Aside from that, FUCOM is useful in assisting DMs in selecting the most appropriate suppliers based on multiple factors in various industries such as automotive (A. R. Mishra et al., 2022), and making the supplier selection process more sustainable (Durmić, 2019; Ecer & Torkayesh, 2022; Stević et al., 2019).

According to the findings in Table (25), this is the first time that FUCOM has been applied in accordance with Grey theory in order to prioritize the wastes that have been found within the context of the Lean concept. In reality, FUCOM can be useful for practitioners in defining an improvement plan as the long- and short-term strategy for the business to eliminate or decrease waste. Through this method, the ultimate objective of the current research is to establish the industry 4.0 roadmap using the priorities that were determined for the wastes.

Table 25 Published papers in different areas by applying FUCOM

Subject Area	papers	# paper
Industrial facility design	(Božanić et al., 2021; Fazlollahtabar, Smailbašić, et al., 2019; Gölcük et al., 2022; Mahmutagić et al., 2021; Ong et al., 2021; Zavadskas et al., 2018)	6
Infrastructure and site location	(Ayadi et al., 2021; Badi & Kridish, 2020; Božanic et al., 2019, 2020; Puška et al., 2022; Ulutaş & Karakuş, 2021; Yazdani et al., 2020)	7
Construction Industry	(Anysz et al., 2020)	1
Supplier selection	(Durmić, 2019; Ecer & Torkayesh, 2022; Erceg & Mularifović, 2019; Matić et al., 2019; A. R. Mishra et al., 2022; Stević et al., 2019)	6
Performance assessment	(Abdullah et al., 2022; Badi & Abdulshahed, 2019; Erceg et al., 2019; Stević et al., 2021; Vukasović et al., 2021)	5
Risk, resilience and FMEA	(Baig et al., 2022; Dhalmahapatra et al., 2022; A. U. Khan & Ali, 2022; F. Khan et al., 2022; Pervez et al., 2022; Rehman et al., 2022; Sharma et al., 2021; Yousefi et al., 2021)	8
Safety	(Blagojević et al., 2021; Nenadić, 2019; Simić et al., 2020)	3
Healthcare	(F. Khan & Ali, 2022; Khosravi et al., 2022; Saha et al., 2022)	3
Mobility and transportation	(Đalić et al., 2021; Ivanović et al., 2022; Noureddine & Ristic, 2019; Pamucar et al., 2020, 2021, 2022; Pamučar et al., n.d.; Starčević et al., 2019; Stevi´c et al., 2022; Van Hoan & Ha, 2020; Vesković et al., 2020, 2022; Zagradjanin et al., 2019)	13
Energy and natural resources	(Akbari et al., 2021; Cao et al., 2019; Feizi et al., 2021; Nunić, 2019; Srivastava & Singh, 2021; Tang et al., 2021; D. Xu et al., 2020)	7
Tourism	(Mijajlović et al., 2020; Ocampo, 2022; Puška et al., 2019, 2021)	4

Following are the essential steps for developing the Grey-FUCOM model to acquire the weight coefficients of the identified wastes for each expert (DM). The steps right below have been defined based on selected reference about the grey as mentioned in section 6.2 and FUCOM presented in (Pamučar et al., 2018).

Step1*:* In the first step is wanted from each decision maker to rank the criteria from a predefined set of criteria. Therefore, based on the weight coefficients of the criteria expected by each DM, a rank from the most important criteria to the least one.

$$C_{j(1)} > C_{j(2)} > \cdots > C_{j(k)} \quad (10)$$

Where k represents the rank of the observed criterion. If there is a judgment of the existence of two or more criteria with the same significance, the sign of " = " is place instead of ">" between these criteria in the expression (10).

Step 2*:* In the second step, a comparison between the ranked criteria is carried out and the comparative priority ($\otimes\varphi_{k/_{k+1}}, k = 1,2, \dots, n$, where k represents the

rank of the criteria) of the evaluation criteria is determined.

$$\Phi = \left(\otimes\varphi_{1/2}, \otimes \varphi_{2/3}, \dots, \otimes\varphi_{k/(k+1)}\right) \quad (11)$$

In order to determine the significance of the criteria, considered a predefined linguistic scale for the comparison of criteria connected to the Grey numbers (see Table (24)), each DM compare the criteria and determine the significance of each individual criterion in the expression (10). In this manner, comparison is made with respect to the first-ranked (the most significant) criterion for the sequence suggested by each decision maker. Thus, the Grey significance of the criteria ($\otimes\varpi_{C_{j(k)}}$) for all of the criteria ranked in Step 1 is obtained. Therefore, the first-ranked criterion is compared with itself ($\varpi_{C_{j(1)}=1}$). As a result, the n−1 comparison of the criteria should be performed.

***Step 3**:* In the last step, the final values of the weight coefficients for all criteria are obtained by regarding the satisfaction of the two conditions below:

(1) The ratio of the weight coefficients is equal to the Grey comparative priority among the observed criteria ($\otimes\varphi_{k/(k+1)}$) defined in Step 2; i.e., that the following condition is met:

$$\frac{w_k}{w_{k+1}} = \otimes\varphi_{k/(k+1)} \quad (12)$$

(2) In addition to the previous condition, the final values of the weight coefficients should satisfy the condition of mathematical transitivity. If $\otimes\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\otimes\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, then weight coefficients of the evaluation criteria need to meet the following:

$$\frac{w_k}{w_{k+2}} = \otimes\varphi_{k/(k+1)}\otimes\varphi_{(k+1)/(k+2)} \quad (13)$$

In this manner, the model could satisfy the minimum Deviation from the Consistency (DFC (x) =0), this is a requirement for maximum consistency to be fulfilled. In the last step, the final Grey weight coefficients have been whitened to convert the Grey intervals to crisp numbers to provide a consistent interpretation of the final outcomes. Therefore, the final model for the Grey-FUCOM method is presented as follows:

$$\begin{aligned} &\text{Min } x \\ &\text{s.t.} \\ &\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \widetilde{\otimes}\,\varphi_{k/(k+1)}\right| \le x, \forall j \\ &\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \widetilde{\otimes}\,\varphi_{k/(k+1)}\widetilde{\otimes}\,\varphi_{(k+1)/(k+2)}\right| \le x, \forall j \\ &\sum_{j=1}^{n} w_j = 1, \forall j, w_j \ge 0, \forall j \end{aligned} \quad (14)$$

Final values for weight coefficients are obtained by solving the model (14), which is $(w_1, w_2, \dots, w_n)^T$ and following that DFC (χ) are generated. The

following chapter discusses the applicability of Grey-FUCOM in constructing the Lean DSC framework for two different real case studies.

Chapter 7

Lean DSC roadmap for Automotive company

This chapter presents the results of the Automotive company as described in section 5.2. The results have been obtained based on the computational procedures detailed in chapter 6. Therefore, the framework discussed in chapter 5 has been applied to the Automotive company by completing it in its parts requiring a real setting be developed. In such way the final solution for the company was created by building the Lean DSC roadmap. Figure (50) describes the different steps to construct such a Lean DSC roadmap (1st phase and 2nd phase).

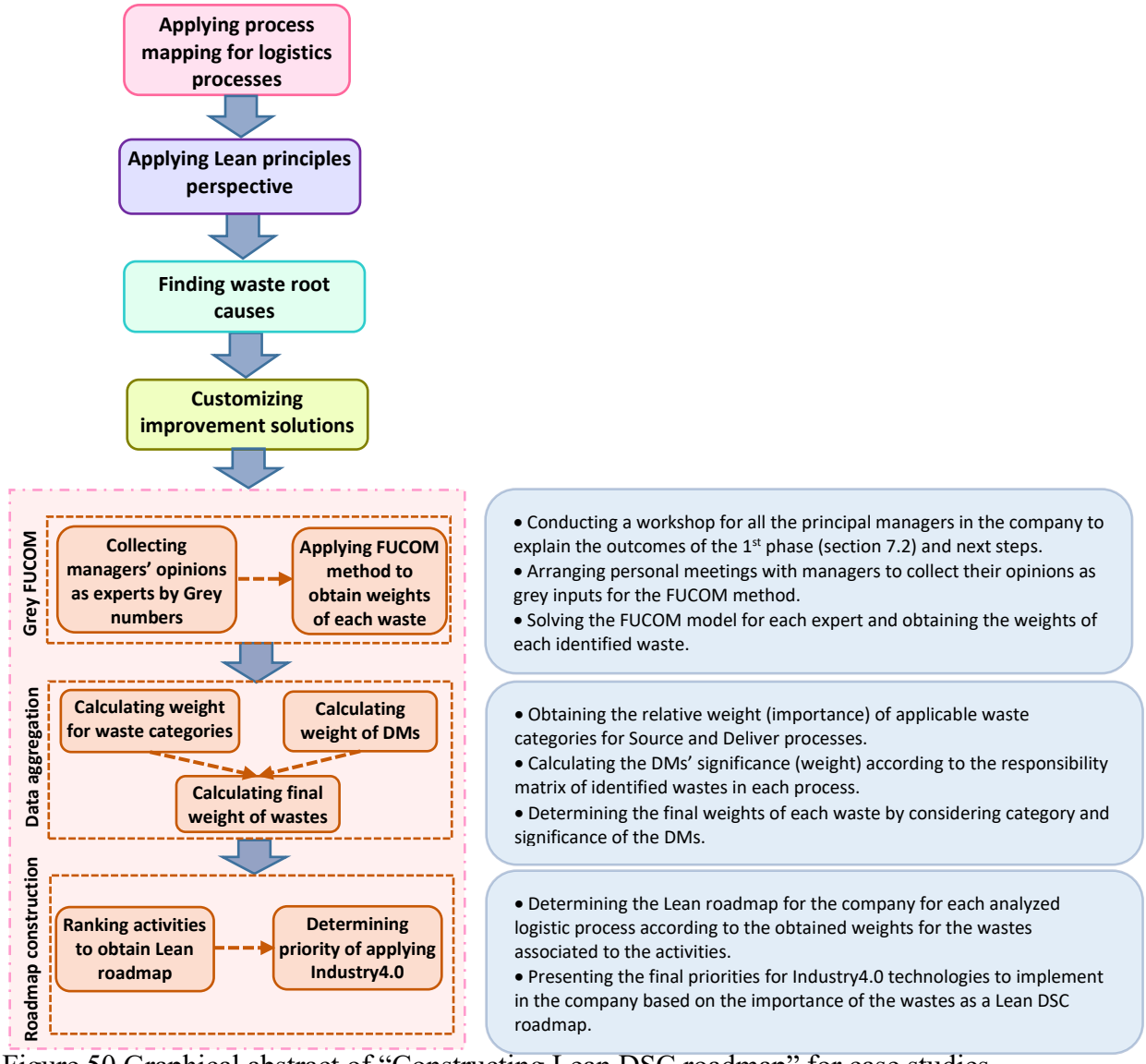


Figure 50 Graphical abstract of "Constructing Lean DSC roadmap" for case studies

7.1 Data collection for Automotive company

This part aims to collect information from the experts in the company. The considered experts are managers from main departments of the company. All of them have authorization and responsibility to decide about strategies to follow for their related department. Therefore, in total they can have an effect also on long term strategies of the company. Thus, seven managers have participated in the final data collection. All these managers are knowledgeable about the related activities of their department and know about the main activities in the other departments since they have daily collaboration and meetings with each other for completing different tasks in the company. Table (26) shows the related information about each manager as the experts for this phase.

Table 26 Information about managers of Automotive company

DM	Position and role of expert	Years of experience
DM1	Logistics manager	20
DM2	Scheduling manager	20
DM3	Procurement manager	22
DM4	Marketing manager	20
DM5	CEO	25
DM6	Quality manager	27
DM7	Financial manager	25

The first stage of the data-collecting process consists of holding a workshop, with all the seven managers. The workshop lasted around one hour, when participants were given the opportunity to discuss and question various topics related to the primary purpose of the work, process mapping, waste that had been discovered, and the value that might be gained from utilizing Industry4.0 technologies for each waste. In fact, this workshop's primary purpose is to introduce project-related details, ensuring that all the experts are aware of the project's primary objectives. Also, the method by which the experts' opinions will be collected is described. Therefore, the results of the first phase (chapter 5) of the research have been communicated to the managers during the workshop, alongside general information about different forms of waste based on Lean and the introduction of Industry 4.0 technologies. The workshop material contained a graphical representation of process mapping in the Source and Deliver processes, the description of identified wastes in each process, an explanation of the root causes for each waste, as well as the advantages of recommended digital technologies for each waste. As a consequence of this, any questions or concerns that may have been raised by managers regarding the provided information and the project have been addressed.

Afterward, individual meetings have been conducted with each manager in the following days to collect their individual opinions and judgments. Each individual meeting takes around 20 to 30 minutes. Also, the meetings have been conducted individually to avoid the bias and effects of the other managers' opinions on every single expert. Therefore, according to the different steps of the FUCOM method (section 6.3) an Excel file has been prepared to facilitate data collection

from managers about the identified wastes. The following section explains the raw data collected from experts and the main steps to obtain the results based on the experts' judgments.

7.2 Applying Grey-FUCOM for Automotive company

Each expert has gone through the following procedure in order to rank the identified wastes in accordance with the steps outlined in sections 6.2 and 6.3 to apply the FUCOM method.

Step 1: In the first phase of the process, during the individual interviews with each manager, they were asked to express their own preferences to rank the identified wastes in each category according to the seven types of Lean wastes, starting from the wastes that are the most significant to the wastes that are the least essential. Therefore, Tables (27) and (28), indicate the individual preferences of each manager on the various types of waste that were detected throughout the Source and Deliver processes, respectively (reference to the table of chapter 5).

Table 27 Automotive managers' preferences about the different categories of identified wastes for the Source process

DM	Ranking preference for Source wastes
Logistics(DM1)	$S-MT_1 > S-MT_2$
Procurement(DM2)	$S-MT_1 > S-MT_2$
Quality(DM3)	$S-MT_2 > S-MT_1$
Financial (DM4)	$S-MT_2 > S-MT_1$
CEO (DM5)	$S-MT_2 > S-MT_1$
Scheduling (DM6)	$S-MT_1 > S-MT_2$
Marketing (DM7)	$S-MT_2 > S-MT_1$
Logistics(DM1)	$S-OPR_6 > S-OPR_4 > S-OPR_5 > S-OPR_3 > S-OPR_2 > S-OPR_1$
Procurement(DM2)	$S-OPR_2 > S-OPR_1 > S-OPR_4 > S-OPR_5 > S-OPR_3 > S-OPR_6$
Quality(DM3)	$S-OPR_4 > S-OPR_5 > S-OPR_6 > S-OPR_3 > S-OPR_2 > S-OPR_1$
Financial (DM4)	$S-OPR_5 > S-OPR_4 > S-OPR_6 > S-OPR_1 > S-OPR_3 > S-OPR_2$
CEO (DM5)	$S-OPR_1 > S-OPR_5 > S-OPR_3 > S-OPR_2 > S-OPR_4 > S-OPR_6$
Scheduling (DM6)	$S-OPR_4 = S-OPR_5 > S-OPR_3 > S-OPR_2 = S-OPR_6 = S-OPR_1$
Marketing (DM7)	$S-OPR_3 = S-OPR_2 = S-OPR_1 = S-OPR_4 > S-OPR_5 = S-OPR_6$

Table 28 Automotive managers' preferences about the different categories of identified wastes for the Deliver process

DM	Ranking preference for Deliver wastes
Logistics(DM1)	$D-MT_1 > D-MT_2$
Procurement(DM2)	$D-MT_1 > D-MT_2$
Quality(DM3)	$D-MT_2 > D-MT_1$
Financial (DM4)	$D-MT_1 > D-MT_2$
CEO (DM5)	$D-MT_1 > D-MT_2$
Scheduling (DM6)	$D-MT_1 > D-MT_2$
Marketing (DM7)	$D-MT_1 > D-MT_2$
Logistics(DM1)	$D-OPR_5 > D-OPR_6 > D-OPR_8 > D-OPR_3 > D-OPR_7 > D-OPR_4 > D-OPR_2 > D-OPR_1$
Procurement(DM2)	$D-OPR_5 > D-OPR_4 > D-OPR_7 > D-OPR_6 > D-OPR_8 > D-OPR_3 > D-OPR_2 > D-OPR_1$
Quality(DM3)	$D-OPR_1 > D-OPR_3 > D-OPR_5 > D-OPR_8 > D-OPR_4 > D-OPR_7 > D-OPR_2 > D-OPR_6$
Financial (DM4)	$D-OPR_3 > D-OPR_5 > D-OPR_6 > D-OPR_2 > D-OPR_4 > D-OPR_7 > D-OPR_1 > D-OPR_8$
CEO (DM5)	$D-OPR_5 > D-OPR_1 > D-OPR_2 > D-OPR_3 > D-OPR_7 > D-OPR_6 > D-OPR_4 > D-OPR_8$
Scheduling (DM6)	$D-OPR_2 > D-OPR_1 = D-OPR_3 = D-OPR_7 = D-OPR_6 > D-OPR_4 = D-OPR_5 = D-OPR_8$
Marketing (DM7)	$D-OPR_1 = D-OPR_2 > D-OPR_3 = D-OPR_6 > D-OPR_7 = D-OPR_5 = D-OPR_4 = D-OPR_8$
Logistics(DM1)	$D-WT_1 > D-WT_2 > D-WT_3$
Procurement(DM2)	$D-WT_1 > D-WT_2 > D-WT_3$
Quality(DM3)	$D-WT_1 > D-WT_3 > D-WT_2$
Financial (DM4)	$D-WT_2 > D-WT_3 > D-WT_1$
CEO (DM5)	$D-WT_1 > D-WT_2 > D-WT_3$
Scheduling (DM6)	$D-WT_2 > D-WT_1 = D-WT_3$
Marketing (DM7)	$D-WT_1 > D-WT_2 = D-WT_3$

Step 2 : In the second step, DMs were asked to determine the comparative priority of each pair of criteria ($\otimes\varphi_{k/(k+1)}$) by evaluating their grey significance $\left(\otimes\varpi_{C_{j(k)}}\right)$. To this end, the experts express the significance of each criterion compared with the first rank according to the linguistic verbal scale presented in section 6.2 Table (24). Therefore, by associating the assigned linguistic scale to the grey numbers and applying the related operators (see expression (2-5) in chapter 6) the following results have been obtained for the grey significance of the wastes ($\otimes\varpi_{C_{j(k)}}$) that have been presented in Tables (29) and (30) for Source and Deliver process respectively.

Additionally, it is important to note that a pairwise comparison via the waste categories with only one recognized waste is not feasible because these Grey significances have been produced by conducting the pairwise comparison among each waste and the first rank wastes. So, in this case, FUCOM's examination of the Defect waste in the Source process and the Transportation waste from the Deliver process are unnecessary for the Automotive company. They will be addressed and added to the findings immediately with the weight that relates to their waste type, which will be explained in greater detail in section 7.3.

Table 29 Grey significance of the wastes $\left(\otimes\varpi_{C_{j(k)}}\right)$ for Source process of Automotive company

$\otimes\varpi_{C_{j(k)}}$	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
DM 1	[1,1]	[1.36,1.88]				
DM 2	[1,1]	[1,1.3]				
DM 3	[1,1]	[1.22,1.85]				
DM 4	[1,1]	[1,1.44]				
DM 5	[1,1]	[1,1.3]				
DM 6	[1,1]	[1.88,2.86]				
DM 7	[1,1]	[1,1.3]				
DM 1	[1,1]	[1,1]	[1.36,1.88]	[1.36,1.88]	[2.14,3.4]	[2.14,3.4]
DM 2	[1,1]	[1, 1]	[1.15,1,54]	[1.36, 1.88]	[1.36, 1.88]	[1.36, 1.88]
DM 3	[1,1]	[1.13, 1.81]	[2.42,4]	[2.42,4]	[3.4,10]	[3.4, 10]
DM 4	[1,1]	[1,1]	[1.15, 1.54]	[1.15, 1.54]	[1.15, 1.54]	[2.14, 3.4]
DM 5	[1,1]	[1.15,1.54]	[1.15,1.54]	[1.15,1.54]	[1.66, 2.43]	[1.66, 2.43]
DM 6	[1,1]	[1,1]	[1,1.33]	[1.3,1.81]	[1.3,1.81]	[1.3,1.81]
DM 7	[1,1]	[1,1]	[1,1]	[1,1]	[1,1.3]	[1,1.3]

Table 30 Grey significance of the wastes $\left(\otimes\varpi_{C_{j(k)}}\right)$ for Source process of Automotive company

$\otimes\varpi_{C_{j(k)}}$	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8
DM 1	[1,1]	[1.36,1.88]						
DM 2	[1,1]	[1,1.3]						
DM 3	[1,1]	[1.22,1.85]						
DM 4	[1,1]	[1,1.44]						
DM 5	[1,1]	[1,1.3]						
DM 6	[1,1]	[1.88,2.86]						
DM 7	[1,1]	[1,1.3]						
DM 1	[1,1]	[1,1]	[1,1]	[1.13,1.54]	[1.13,1.54]	[1.3,1.81]	[1.3,1.81]	[1.3,1.81]
DM 2	[1,1]	[1,1]	[1.15,1.54]	[1.15,1.54]	[1.15,1.54]	[2.14,3.4]	[2.14,3.4]	[2.14,3.4]
DM 3	[1,1]	[1,1]	[1.13,1.54]	[1.13,1.54]	[1.13,1.54]	[1.88,2.86]	[1.88,2.86]	[1.88,2.86]
DM 4	[1,1]	[1,1]	[1.13,1.54]	[1.3,1.81]	[1.3,1.81]	[1.3,1.81]	[2.43,4]	[2.43,4]
DM 5	[1,1]	[1,1]	[1,1.3]	[1.15,1.54]	[1.15,1.54]	[1.66,2.43]	[1.66,2.43]	[1.66,2.43]
DM 6	[1,1]	[1, 1.3]	[1, 1.3]	[1, 1.3]	[1, 1.3]	[1.13, 1.54]	[1.13, 1.54]	[1.13, 1.54]
DM 7	[1,1]	[1,1]	[1, 1.3]	[1, 1.3]	[1.13, 1.54]	[1.13, 1.54]	[1.13, 1.54]	[1.13, 1.54]
DM 1	[1,1]	[1,1.33]	[1.3,1.81]					
DM 2	[1,1]	[1,1.3]	[1.15, 1.54]					
DM 3	[1,1]	[1.13,1.54]	[1.3,1.81]					
DM 4	[1,1]	[1,1.33]	[1.13,1.54]					
DM 5	[1,1]	[1,1.33]	[1.3,1.81]					
DM 6	[1,1]	[1.13,1.54]	[1.13,1.54]					
DM 7	[1,1]	[1,1.33]	[1,1.33]					

Step 3: After obtaining the Grey significance of each waste for each expert, the conditions (12) and (13) as described in section 6.3 should be satisfied about to the ratio

of the weight coefficients ($\otimes\varphi_{k/(k+1)}$) and mathematical transitivity($\otimes\varphi_{k/(k+1)}\otimes\varphi_{(k+1)/(k+2)}$). Therefore, for constructing the FUCOM method the following results in Tables (31) and (32) present the values for satisfaction of these conditions and guarantee the maximum consistency (Minimum DFC) for Source and Deliver respectively. It is worth mentioning that as discussed in step 3 of section 6.3, the values shown here have been whitened according to the expression (9).

Table 31 FUCOM model for each manager in different waste category of Source process in Automotive company

S-MT	$\boldsymbol{DM_1}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_1}{w_2}-1.62\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_2}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_3}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-1.53\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$
	$\boldsymbol{DM_4}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-1.22\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_5}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-1.15\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_6}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-2.37\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$
	$\boldsymbol{DM_7}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-1.15\right\| \le \chi, \\ \sum_{j=1}^{2} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$		
S-OPR	$\boldsymbol{DM_1}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_6}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_5}-1.62\right\| \le \chi, \left\|\frac{w_5}{w_3}-1\right\| \le \chi \\ \left\|\frac{w_3}{w_2}-1.81\right\| \le \chi, \left\|\frac{w_2}{w_1}-1\right\| \le \chi, \left\|\frac{w_6}{w_5}-1.62\right\| \le \chi \\ \left\|\frac{w_4}{w_3}-1.62\right\| \le \chi, \left\|\frac{w_5}{w_2}-1.81\right\| \le \chi, \left\|\frac{w_3}{w_1}-1.81\right\| \le \chi \\ \sum_{j=1}^{6} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_2}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_2}{w_1}-1\right\| \le \chi, \left\|\frac{w_1}{w_4}-1.34\right\| \le \chi, \left\|\frac{w_4}{w_5}-1.25\right\| \le \chi \\ \left\|\frac{w_5}{w_3}-1\right\| \le \chi, \left\|\frac{w_3}{w_6}-1\right\| \le \chi, \left\|\frac{w_2}{w_4}-1.34\right\| \le \chi \\ \left\|\frac{w_1}{w_5}-1.75\right\| \le \chi, \left\|\frac{w_4}{w_3}-1.25\right\| \le \chi, \left\|\frac{w_5}{w_6}-1\right\| \le \chi \\ \sum_{j=1}^{6} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	
	$\boldsymbol{DM_3}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_4}{w_5}-1.55\right\| \le \chi, \left\|\frac{w_5}{w_6}-2.44\right\| \le \chi, \left\|\frac{w_6}{w_3}-1\right\| \le \chi \\ \left\|\frac{w_3}{w_2}-2.49\right\| \le \chi, \left\|\frac{w_2}{w_1}-1\right\| \le \chi, \left\|\frac{w_4}{w_6}-4.07\right\| \le \chi \\ \left\|\frac{w_5}{w_3}-2.44\right\| \le \chi, \left\|\frac{w_6}{w_2}-2.49\right\| \le \chi, \left\|\frac{w_3}{w_1}-2.49\right\| \le \chi \\ \sum_{j=1}^{6} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_4}$: Min $\boldsymbol{\chi}$ $\begin{cases} \left\|\frac{w_5}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_6}-1.34\right\| \le \chi, \left\|\frac{w_6}{w_1}-1\right\| \le \chi \\ \left\|\frac{w_1}{w_3}-1\right\| \le \chi, \left\|\frac{w_3}{w_2}-2.17\right\| \le \chi, \left\|\frac{w_5}{w_6}-1.34\right\| \le \chi \\ \left\|\frac{w_4}{w_1}-1.34\right\| \le \chi, \left\|\frac{w_6}{w_3}-1\right\| \le \chi, \left\|\frac{w_1}{w_2}-2.17\right\| \le \chi \\ \sum_{j=1}^{6} w_j = 1\ , w_j \ge 0, \forall j \end{cases}$	

	DM_5: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_5}-1.34\right\|\le\chi,\left\|\frac{w_5}{w_3}-1\right\|\le\chi,\left\|\frac{w_3}{w_2}-1\right\|\le\chi\\ \left\|\frac{w_2}{w_4}-1.59\right\|\le\chi,\left\|\frac{w_4}{w_6}-1\right\|\le\chi,\left\|\frac{w_1}{w_3}-1.34\right\|\le\chi\\ \left\|\frac{w_5}{w_2}-1\right\|\le\chi,\left\|\frac{w_3}{w_4}-1.59\right\|\le\chi,\left\|\frac{w_2}{w_6}-1.59\right\|\le\chi\\ \sum_{j=1}^{6}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_6: Min χ $\left\{\begin{array}{l}\left\|\frac{w_4}{w_5}-1\right\|\le\chi,\left\|\frac{w_5}{w_3}-1.16\right\|\le\chi,\left\|\frac{w_3}{w_2}-1.39\right\|\le\chi\\ \left\|\frac{w_2}{w_6}-1\right\|\le\chi,\left\|\frac{w_6}{w_1}-1\right\|\le\chi,\left\|\frac{w_4}{w_3}-1.16\right\|\le\chi\\ \left\|\frac{w_5}{w_2}-1.69\right\|\le\chi,\left\|\frac{w_3}{w_6}-1.39\right\|\le\chi,\left\|\frac{w_2}{w_1}-1\right\|\le\chi\\ \sum_{j=1}^{6}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$
	DM_7: Min χ $\left\{\begin{array}{l}\left\|\frac{w_3}{w_2}-1\right\|\le\chi,\left\|\frac{w_2}{w_1}-1\right\|\le\chi,\left\|\frac{w_1}{w_4}-1\right\|\le\chi\\ \left\|\frac{w_4}{w_5}-1.15\right\|\le\chi,\left\|\frac{w_5}{w_6}-1\right\|\le\chi,\left\|\frac{w_3}{w_1}-1\right\|\le\chi\\ \left\|\frac{w_2}{w_4}-1\right\|\le\chi,\left\|\frac{w_1}{w_5}-1.15\right\|\le\chi,\left\|\frac{w_4}{w_6}-1.15\right\|\le\chi\\ \sum_{j=1}^{6}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	

Table 32 FUCOM model for each manager in different waste category of Deliver process in Automotive company

D-MT	DM_1: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.16\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_2: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.15\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_3: Min χ $\left\{\begin{array}{l}\left\|\frac{w_2}{w_1}-1.62\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$
	DM_4: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.16\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_5: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.88\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_6: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.16\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$
	DM_7: Min χ $\left\{\begin{array}{l}\left\|\frac{w_1}{w_2}-1.16\right\|\le\chi,\\ \sum_{j=1}^{2}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$		
D-OPR	DM_1: Min χ $\left\{\begin{array}{l}\left\|\frac{w_5}{w_6}-1\right\|\le\chi,\left\|\frac{w_6}{w_8}-1\right\|\le\chi,\left\|\frac{w_8}{w_3}-1.33\right\|\le\chi\\ \left\|\frac{w_3}{w_7}-1\right\|\le\chi,\left\|\frac{w_7}{w_4}-1.22\right\|\le\chi,\left\|\frac{w_4}{w_2}-1\right\|\le\chi\\ \left\|\frac{w_2}{w_1}-1\right\|\le\chi,\left\|\frac{w_5}{w_8}-1\right\|\le\chi,\left\|\frac{w_6}{w_3}-1.33\right\|\le\chi,\\ \left\|\frac{w_8}{w_7}-1.33\right\|\le\chi,\left\|\frac{w_3}{w_4}-1.22\right\|\le\chi,\left\|\frac{w_7}{w_2}-1.22\right\|\le\chi\\ \left\|\frac{w_4}{w_1}-1\right\|\le\chi,\\ \sum_{j=1}^{8}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	DM_2: Min χ $\left\{\begin{array}{l}\left\|\frac{w_5}{w_4}-1\right\|\le\chi,\left\|\frac{w_4}{w_7}-1.34\right\|\le\chi,\left\|\frac{w_7}{w_6}-1\right\|\le\chi\\ \left\|\frac{w_6}{w_8}-1\right\|\le\chi,\left\|\frac{w_8}{w_3}-2.17\right\|\le\chi,\left\|\frac{w_3}{w_2}-1\right\|\le\chi\\ \left\|\frac{w_2}{w_1}-1\right\|\le\chi,\left\|\frac{w_5}{w_7}-1.34\right\|\le\chi,\left\|\frac{w_4}{w_6}-1.34\right\|\le\chi,\\ \left\|\frac{w_7}{w_8}-1\right\|\le\chi,\left\|\frac{w_6}{w_3}-2.17\right\|\le\chi,\left\|\frac{w_8}{w_2}2.17\right\|\le\chi,\\ \left\|\frac{w_3}{w_1}-1\right\|\le\chi,\\ \sum_{j=1}^{8}w_j=1\ ,w_j\ge0,\forall j\end{array}\right.$	

DM_3: Min χ

$$\begin{cases} \left|\frac{w_1}{w_3}-1\right|\le\chi,\left|\frac{w_3}{w_5}-1.33\right|\le\chi,\left|\frac{w_5}{w_8}-1\right|\le\chi \\ \left|\frac{w_8}{w_4}-1\right|\le\chi,\left|\frac{w_4}{w_7}-1.86\right|\le\chi,\left|\frac{w_7}{w_2}-1\right|\le\chi \\ \left|\frac{w_2}{w_6}-1\right|\le\chi,\left|\frac{w_1}{w_5}-1.33\right|\le\chi,\left|\frac{w_3}{w_8}-1.33\right|\le\chi, \\ \left|\frac{w_5}{w_4}-1\right|\le\chi,\left|\frac{w_8}{w_7}-1.86\right|\le\chi,\left|\frac{w_4}{w_2}-1.86\right|\le\chi, \\ \left|\frac{w_7}{w_6}-1\right|\le\chi, \\ \sum_{j=1}^{8} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_4: Min χ

$$\begin{cases} \left|\frac{w_3}{w_5}-1\right|\le\chi,\left|\frac{w_5}{w_6}-1.33\right|\le\chi,\left|\frac{w_6}{w_2}-1.22\right|\le\chi \\ \left|\frac{w_2}{w_4}-1\right|\le\chi,\left|\frac{w_4}{w_7}-1\right|\le\chi,\left|\frac{w_7}{w_1}-2.2\right|\le\chi \\ \left|\frac{w_1}{w_8}-1\right|\le\chi,\left|\frac{w_3}{w_6}-1.33\right|\le\chi,\left|\frac{w_5}{w_2}-1.7\right|\le\chi, \\ \left|\frac{w_6}{w_4}-1.22\right|\le\chi,\left|\frac{w_2}{w_7}-1\right|\le\chi,\left|\frac{w_4}{w_1}-2.2\right|\le\chi, \\ \left|\frac{w_7}{w_8}-2.2\right|\le\chi, \\ \sum_{j=1}^{8} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_5: Min χ

$$\begin{cases} \left|\frac{w_5}{w_1}-1\right|\le\chi,\left|\frac{w_1}{w_2}-1.15\right|\le\chi,\left|\frac{w_2}{w_3}-1.21\right|\le\chi \\ \left|\frac{w_3}{w_7}-1\right|\le\chi,\left|\frac{w_7}{w_6}-1.59\right|\le\chi,\left|\frac{w_6}{w_4}-1\right|\le\chi \\ \left|\frac{w_4}{w_8}-1\right|\le\chi,\left|\frac{w_5}{w_2}-1.15\right|\le\chi,\left|\frac{w_1}{w_3}-1.44\right|\le\chi, \\ \left|\frac{w_2}{w_7}-1.21\right|\le\chi,\left|\frac{w_3}{w_6}-1.59\right|\le\chi,\left|\frac{w_7}{w_4}-1.59\right|\le\chi \\ \left|\frac{w_6}{w_8}-1\right|\le\chi, \\ \sum_{j=1}^{8} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_6: Min χ

$$\begin{cases} \left|\frac{w_2}{w_1}-1.15\right|\le\chi,\left|\frac{w_1}{w_3}-1\right|\le\chi,\left|\frac{w_3}{w_7}-1\right|\le\chi \\ \left|\frac{w_7}{w_6}-1\right|\le\chi,\left|\frac{w_6}{w_4}-1.19\right|\le\chi,\left|\frac{w_4}{w_5}-1\right|\le\chi \\ \left|\frac{w_5}{w_8}-1\right|\le\chi,\left|\frac{w_2}{w_3}-1.15\right|\le\chi,\left|\frac{w_1}{w_7}-1\right|\le\chi, \\ \left|\frac{w_3}{w_6}-1\right|\le\chi,\left|\frac{w_7}{w_4}-1.19\right|\le\chi,\left|\frac{w_6}{w_5}-1.19\right|\le\chi, \\ \left|\frac{w_4}{w_8}-1\right|\le\chi, \\ \sum_{j=1}^{8} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_7: Min χ

$$\begin{cases} \left|\frac{w_1}{w_2}-1.15\right|\le\chi,\left|\frac{w_2}{w_3}-1\right|\le\chi,\left|\frac{w_3}{w_6}-1\right|\le\chi \\ \left|\frac{w_6}{w_7}-1\right|\le\chi,\left|\frac{w_7}{w_5}-1.19\right|\le\chi,\left|\frac{w_5}{w_4}-1\right|\le\chi \\ \left|\frac{w_4}{w_8}-1\right|\le\chi,\left|\frac{w_1}{w_3}-1.15\right|\le\chi,\left|\frac{w_2}{w_6}-1\right|\le\chi, \\ \left|\frac{w_3}{w_7}-1\right|\le\chi,\left|\frac{w_6}{w_5}-1.19\right|\le\chi,\left|\frac{w_7}{w_4}-1.19\right|\le\chi, \\ \left|\frac{w_5}{w_8}-1\right|\le\chi, \\ \sum_{j=1}^{8} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

D-WT

DM_1: Min χ

$$\begin{cases} \left|\frac{w_1}{w_2}-1.16\right|\le\chi,\left|\frac{w_2}{w_3}-1.39\right|\le\chi,\left|\frac{w_1}{w_3}-1.69\right| \\ \sum_{j=1}^{3} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_2: Min χ

$$\begin{cases} \left|\frac{w_1}{w_2}-1.15\right|\le\chi,\left|\frac{w_2}{w_3}-1.21\right|\le\chi,\left|\frac{w_1}{w_3}-1.44\right|\le\chi \\ \sum_{j=1}^{3} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_3: Min χ

$$\begin{cases} \left|\frac{w_1}{w_3}-1.33\right|\le\chi,\left|\frac{w_3}{w_2}-1.22\right|\le\chi,\left|\frac{w_1}{w_2}-1.70\right|\le\chi \\ \sum_{j=1}^{3} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_4: Min χ

$$\begin{cases} \left|\frac{w_2}{w_3}-1.16\right|\le\chi,\left|\frac{w_3}{w_1}-1.19\right|\le\chi,\left|\frac{w_2}{w_1}-1.44\right|\le \\ \sum_{j=1}^{3} w_j=1\ , w_j\ge 0,\forall j \end{cases}$$

DM_5: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.21\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.44\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$	DM_6: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.33\right\| \le \chi, \left\|\frac{w_1}{w_3}-1\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.33\right\| \le \chi, \\ \sum_{j=1}^{3} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$
DM_7: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.16\right\| \le \chi, \left\|\frac{w_2}{w_3}-1\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.16\right\| \le \chi, \\ \sum_{j=1}^{3} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$	

After running all 35 FUCOM (for 7 DM in 5 types of identified wastes in Source and Deliver) models by GAMS 24.1 software for all the seven experts, the following weights have been obtained by solving the model with the related DFC(x) as represented in Tables (33) and (34) for Source and Deliver process respectively. More details about the codes in GAMS are available in appendix B. Here we called the obtained results that have been represented in Tables (33) and (34) as c_{ik} for Source process and c_{jk} for Deliver process. In fact, c_{ik} or c_{jk} show the obtained values for each identified waste in Source and Deliver by k^{th} DM as expert.

Table 33 Relative weights obtained by FUCOM for each waste in the Source process of Automotive company

DM	c1	c2	c3	c4	c5	c6	DFC(x)
DM1	0,618	0,382	-	-	-	-	0
DM2	0,535	0,465	-	-	-	-	0
DM3	0,395	0,605	-	-	-	-	0
DM4	0,451	0,549	-	-	-	-	0
DM5	0,465	0,535	-	-	-	-	0
DM6	0,297	0,703	-	-	-	-	0
DM7	0,465	0,535	-	-	-	-	0
DM1	0,087	0,087	0,158	0,255	0,158	0,255	0
DM2	0,225	0,22	0,13	0,166	0,13	0,128	0,021
DM3	0,042	0,042	0,108	0,431	0,269	0,108	0,025
DM4	0,163	0,075	0,163	0,218	0,218	0,163	0
DM5	0,239	0,179	0,179	0,112	0,179	0,112	0
DM6	0,127	0,13	0,184	0,212	0,217	0,13	0,022
DM7	0,174	0,174	0,174	0,174	0,152	0,152	0

Table 34 Relative weights obtained by FUCOM for each waste in the Deliver process of Automotive company

DM	C1	c2	c3	c4	c5	c6	c7	c8	DFC(x)
DM1	0,537	0,463	-	-	-	-	-	-	0
DM2	0,535	0,465	-	-	-	-	-	-	0
DM3	0,382	0,618	-	-	-	-	-	-	0
DM4	0,537	0,463	-	-	-	-	-	-	0
DM5	0,653	0,347	-	-	-	-	-	-	0
DM6	0,537	0,463	-	-	-	-	-	-	0
DM7	0,5	0,5	-	-	-	-	-	-	0
DM1	0,097	0,097	0,118	0,097	0,157	0,157	0,118	0,157	0
DM2	0,065	0,065	0,065	0,19	0,189	0,142	0,142	0,142	0
DM3	0,183	0,074	0,183	0,138	0,137	0,074	0,074	0,138	0
DM4	0,053	0,119	0,194	0,119	0,199	0,147	0,116	0,052	0,022
DM5	0,18	0,155	0,126	0,079	0,177	0,079	0,126	0,078	0,015
DM6	0,13	0,15	0,13	0,11	0,11	0,13	0,13	0,11	0
DM7	0,15	0,13	0,13	0,11	0,11	0,13	0,13	0,11	0
DM1	0,409	0,346	0,245	-	-	-	-	-	0,022
DM2	0,391	0,335	0,274	-	-	-	-	-	0,014
DM3	0,428	0,255	0,317	-	-	-	-	-	0,022
DM4	0,276	0,392	0,333	-	-	-	-	-	0,018
DM5	0,409	0,346	0,245	-	-	-	-	-	0,022
DM6	0,3	0,399	0,3	-	-	-	-	-	0
DM7	0,367	0,316	0,317	-	-	-	-	-	0

7.3 Analysis of experts' results for Automotive company

In this section the results of the experts' judgments have been discussed for each waste category in Source and Deliver process separately based on the obtained results in Tables (33) and (34). It is worth mentioning that in the present section the results have been addressed without considering the importance or weight of each expert.

7.3.1 Analysis of experts' results for Source process in Automotive company

As it is evident from Figure (51), unnecessary motions to read and update information about barcodes of pallets (S-MT2) are more important for the company based on the total experts' judgments. It can be due to the fact that the related activity to S-MT2 is more general compared to going around to finalize the reception documents (S-MT1). In fact, the task associated to S-MT1 is related to the staff in logistics department. As a result, any problem related to that can affect mainly the logistics department rather than other ones. On the other hand, any problem in reading the barcodes of pallets and storage location(S-MT2) can have deep direct and indirect effect on the other departments. As a matter of fact, based on the experts' judgment in Figure (51), S-MT1 has the highest importance for Logistic manager (0.618) compared with the other managers. However, S-MT2 has the highest importance for Scheduling (0.703) and Quality (0.605) managers. This

can arise from the possible consequences of any mismatch in doing activity related to S-MT2. In fact, S-MT2 can make delays in quality checking plan and also executing the manufacturing scheduling plan. For instance, if the production staff want to produce the items according to the scheduling plan and due to the mismatching of barcodes, they cannot find the related raw materials. Therefore, receiving correct information about the barcodes of raw materials to be picked can allow the production scheduling plan to be performed without interruptions. For the other managers the waste could have more similar importance since their jobs cannot be affected significantly by inefficiencies related to this waste.

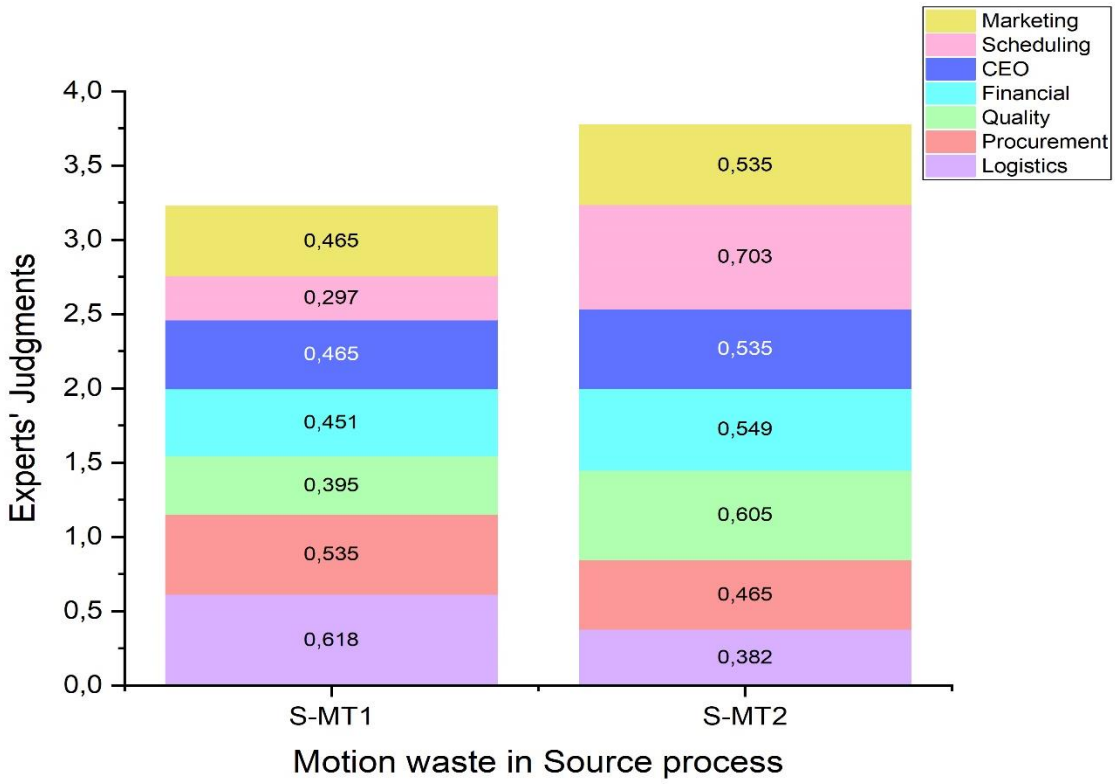


Figure 51 Distribution of experts' judgement for Motion waste in Source process for Automotive company

Figure (52), reveals that in overall the most significant waste among six different wastes in Over Processing is Every day data integration to prioritize delays from different suppliers (S-OPR4) and the least important one is Collecting information about the previous performance of new registered suppliers each time before new contracts (S-OPR2). The high importance of S-OPR4 can be related to its high criticality for some departments. In this regard, it can be concluded from Figure (52) that S-OPR4 has higher relative importance for Quality and Logistics managers. Since the activities related to these two departments can be negatively affected by any delays from suppliers. In addition, for the logistics manager Providing the paper receipt of the delivery for receiving containers from each supplier every day (S-OPR6) can have relative importance since it is directly one of the responsibilities of the Logistics department. However, other activities with less connection with the Logistics department activities have less importance. For instance, the logistics manager assigned the least importance to Collecting and

integrating the available information about performance from different sources every time an issue arises with the supplier (S-OPR1) and S-OPR2. In fact, these two wastes are more related to the procurement department and logistics department just relies on their decision about suppliers of raw materials. Also, the Financial manager assigned his highest relative weight to S-OPR4 since such delays should also be considered in the payment to the suppliers. However, like the logistics manager the least priority among Over Processing wastes for Financial manager is related to the S-OPR2. To be precise, the related consequences of inefficiency in doing activity associated with S-OPR2 do not have a strong relation with Financial manager responsibilities. In addition, the Scheduling manager assigned very close relative weights for S-OPR4 (0,212) and Every day contacting with supplier about delays to resolve (S-OPR) (0.217). Therefore, from the Scheduling Manager's point of view, both of these activities are the most important ones. Moreover, from the obtained results in Figure (52), it is clear that for the CEO the most significant waste is(S-OPR1) since it is more related to the strategic decisions of the company to collaborate with suitable suppliers. In fact, it can affect the company's total performance in the long term. In this regard, second priority for the CEO is another group of wastes such as (S-OPR2, S-OPR3, S-OPR5) since the activities related to these wastes also need to have communications or access to sources from outside of the company. Therefore, for the CEO those wastes more related to the operational tasks inside the company have the least importance (S-OPR4, S-OPR6). It can be reasonable due to the focus of the CEO on the strategic tasks compared with the operational tasks. Moreover, for the procurement manager, the most significant waste in Over Process is S-OPR1 and S-OPR2 with relative weights of 0.225 and 0.222 respectively. This can arise from the fact that S-OPR1 and S-OPR2 are the wastes directly related to the Procurement managers' responsibilities. Finally, since none of the identified waste in the over-processing of the Source process is related to the marketing activities in a direct or indirect way, the Marketing manager assigned very similar relative weights to each addressed waste.

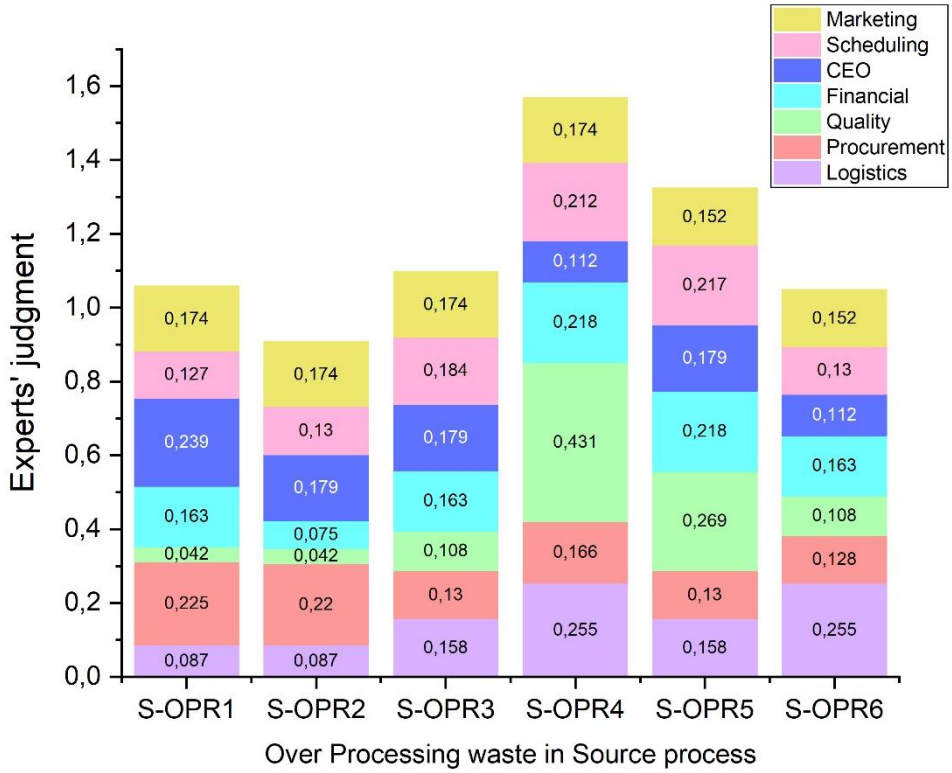


Figure 52 Distribution of experts' judgement for Over Process waste in Source process in Automotive company

7.3.2 Analysis of experts' results for Deliver process in Automotive company

Figure (53) illustrates the experts' judgment and results about the relative weights of the Motion waste for Deliver process. From a general point of view, it seems that Going around long way to complete shipment and delivery documents (D-MT1) is more important than Unnecessary motions for reading the barcodes of pallets for picking up (D-MT2).

It seems reasonable since D-MT2 is the pure responsibility of the logistic staff. Therefore, as is evident from Figure (53) all managers assigned a higher relative weight to D-MT1 compared to D-MT2.

However, for the Quality manager D-MT2 is more significant than D-MT1. It can be explained by the negative consequences of a wrong reading of product barcodes to be shipped, which might lead to a quality issue related to delivering the wrong products to customers. Moreover, by considering the fact that both D-MT1 and D-MT2 can be related to the responsibilities of the Logistics department, the Logistics manager assigned very close weights to both of them.

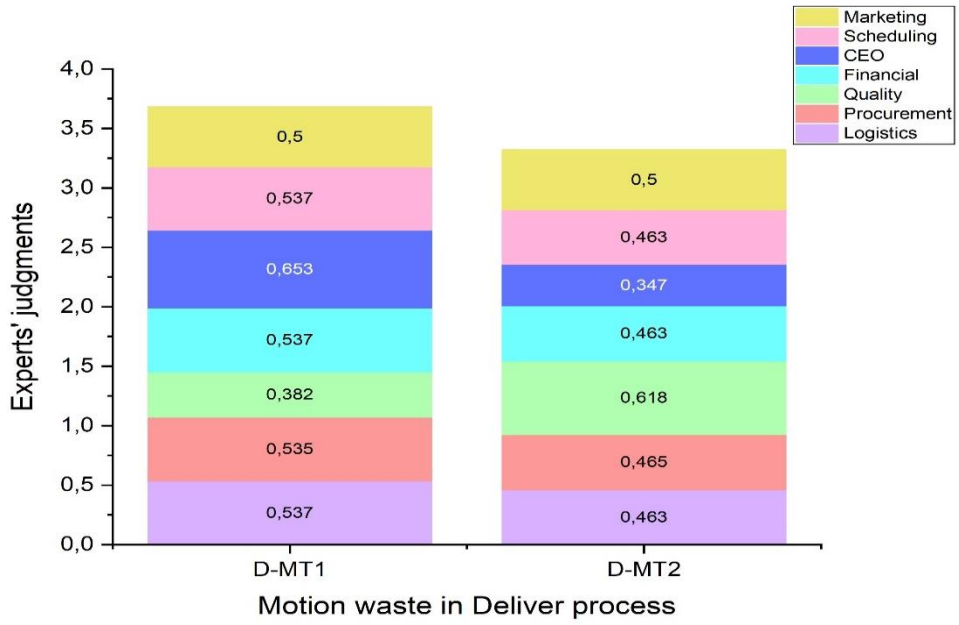
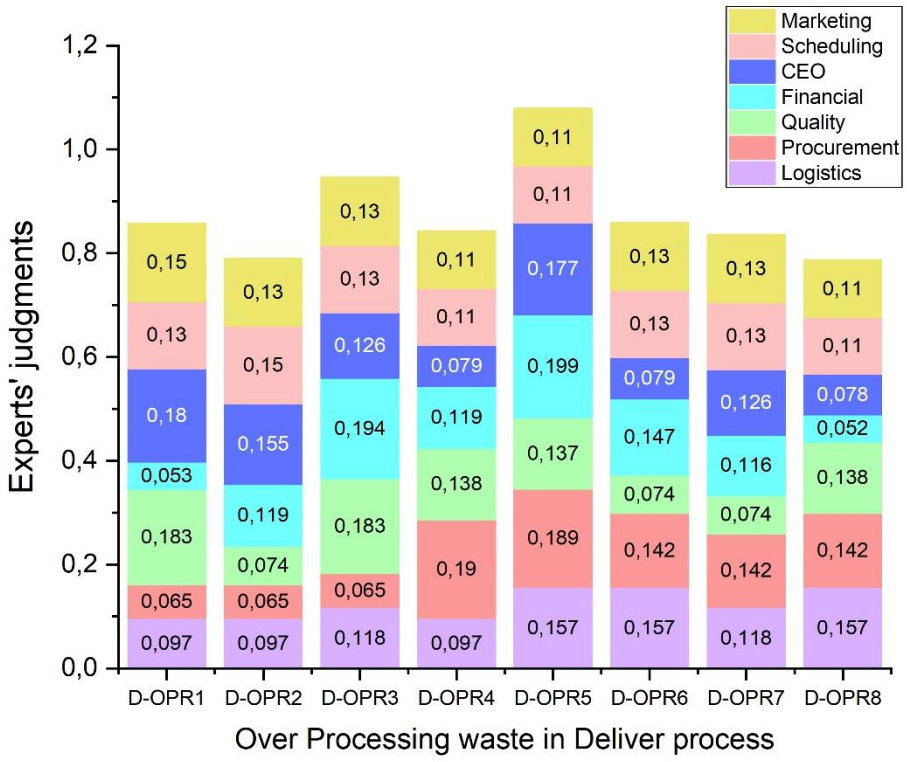


Figure 53 Distribution of experts' judgement for Motion waste in Deliver process for Automotive company

The relative weights of each expert in Over Processing waste in Deliver process have been indicated in Figure (54). According to overall experts' judgments, the most significant waste is Every day for each pick up from warehouse the information should be integrated for providing a picking plan from warehouse (D-OPR5). In this regard, D-OPR5 obtained the highest relative weight in comparison to the other identified waste in the same category from the Logistics Manager (0,157), Procurement Manager (0,189), Financial manager (0,199), and CEO (0,177). Moreover, from the logistics manager point of view also Providing and organizing the shipment and delivery documents in paper form for each shipment to the customers every day (D-OPR6) and Every time Looking for picking the right products for delivery (D-OPR8) have the same relative weight (0,157). It can arise

from the fact that all the identified waste in the Over Processing of Deliver is related to the Logistics department or have some connection with it. Therefore, for the logistics manager, all of these identified wastes could have approximate relative importance in some way. Nonetheless, as can be seen from Figure (54), D-OPR5, D-OPR6, D-OPR8 are all the first important for the Logistics manager. It can arise from the fact that these three wastes in the Over Processing have direct effect on the final shipment to the customer as the last step of the delivery. In addition, in general, it seems that experts believe Updating the changes received from customers every day (D-OPR3) is the second most significant waste among the other ones in the same class of waste. It can be reasonable since this could be a task that can affect the performance of multiple departments in some ways. For instance, the Quality manager assigned the highest relative weight to this waste due to the fact that any problem or delay in performing this task can change the internal planning of the Quality department for checking the products and their scheduling for doing that.

Figure 54 Distribution of experts' judgement for Over Process waste in Deliver process for Automotive company

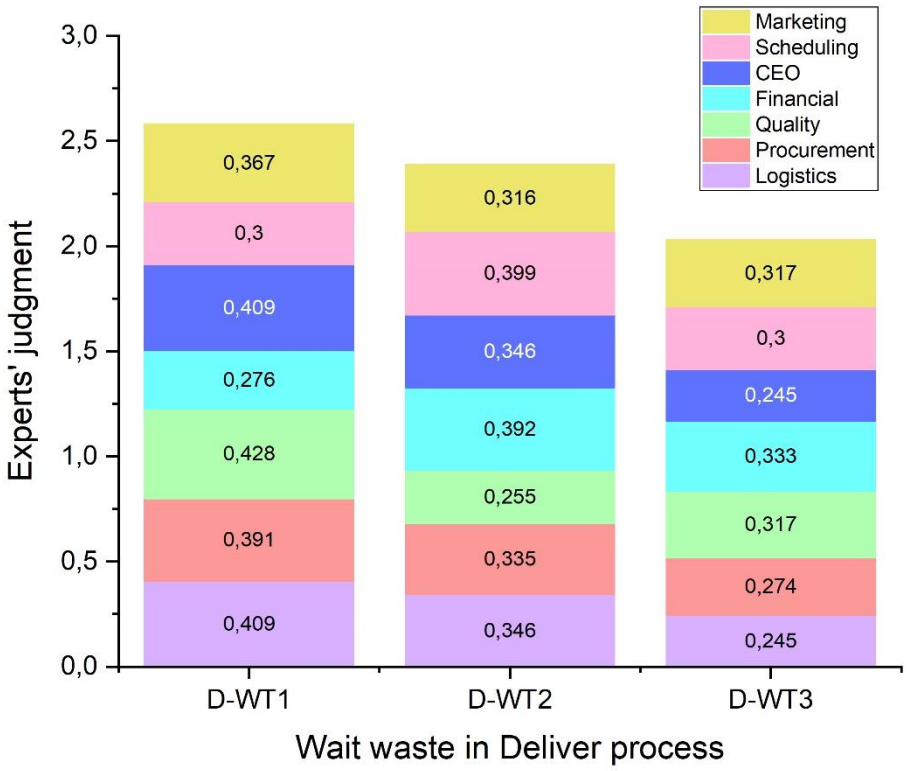


However, the least important waste from experts' viewpoint could be Checking the customers' orders for production plan every day (D-OPR2) and D-OPR8. Both of these wastes are the responsibility of the Logistics department. Nevertheless, there is less connection between these two wastes (D-OPR2, D-OPR8) and other departments. Hence, the highest importance to D-OPR2 has been assigned by the CEO (0.155) thanks to the fact that any problem in checking and initial processing of orders from customers can have a negative effect on the future orders from the customers. Therefore, from the CEO's point of view, it could be a critical task. Also, about D-OPR8 since it is one of the sheer responsibilities of the

logistics department and critical for logistics staff the highest relative weight has been assigned by the Logistics manager (0.157). In this regard, from the results of Figure (54), it is evident that for logistics manager D-OPR8 is one of the most significant wastes (0.157) compared with the other ones. Nonetheless, for other managers such as CEO (0.78), financial (0.052), Scheduling (0.11), Marketing (0.11) D-OPR8 has the least importance.

For the Marketing manager Before each contract checking the resource availability (D-OPR1) is the most important identified waste. This can be explained by the fact that to do this task marketing manager should have close communication with the logistic departments for issuing new contracts. Therefore, it can be reasonable that D-OPR1 is assigned the highest weight by the Marketing manager. Aside from D-OPR1, the other waste can have very similar importance from the Marketing manager's point of view. Additionally, the Scheduling manager believes that the most significant waste in Over Processing should be D-OPR2 since it has a direct effect on the performance of scheduling production execution.

Figure 55 Distribution of experts' judgement for Wait waste in Source process for Automotive company



As Figure (55) illustrates, totally all managers believe that the waiting for integrating the information for picking plan (D-WT1) is the most significant Wait waste. However, it has less comparative importance for Financial manager (0.276), Scheduling manager (0.3), and Marketing Manager (0.367). It can be explained by the fact that the main activities of these departments cannot be affected by delays or waiting from this waste. However, waiting to generate the required documents for the shipment (D-WT2) can have some strong connection with the responsibilities of the financial department. To be more precise, it is possible that customers do not pay if the shipment documents are incomplete or wrong.

Therefore, Financial manager assigned the highest relative weight to D-WT2 (0.392). On the other hand, from the Quality manager perspective the performance of doing the activity related to the D-WT2 does not have high priority since these are documents related to shipment to customer and do not affect the quality of the shipped products. Hence, he assigned the least importance to D-WT2 (0.255). Furthermore, Logistics manager considered D-WT1 as the most significant (0.409) and D-WT3 as the least one (0.245). In fact, any improvement in performance of D-WT1 can directly have an effect on waiting for completed picking items to shipment (D-WT3) as a waste depending on the consequences that arise from D-WT1. Totally, D-WT3 can be identified as the least importance for Wait waste in overall.

7.4 Data aggregation for Automotive company

Practitioners need to have a clear understanding of the significance of each identified waste in the organization before they can begin to develop the roadmap for applying Industry 4.0 technologies. Therefore, the primary objective of this part is to first establish a structured framework for identifying the key wastes through the incorporation of expert opinions from the previous section 7.2. This can help strategic decision-makers in the company decide which wastes to improve first based on data collected from actual operations.

In the first step, it should be noted that the results in sections 7.3.1 and 7.3.2 have been based on different categories of Lean wastes. Therefore, for final integration of results, it is needed to consider the importance of each category of wastes in Source and Deliver processes. Hence, for assigning the weight to each waste category, the following equations have been applied:

$$W_{LCms} = \frac{\sum_{i=1}^{M_s} b_{im}}{\sum_{m=1}^{7}\sum_{i=1}^{M_s} b_{im}} \quad (15)$$

$$W_{LCmd} = \frac{\sum_{j=1}^{M_d} b_{jm}}{\sum_{m=1}^{7}\sum_{j=1}^{M_d} b_{jm}} \quad (16)$$

In equations (15) for Source process,W_{Lcms} represents the obtained weight for the m^{th} Lean waste category in Source process. In addition, (b_{im}) indicates the i^{th} identified waste in the m^{th} Lean waste category when $(i \in \{1,2,i,\dots,M_s\})$ and $(m \in \{1,2,m,\dots,7\})$. In this regard, M_s shows the ultimate number of identified wastes in Source process. Thus, $b_{im} = 1$, if i^{th} waste exists in the m^{th} Lean waste category, otherwise, $b_{im} = 0$. Also, equation (16) should be interpreted in a similar way. Therefore, (W_{Lcmd}) represents the weight of each category in Deliver process when $(j \in \{1,2,i,\dots,M_d\})$ and M_d represents the final number for the identified wastes in Deliver process. Hence, the weights for each Lean waste category have been obtained according to the equations (15) and (16). The results have been presented in Table (35) and also under Level 1 in Figures (65) and (66).

Table 35 Relative weight of each Lean waste category for Source and Deliver processes of Automotive company

Wastes category (m)	Number of wastes in each category $\sum_{i=1}^{M_s} b_{im}$	Weight of category (W_{LCms})
S-MT1	2	0,222
S-MT2		
s-OPR1	6	0,667
S-OPR2		
s-OPR3		
s-OPR4		
s-OPR5		
s-OPR6		
S-DF1	1	0,111

Wastes category (m)	Total number of wastes in each category $\sum_{j=1}^{M_d} b_{jm}$	Weight of category (W_{LCmd})
D-MT1	2	0,143
D-MT2		
D-OPR1	8	0,571
D-OPR2		
D-OPR3		
D-OPR4		
D-OPR5		
D-OPR6		
D-OPR7		
D-OPR8		
D-WT1	3	0,214
D-WT2		
D-WT3		
D-TR1	1	0,071

The identified wastes in section 5.2.2 are related to the different departments. Therefore, as discussed in section 6.2 this fact can affect the relative weights assigned by each expert to the identified wastes. For integrating the final results of all the experts for each waste, the obtained relative weights for every single waste should be associated with the relative importance of the responsible manager in doing the activity.

As a result, for calculating the weight of each expert in Source and Deliver processes a responsibility matrix is drawn for all the identified wastes versus each manager. Hence, Tables (36) and (37) have been presented with the mentioned responsibility matrix of each manager as expert.

Based on the responsibility matrix in Table (36) the weight of each expert for the Source process (DM_{ks}) is calculated according to the equation (17). Similarly, Table (37) has been considered for calculating the experts' weights in the Deliver process (DM_{kd}) by equation (18). Therefore, k^{th} decision makers' weight is obtained as follows in each process:

$$DM_{ks} = 0.05 + (1 - 0.05 * E)\frac{\sum_{i=1}^{M_s} a_{ik}}{\sum_{k=1}^{E}\sum_{i=1}^{M_s} a_{ik}} \quad (17)$$

$$DM_{kd} = 0.05 + (1 - 0.05 * E)\frac{\sum_{j=1}^{M_d} a_{jk}}{\sum_{k=1}^{E}\sum_{j=1}^{M_d} a_{jk}} \quad (18)$$

In this regard, E shows the number of DMs as experts, and M_s and M_d represent the number of identified wastes in Source and Deliver process respectively. Accordingly, here $E = \{1,2,k,\dots,7\}$, $i \in \{1,2,i,\dots,M_s\}, j \in \{1,2,j,\dots,M_d\}$. Therefore, $a_{ik} = 1$ if i^{th} waste in the Source process is related to the k^{th} expert, otherwise, $a_{ik} = 0$. A same explanation applies to a_{jk} in the Deliver process.

According to the author's previous experience the value of 0.05 is originally allocated to each DM in equations (17) and (18) regardless of their amount of connection with the identified wastes in Source and Deliver processes. To be more precise, this value is assigned to represent the minimum weight of each manager as expert for taking part in the research. Then, when more wastes fall under the manager's supervision, the DM weight ratio rises accordingly. As a result, the obtained corresponding weights of each expert are represented in the last rows of Tables (36) and (37) for Source and Deliver processes.

Table 36 Responsibility matrix and relative weights of each manager as expert in Source process of Automotive company

	Logistics (DM1)	Procurement (DM2)	Quality (DM3)	Financial (DM4)	CEO (DM5)	Scheduling (DM6)	Marketing (DM7)
S-MT1	■						
S-MT2	■						
S-OPR1		■			■		
S-OPR2		■					
S-OPR3		■			■		
S-OPR4						■	
S-OPR5					■	■	
S-OPR6	■						
S-DF1		■					
DM_{ks}	**0.21**	**0.27**	**0.05**	**0.05**	**0.21**	**0.16**	**0.05**

Table 37 Responsibility matrix and relative weights of each manager as expert in Source process of Automotive company

	Logistics (DM1)	Procurement (DM2)	Quality (DM3)	Financial (DM4)	CEO (DM5)	Scheduling (DM6)	Marketing (DM7)
D-MT1							
D-MT2							
D-OPR1							
D-OPR2							
D-OPR3							
D-OPR4							
D-OPR5							
D-OPR6							
D-OPR7							
D-OPR8							
D-WT1							
D-WT2							
D-WT3							
D-TR1							
DM_{kd}	0.62	0.05	0.05	0.05	0.05	0.09	0.09

According to the equations (19) and (20), the final integration of the weights of each single identified waste in Source (C_{nsi}) and in Deliver (C_{ndj}) have been obtained by a weighted average. Also, the results have been presented under Level 2 in Figure (65) for Source process, and in Figure (66) for Deliver process.

$$C_{nsi} = \frac{\sum_{k=1}^{E} DM_{ks}.c_{ik}}{\sum_{k=1}^{E} DM_{ks}} \quad (19)$$

$$C_{ndj} = \frac{\sum_{k=1}^{E} DM_{kd}.c_{jk}}{\sum_{k=1}^{E} DM_{kd}} \quad (20)$$

Finally, to obtain the results of Level 3 (see Figures (65) and (66)), the following equations (21) and (22) are utilized for the final integration of the outcomes and prioritization of the Lean wastes. To be more precise, here the relative importance of the waste categories (Level 1) has also been addressed to establish the ultimate weights of each waste in Source (W_{Fsi}) and Deliver (W_{Fdj}) processes.

$$W_{Fsi} = \frac{b_{im}.W_{LCms}.C_{nsi}}{\sum_{m=1}^{7} W_{LCms}} \quad (21)$$

$$W_{Fdj} = \frac{b_{jm}.W_{LCmd}.C_{nsj}}{\sum_{m=1}^{7} W_{LCmd}} \quad (22)$$

7.4.1 Lean roadmap for Automotive company

The wastes have been ranked for each process in Source and Delivery based on the final findings obtained in Level 3, as shown in Figures (65) and (66). Figures (56) and (57) below show a comprehensive overview of how the firm might improve and reduce the Lean wastes that have been identified. Thus, the purpose of this part is not just to present the Lean improvement roadmap but also to illustrate the connections and justifications that may be used to support the outcomes. To this end, the most important wastes have been placed in the initial parts of the Figures (56) and (57) to show the sequence of different steps for improvement of Source and Deliver processes.

Therefore, in Source process the first step for improvement should be removing Over Processing of S-OPR4 that is related to the prioritizing delays in deliveries from suppliers. The second step should be related to the Over Processing waste associated with contacting with supplier to follow the situation (S-OPR5). In this regard, the last step in the improvement of Source process can be improving Over Process in checking the information about new registered suppliers (S-OPR2). It is worth mentioning that the effect of this activity in the Defect waste has been considered as one of the initial steps (5th ranked S-DF1). This is because of the intense consequences of Defect waste in the related activity compared to its Over Processing waste (S-OPR2). In fact, Defect waste here can give rise to low quality in the output products of the company and can engaged whole company in some ways. However, S-OPR2 as the Over Processing waste related to this activity can just have effect on the Procurement staffs.

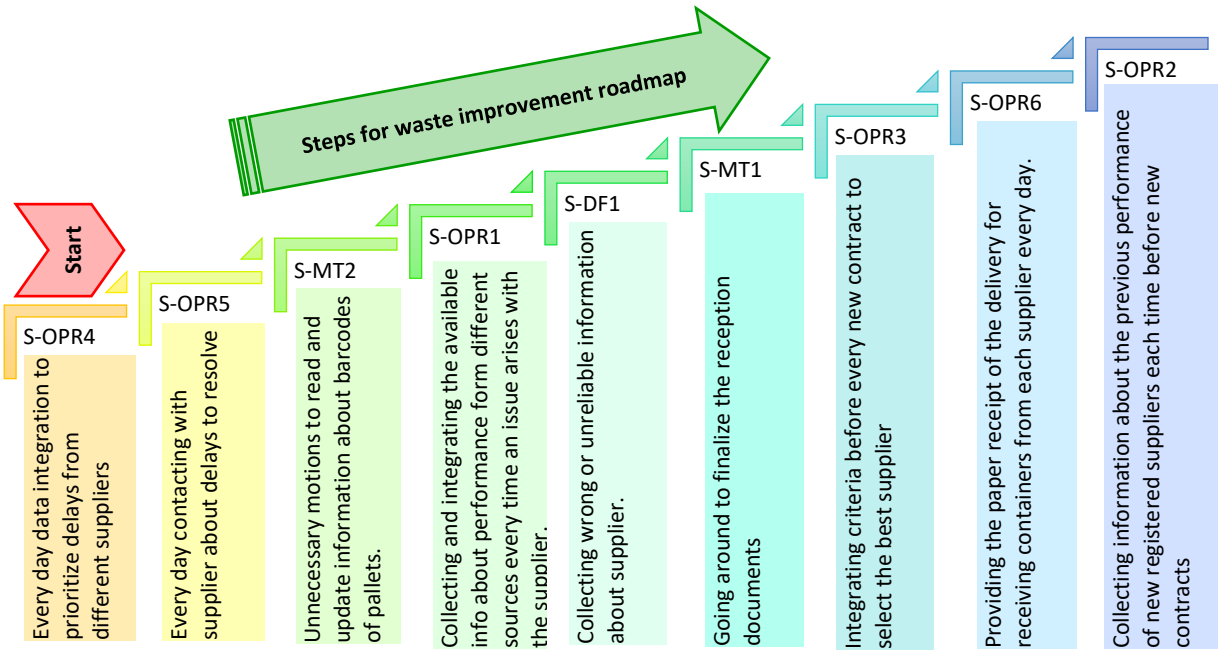


Figure 56 Wastes improvement for Source process in Automotive company

For the Deliver process (See Figure (57)) the two first steps are related to the Over Processing (D-OPR5) and Wait (D-WT1) wastes of one activity that is information integration for providing picking plan. It emphasizes the important role of this activity to start the way for improvement of wastes in the Deliver process.

Moreover, the last step can be alleviating the Wait waste related to picking the items based on the scheduled delivery (D-WT3). Totally, the reason behind ranking this waste (D-WT3) can arise from the dependency among D-WT3 and information integration for providing picking plan as a prerequisite for doing this task. Therefore, it is expected to also improve D-WT3 by improving the wastes related to the information integration in picking plan as the most important wastes in the Deliver process (D-OPR5, D-WT1).

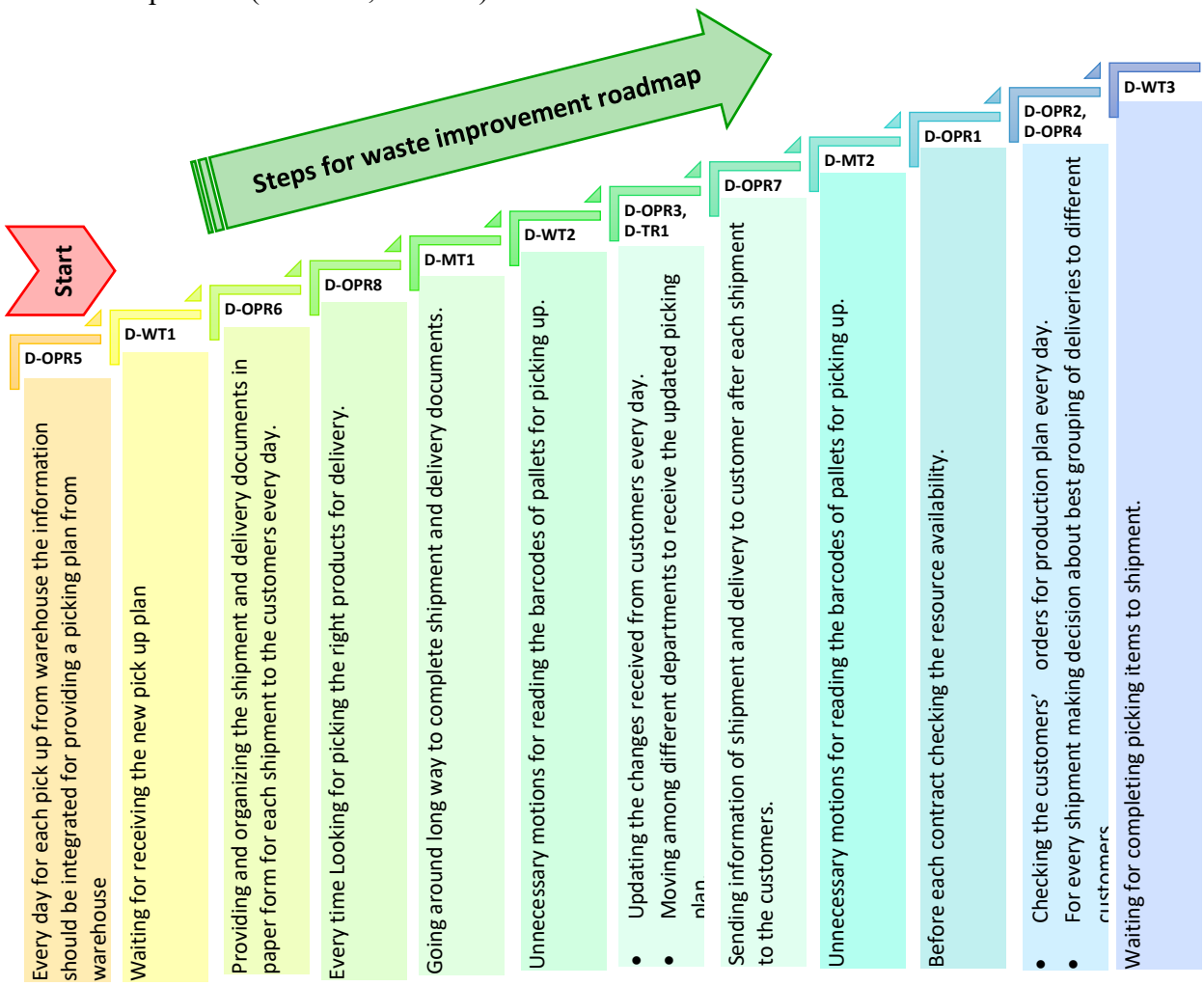


Figure 57 Wastes improvement for Deliver process in Automotive company

One of the main goals of this research is to provide a detailed perspective for industries to assist them in constructing their customized roadmap based on the real state of the waste in their company. To this end, for every single activity mentioned in Tables (15) and (16), all related weights obtained by equations (21) and (22) have been integrated. Hence, different activities have been ranked based on the most significant to the least one for constructing the Lean improvement roadmap. Therefore, the relative waste weights associated with each activity were taken into account, and a final ranking of activities was constructed to determine their respective importance. Tables (38) and (39) provide further information on the methodology used in the calculations. Figures (58), (59) show the final Lean roadmap for the automotive company's wasteful activities in the Source and Deliver processes, respectively.

Table 38 final relative weight of each activity in Source process of Automotive company

Wasteful activity	S-MT	S-OPD	S-OPR	S-WT	S-TR	S-IV	S-DF	Activity weight
Generate the receipt of verification	S-MT1 (0.108)		S-OPR6 (0.102)					**0.210**
Reading the barcode Of pallets and storage location to match them	S-MT2 (0.114)							**0.114**
Making decision by experts about best supplier and finalizing			S-OPR3 (0.105)					**0.105**
Responsible person Stops the collaboration with supplier (with " go supply" inform about suppliers'			S-OPR1 (0.112)					**0.112**
Checking the information about new registered suppliers (like sustainability issues etc.) from agencies or other			S-OPR2 (0.100)				S-DF1 (0.111)	**0.211**
Contact with suppliers to follow the situation			S-OPR5 (0.115)					**0.115**
Prioritizing Delays in deliveries from suppliers			S-OPR4 (0.131)					**0.131**

As depicted in Figure (58) for the Source process the first step is improving checking information about new registered suppliers. This could be the first since checking this information in a reliable way can have a direct effect on the outcomes of the other processes in the next steps and also can influence the quality of the finished products in an indirect way. Generating the receipt of verification is the second step for improvement in this Automotive company due to the fact that such task brings about different types of waste including Motion waste and Over Processing waste. Therefore, alleviating this waste can have a great effect on improving the associated task in the current state of the company. In addition, making decisions by experts about the best supplier and finalizing that should be the last step for the Lean roadmap in the Source process. Focusing on this waste as the last step can be explained by the existing relation between this waste and the first step, which is checking the information about new registered suppliers. To be more precise, by providing more reliable and trustful data about newly registered suppliers in the first step, making decisions about new suppliers can be facilitated for managers.

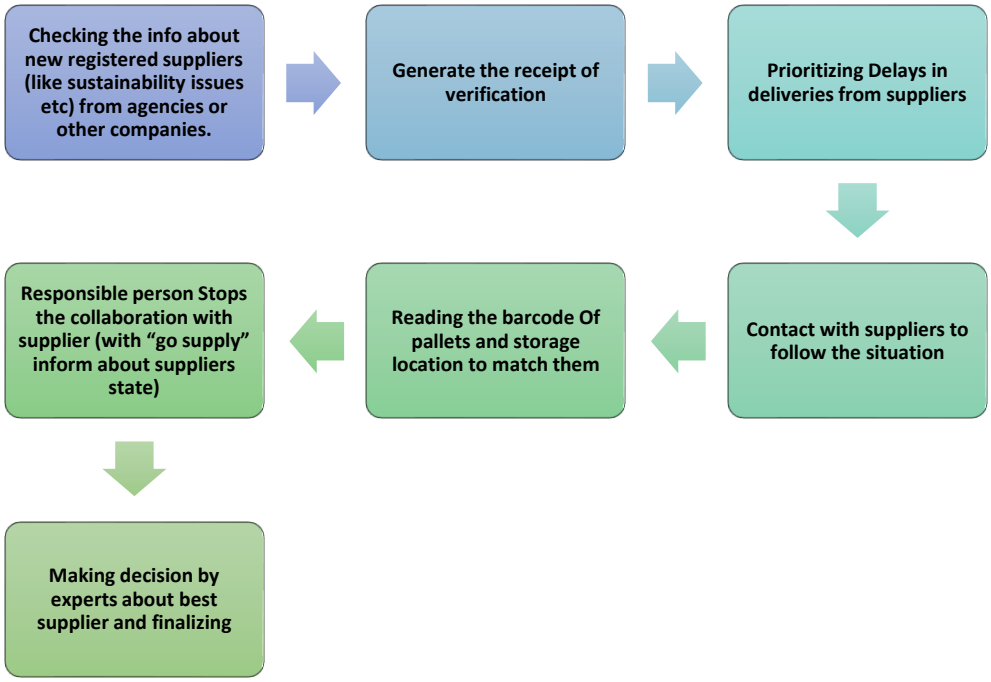


Figure 58 Roadmap based on prioritizing the identified wastes in source process of Automotive company

Figure (59) describes the Lean roadmap for the Deliver process. According to this roadmap for the investigated automotive company, the initial step in improving the waste is related to generating required documents for delivery. Moreover, the second step will be improving picking items based on the scheduled delivery. These two tasks should be the first ones thanks to the fact that both of them can bring about different wastes. In this regard, by improving generating required documents as the first step the company can alleviate Motion, Over Processing, and Wait as the main wastes of this activity. Furthermore, improving picking items based on the scheduled delivery can also improve the related wastes such as Over Processing, Transportation, and Wait ones. Also, the last two steps for improving the delivery process are checking the customer contacts and schedule and making decisions about the best transportation groups. As a matter of fact, these two tasks are more internal activities related to one department. Therefore, individual performance in doing these tasks can have fewer consequences for the other parts of the company. As a result, at the first step company should focus on the more critical tasks to improve its general performance and then focus on more specific tasks like the two last ones (see Figure (59)).

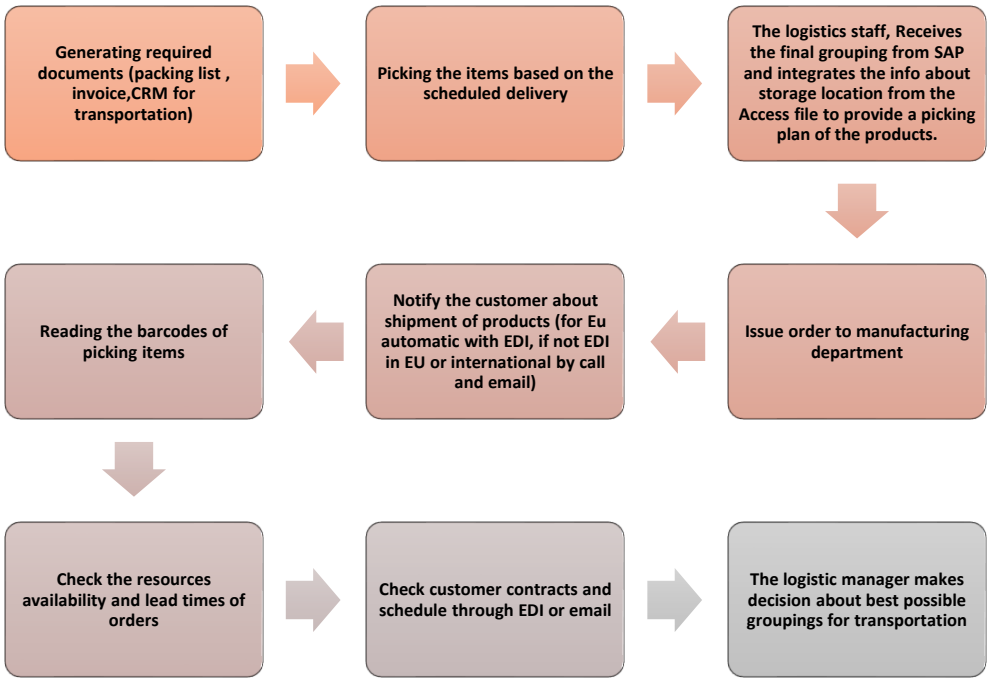


Figure 59 Roadmap based on prioritizing the identified wastes in Deliver process of Automotive company

Table 39 Final relative weight of each activity in Deliver process of Automotive company

Wasteful activity	S-MT	S-OPD	S-OPR	S-WT	S-TR	S-IV	S-DF	Activity weight
Check customer contracts and schedule through EDI or email			D-OPR2 (0.061)					**0.061**
Notify the customer about shipment of products (for Eu automatic with EDI, if not EDI in EU or international by call and email)			D-OPR7 (0.068)					**0.068**
Picking the items based on the scheduled delivery			D-OPR8 (0.079)	D-WT3 (0.057)	D-TR1 (0.071)			**0.207**
Check the resources availability and lead times of orders			D-OPR1 (0.062)					**0.062**
Reading the barcodes of picking items	D-MT2 (0.067)							**0.067**
Generating required documents (packing list , invoice for transportation)	D-MT1 (0.076)		D-OPR6 (0.082)	D-WT2 (0.074)				**0.232**
The logistic manager makes decision about best possible groupings for transportation			D-OPR4 (0.061)					**0.061**
Issue order to manufacturing department			D-OPR3 (0.071)					**0.071**
The logistics staff, Receives the final grouping from SAP and integrates the information about storage location from the Access file to provide a picking plan of the products.			D-OPR5 (0.087)	D-WT1 (0.083)				**0.170**

7.4.2 Lean DSC roadmap for Automotive company

For providing the Industry4.0 roadmap (Lean DSC) for the Automotive company, the final ranking of the identified wastes has been considered. To this end, the obtained results in the first phase (section 5.3.4) have been considered the basic for developing the main part for establishing the Industry 4.0 roadmap. Therefore, as described in Figures (65) and (66) each identified waste has been connected by arrows to the useful Industry4.0 technologies in Level 4 according to the results of section 5.3.4. The summation of weights for each waste (see level 3) which connected into each technology can be identified as the importance of the technology. The results have been shown in Level 5 for Figures (65) and (66).

This can be a creative and valuable way to construct the Industry 4.0 roadmap for each company. To be more precise, the connected arrows from each waste to the individual technology have addressed the experts' judgments about the importance of waste and consequently imply the benefits of the proposed Industry 4.0 technologies for that waste. In fact, the benefits of the proposed Industry 4.0 technologies have been discussed in the workshop and experts have become familiar with the benefits of these technologies at the time of judgment.

Results in Table (40) represent the importance of each Industry 4.0 technology for the Source and Deliver processes. Moreover, the fourth column of Table (40) shows the average of final weights of these technologies for the company in general. This is important to evaluate Industry 4.0 technologies based on their final weight since when the company proceeds to invest in these Industry 4.0 technologies, they consider that for improving all possible wastes rather than focusing on just the Source or Deliver process.

As a result, according to the last column in Table (40) to alleviate the most significant identified wastes in the company the first technology to implement should be IoT (0.619). In fact, IoT can collect real time data as one of the basic prerequisites for increasing data availability about products in different steps of the SC. Afterward, in second step the company should develop its information system based on the CC technology to facilitate access to the real time and shared information with less difficulties and cheaper prices for all the SC members. The next technology should be BC since it can provide trustful data. Moreover, BC can provide a tamperproof network for applying smart contracts that is a great opportunity for having less paper works in an automated way. Finally, the last technology to invest in could be BDA since it can be more a decision support technology and more related to the internal analysis of the company for making the best decisions.

Table 40 Final ranking of Industry 4.0 technologies for Automotive company

Tech	Source	Deliver	Final weight	Rank
CC	0.325	0.733	0.529	**2**
BDA	0.348	0.255	0.301	**4**
IoT	0.439	0.800	0.619	**1**
BC	0.421	0.232	0.326	**3**

Figure (60) describes a detailed roadmap for implementing Industry4.0 technologies in the Automotive company. Also, in this Figure all the related identified wastes that can be alleviated by applying each technology have been listed below them.

As illustrated in Figure (60), IoT is a basic technology for implementation since it is capable of improving many identified Lean wastes in both Source and Delivery processes. In fact, IoT is the first technology since it not only applies for improving many wastes but also the related wastes are significant from the experts' perspectives.

Furthermore, BDA is the last step in the Industry 4.0 roadmap for the company since its application is more limited to the internal tasks of each department and less influential for the whole company. For instance, as evident from Figure (60) in both Deliver and Source the BDA is related to improving Over Processing waste in limited number of activities. However, BC like BDA is still linked to small quantity of identified wastes, but these wastes are more significant for the company. As a matter of fact, the wastes related to BC usually are in connection with the other SC members. Therefore, it seems that the first priority for the experts is improving the wastes in relation to the out of the company, through the other SC members as upstream and downstream tiers, and then focusing more on the internal wastes.

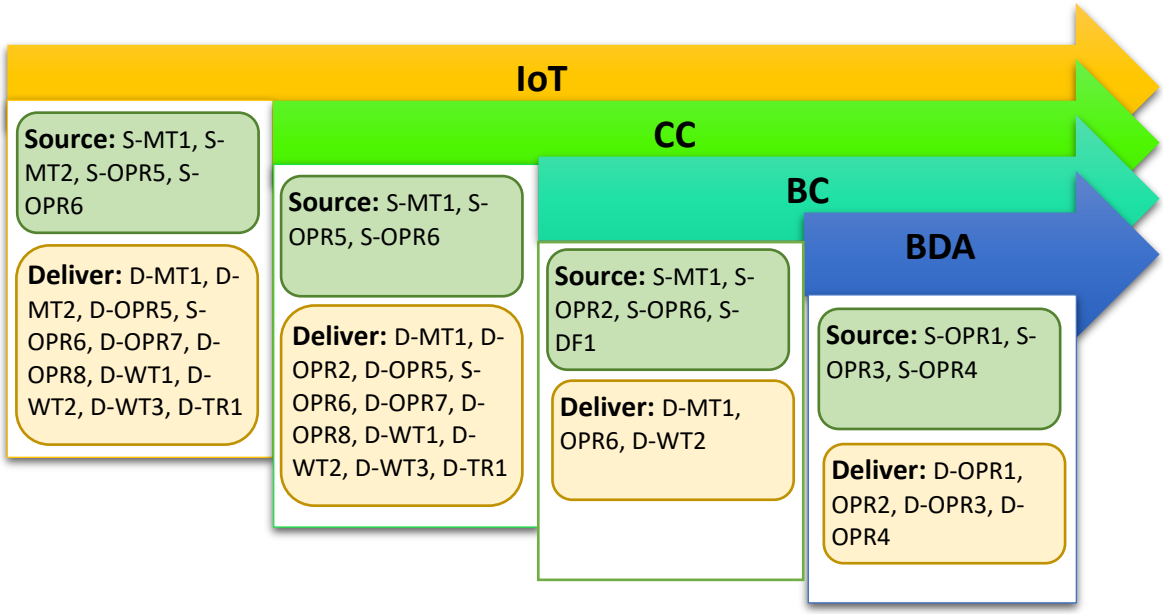


Figure 60 Roadmap for implementing Industry 4.0 technologies in Automotive company

Figures (61) and (62) provide a more precise idea about the application of each Industry4.0 technology for improving the different types of Lean wastes in the Automotive company. Therefore, according to the results from Figure (61), for Source process of the company, BC can be useful for all the types of identified wastes including Motion, Over Process, Defect. However, BDA can just be applicable to improve the wastes related to Over Processing. This can be explained by the role of these technologies in SC. In fact, BC can also be used for connecting and making trust among different SC members. Instead, BDA is usually used as a

decision tool inside the company. Therefore, it brings about more applicability of BC in different types of waste compared to BDA. Aside from BC, IoT is also one of the most beneficial technologies to apply for most of the identified wastes. It can arise from the basic role of this technology for collecting and providing data to be processed or used by other technologies like CC, BC, or BDA.

In figure (62), the results have been depicted for the Deliver process of the Automotive company. In this regard, IoT and CC can be identified as the predominant technologies to improve waste in the Deliver process. This is because the majority of activities in the delivery process need to collect and share various data and information among different parts and SC members. Also, similarly to the Source process, BDA just alleviates the waste of Over Processing thanks to its nature of providing a decision support system for internal parts of the company. Moreover, BC cannot be capable of improving any identified waste related to Transportation because of the fact that the Transportation waste is more related to the internal movement of staff among different departments. Therefore, the main issue is not related to the trust among SC members.

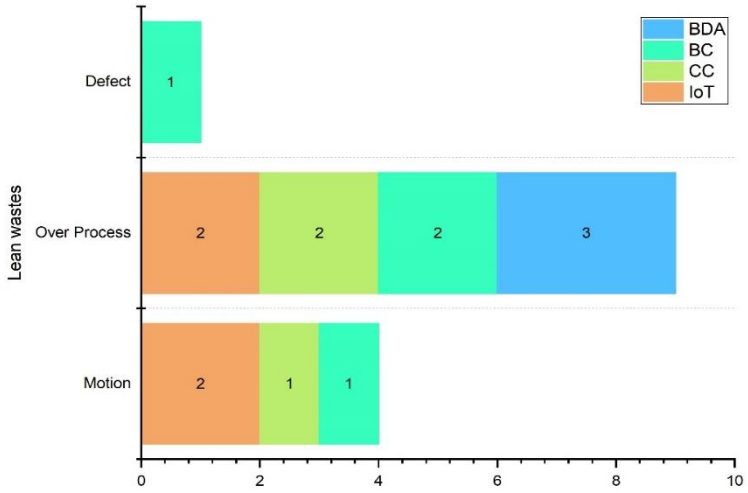


Figure 61 Application of Industry 4.0 technologies in Lean wastes for Source process

Figures (63) and (64) depict the status of different Industry4.0 technologies in relation to each other in order to be applied together as a combination of various technologies in alleviating the related wastes. In fact, these figures describe the inter relation of different Industry4.0 technologies for Source and Deliver processes for concurrent application.

For instance, in Figure (63) for Source process CC just applied with the IoT (S-OPR5) to improve Over Processing. In fact, CC is used as a complementary technology for integration of data collected by IoT tags and sharing them in real time with the other departments or SC members. Nevertheless, BDA is applied as a single technology for improving Over Processing wastes (S-OPR4, S-OPR, S-OPR3) without connection to the other ones. As a result, BDA can also be used as an individual technology in related wastes based on the available information through the information system in the Automotive company such as SAP.

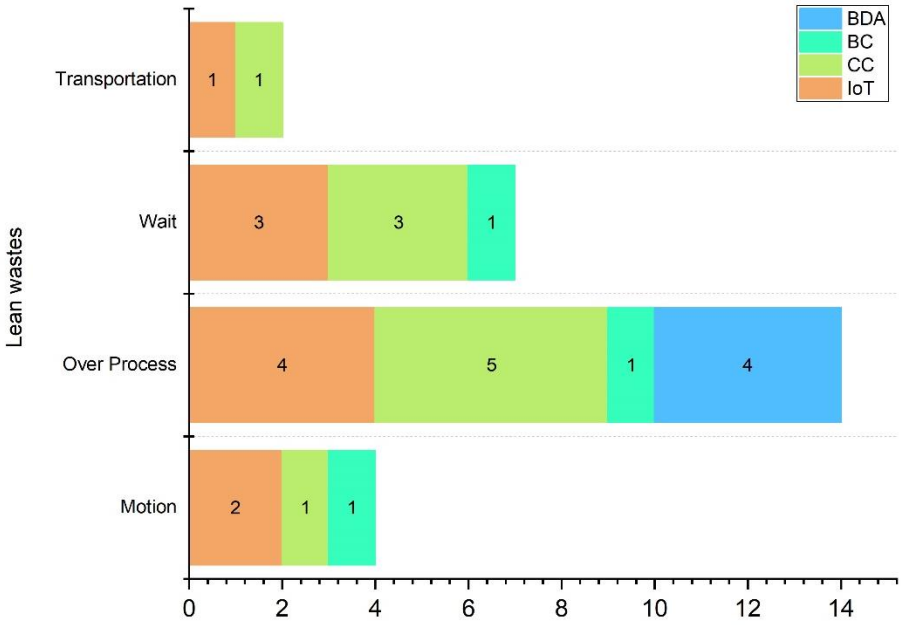


Figure 62 Application of Industry 4.0 technologies in Lean wastes for Source process

On the other hand, BC should be supported by IoT and CC when it is applied to improve the relationship among two SC members. Nonetheless, when the addressed waste is related to provide reliable information from 3rd parties that could be enough to just use BC as a single technology. This can arise from different applications of BC to achieve different goals. In fact, when BC is related to obtaining information or data from out of the company it uses for making trust and benefits of tamper proof data. However, for the internal activities related to the different processes inside the company BC is used to take the advantage of smart contracts based on BC to do some tasks automatically without need to human intervention. Therefore, for applying these smart contracts by BC it needs to collect and share related data for satisfying conditions by IoT and CC.

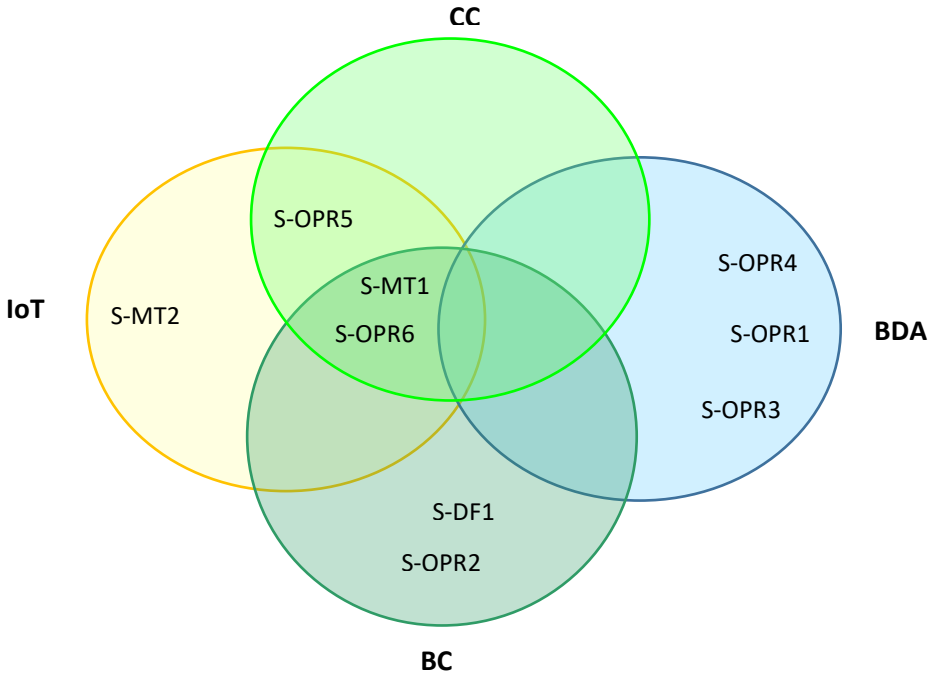


Figure 63 Analysis of combination of Industry 4.0 technologies in Source process in Automotive company

Similarly, Figure (64) shows the combination of different Industry4.0 technologies in the Deliver process. For this process in general the situation of concurrent using of technologies is similar to Source process. However, in the Deliver process BDA can also be used in combination with CC and IoT to facilitate the process of checking customer contracts and scheduling for providing more accurate production plans based on the received changes in customers' orders. Moreover, in both processes IoT can be used individually without other technologies for reducing the Motion waste in activities related to read the barcodes of pallets in Source and Deliver processes as internal activities of the company.

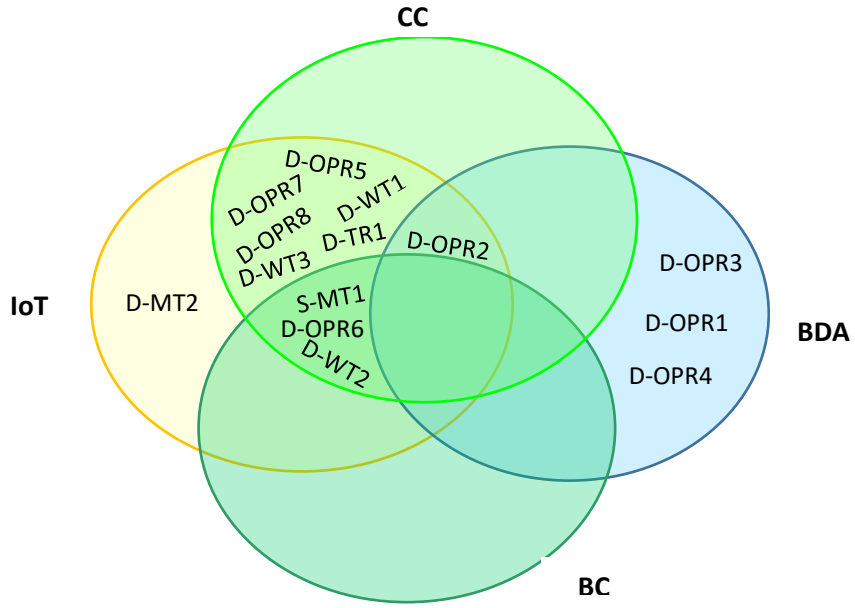


Figure 64 Analysis of combination of Industry 4.0 technologies in Deliver process in Automotive company

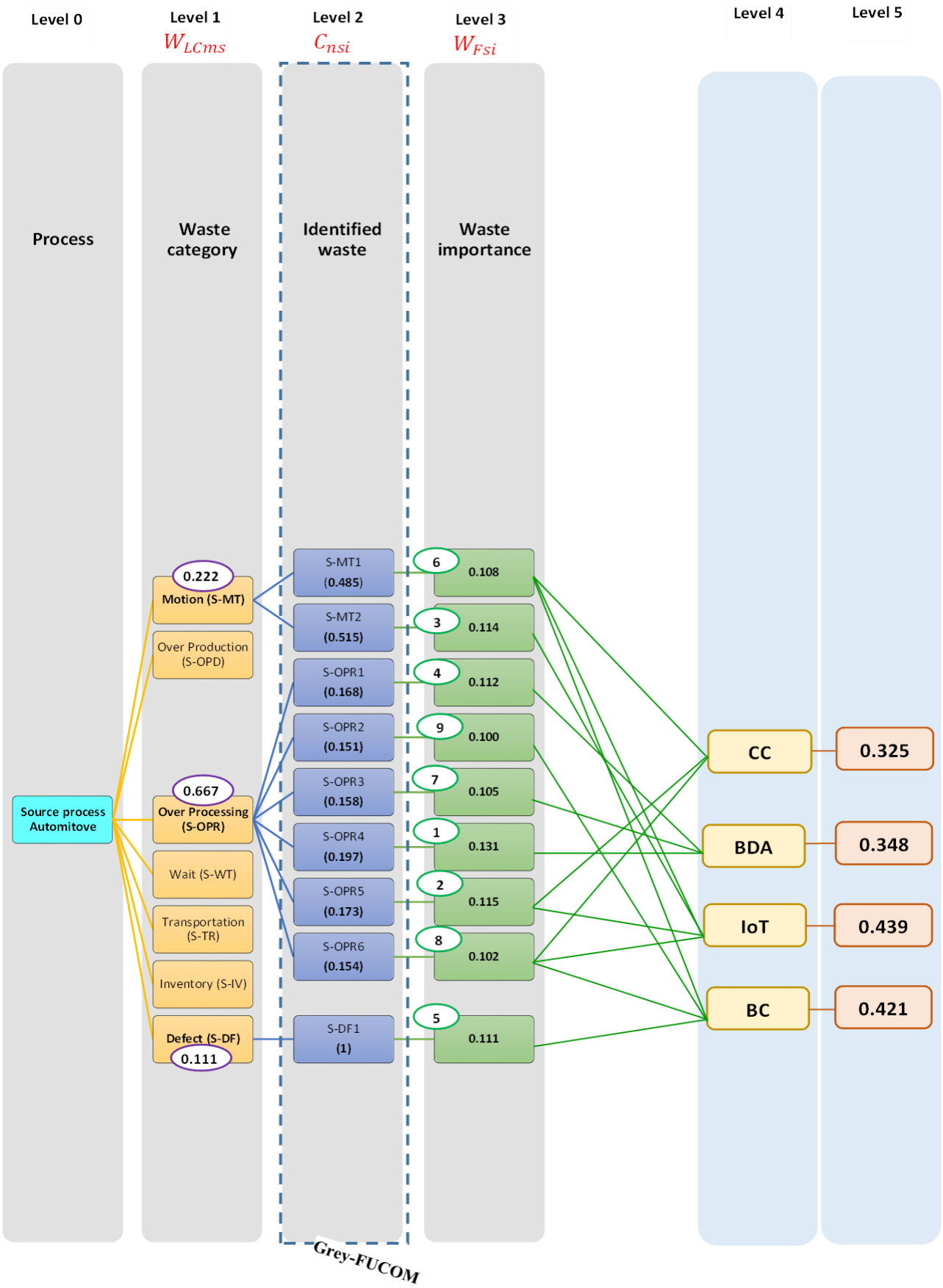


Figure 65 Computational structure of the Source process for developing Lean DSC roadmap in Automotive company

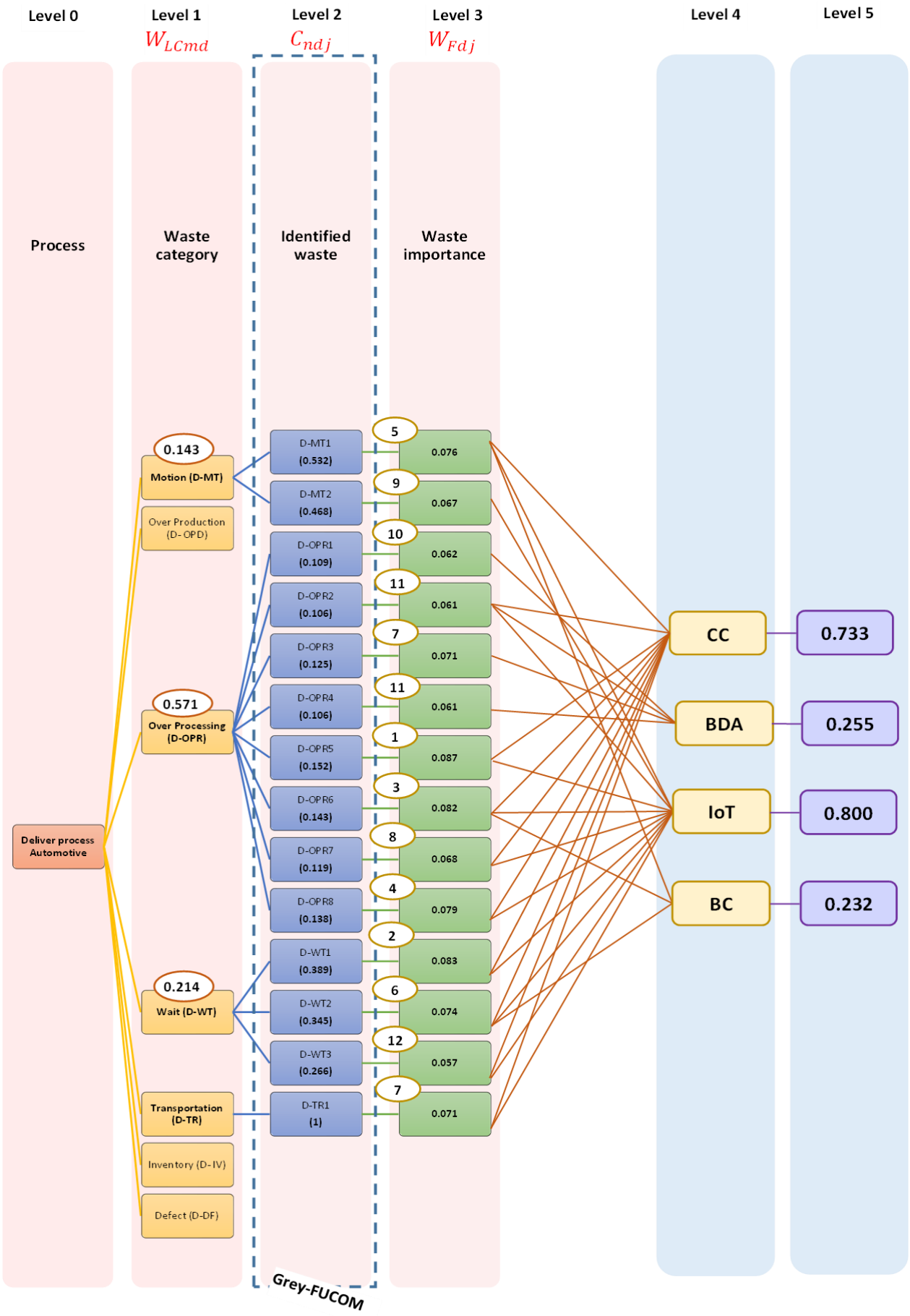


Figure 66 Computational structure of the Deliver process for developing Lean DSC roadmap in Automotive company

Chapter 8

Lean DSC roadmap for Food company

This chapter has been developed to demonstrate how to construct the Lean DSC roadmap and to discuss the associated findings of the Food company as the second case study. Therefore, the case study methodology and related formulas are similar to those described in chapters 6 and 7 for the case study regarding the Automotive industry. Accordingly, this chapter adapts the associated formulas for the Food company by using the same argument as in chapters 6 and 7.

8.1 Data collection for Food company

In this Phase, the primary objective is to gather information from the Food company so that the experts' opinions can be reflected in the development of the Lean DSC (as mentioned in Section 7.1). The Food company's top executives are also specialists in their field. Each of them is assigned the authority and obligation to make key decisions about the direction and focus of their respective divisions. So, taken as a whole, they can affect the company's future plans. As a result, the final data set was collected with input from six managers representing the core divisions of the Food company. Due to their regular meetings and teamwork, all these managers are aware of the responsibilities that pertain to their own departments and are also familiar with the primary operations of the other departments. The proficiency of each manager is displayed in Table (41) according to their year of experience in the field.

Table 41 Information about managers of Food company

DM	Position and role of expert	Years of experience
DM1	Marketing manager	8
DM2	Logistic manager	6
DM3	Financial manager	8
DM4	Production manager	20
DM5	Warehouse manager	12
DM6	Procurement manager	25

In the initial stage of the process, a workshop was carried out, in which each of the six managers took part. This workshop lasted around one hour, and its primary goals and implementation process are the same as outlined in section 7.1 for the Automotive company.

8.2 Applying Grey-FUCOM for Food company

For collecting personal judgment of each manager as expert the following steps have been established as described in section 7.2.

Step 1: Tables (42) and (43) show the preferred ranking of the identified wastes for the Food company in different Lean categories from the perspective of each expert. In fact, for each waste category, experts prioritized the identified wastes in order of their importance from the most significant to the least one. The outcomes of this stage for each of the six experts for source and Deliver process of the Food company are summarized in Tables (42) and (43).

Table 42 Food managers' preferences about the different categories of identified wastes for the Source process

DM	Ranking preference for Source wastes
Marketing (DM1)	$S-OPR_1 > S-OPR_4 = S-OPR_2 = S-OPR_5 = S-OPR_3$
Logistic (DM2)	$S-OPR_1 > S-OPR_2 = S-OPR_5 = S-OPR_4 = S-OPR_3$
Financial (DM3)	$S-OPR_1 > S-OPR_2 > S-OPR_4 = S-OPR_5 = S-OPR_3$
Production (DM4)	$S-OPR_1 > S-OPR_5 > S-OPR_2 > S-OPR_3 > S-OPR_4$
Warehouse (DM5)	$S-OPR_3 > S-OPR_1 > S-OPR_2 = S-OPR_5 = S-OPR_4$
Procurement (DM6)	$S-OPR_2 = S-OPR_4 = S-OPR_5 > S-OPR_1 > S-OPR_3$
Marketing (DM1)	$S-WT_2 > S-WT_1 > S-WT_3$
Logistic (DM2)	$S-WT_1 > S-WT_3 > S-WT_2$
Financial (DM3)	$S-WT_2 > S-WT_1 > S-WT_3$
Production (DM4)	$S-WT_1 > S-WT_3 > S-WT_2$
Warehouse (DM5)	$S-WT_1 > S-WT_3 > S-WT_2$
Procurement (DM6)	$S-WT_1 > S-WT_3 > S-WT_2$
Marketing (DM1)	$S-TR_1 > S-TR_2 = S-TR_3 > S-TR_4$
Logistic (DM2)	$S-TR_1 > S-TR_3 = S-TR_2 = S-TR_4$
Financial (DM3)	$S-TR_2 > S-TR_3 = S-TR_4 > S-TR_1$
Production (DM4)	$S-TR_2 > S-TR_4 = S-TR_3 > S-TR_1$
Warehouse (DM5)	$S-TR_2 = S-TR_3 > S-TR_4 > S-TR_1$
Procurement (DM6)	$S-TR_3 = S-TR_4 > S-TR_2 > S-TR_1$
Marketing (DM1)	$S-DF_1 > S-DF_2$
Logistic (DM2)	$S-DF_1 > S-DF_2$
Financial (DM3)	$S-DF_2 > S-DF_1$
Production (DM4)	$S-DF_1 > S-DF_2$
Warehouse (DM5)	$S-DF_1 > S-DF_2$
Procurement (DM6)	$S-DF_2 > S-DF_1$

Table 43 Food managers' preferences about the different categories of identified wastes for the Deliver process

DM	Ranking preference for Deliver wastes
Marketing (DM1)	$D-OPR_1 > D-OPR_2 > D-OPR_3 = D-OPR_4 = D-OPR_5$
Logistic (DM2)	$D-OPR_5 > D-OPR_1 > D-OPR_2 = D-OPR_3 = D-OPR_4$
Financial (DM3)	$D-OPR_4 > D-OPR_2 > D-OPR_1 = D-OPR_3 = D-OPR_5$
Production (DM4)	$D-OPR_3 > D-OPR_2 > D-OPR_1 > D-OPR_4 = D-OPR_5$
Warehouse (DM5)	$D-OPR_2 > D-OPR_1 = D-OPR_3 = D-OPR_4 > D-OPR_5$
Procurement (DM6)	$D-OPR_1 = D-OPR_2 > D-OPR_3 = D-OPR_4 = D-OPR_5$

Step 2: Here, each ranked criterion has been compared with the first rank in order to represent their grey significance $\left(\otimes\varpi_{C_{j(k)}}\right)$ via the linguistic scale associated with the grey numbers (see Table (24)). Tables (44) and (45) provide the results of this stage for the Food company in accordance with the expressions () in section 6.3 and the arguments in section 7.2.

Table 44 Grey significance of the wastes $\left(\otimes\varpi_{C_{j(k)}}\right)$ for Source process of Food company

$\otimes\varpi_{C_{j(k)}}$	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
DM 1	[1,1]	[1.36,1.88]	[1.36,1.88]	[1.36,1.88]	[1.36,1.88]
DM 2	[1,1]	[1.44, 2.14]	[1.44, 2.14]	[1.44, 2.14]	[1.44, 2.14]
DM 3	[1,1]	[1.13,1.53]	[1.3,1.81]	[1.3,1.81]	[1.3,1.81]
DM 4	[1,1]	[1.54,2.22]	[1.54,2.22]	[1.54,2.22]	[2.42,4]
DM 5	[1,1]	[1.13,1.54]	[1.54,2.22]	[1.54,2.22]	[1.54,2.22]
DM 6	[1,1]	[1,1]	[1,1]	[1.13,1.54]	[1.3,1.82]
DM 1	[1,1]	[1.16,1.54]	[1.36,1.88]		
DM 2	[1,1]	[1.18, 1.66]	[1.44,2.14]		
DM 3	[1,1]	[1.13, 1.54]	[1.3, 1.81]		
DM 4	[1,1]	[1,1]	[1.3, 1.81]		
DM 5	[1,1]	[1,1]	[1.3, 1.81]		
DM 6	[1,1]	[1,1.33]	[1.13,1.54]		
DM 1	[1,1]	[1.15, 1.54]	[1.15,1.54]	[1.66,2.43]	
DM 2	[1,1]	[1.18,1.66]	[1.18,1.66]	[1.18,1.66]	
DM 3	[1,1]	[1,1.36]	[1,1.36]	[1.44,2.14]	
DM 4	[1,1]	[1.15, 1.54]	[1.15, 1.54]	[1.66,2.43]	
DM 5	[1,1]	[1.3, 1.81]	[1.3, 1.81]	[1.89,2.86]	
DM 6	[1,1]	[1,1]	[1.13,1.54]	[1.3,1.82]	
DM 1	[1,1]	[1,1.3]			
DM 2	[1,1]	[1,1.3]			
DM 3	[1,1]	[1.18, 1.67]			
DM 4	[1,1]	[1,1.3]			
DM 5	[1,1]	[1.3,1.81]			
DM 6	[1,1]	[1,1.33]			

Table 45 Grey significance of the wastes $\left(\otimes\varpi_{C_{j(k)}}\right)$ for Deliver process of Food company

$\otimes\varpi_{C_{j(k)}}$	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
DM 1	[1,1]	[1,1.3]	[1.36,1.89]	[1.36,1.89]	[1.36,1.89]
DM 2	[1,1]	[1,1.3]	[1.36,1.89]	[1.36,1.89]	[1.36,1.89]
DM 3	[1,1]	[1.15,1.54]	[1.36,1.89]	[1.36,1.89]	[1.36,1.89]
DM 4	[1,1]	[1.3,1.81]	[1.36,1.89]	[1.36,1.89]	[1.36,1.89]
DM 5	[1,1]	[1.13,1.53]	[1.13,1.53]	[1.13,1.53]	[1.3,1.82]
DM 6	[1,1]	[1,1]	[1.44,2.14]	[1.44,2.14]	[1.44,2.14]

Step 3: In order to guarantee the minimum DFC during the construction of the FUCOM model, the requirements () and () must be met. As a result, the following mathematical models have been developed after full consideration of all conditions for each waste category recognized by the Source and Deliver processes. Tables (46) and (47) depict the FUCOM models for Source and Deliver processes and their related wastes, for each expert.

Table 46 FUCOM model for each manager in different waste category of Source process in Food company

S-OPR	DM_1: Min χ $\begin{cases} \left\|\frac{w_1}{w_4}-1.62\right\| \le \chi, \left\|\frac{w_4}{w_2}-1\right\| \le \chi, \left\|\frac{w_2}{w_5}-1\right\| \le \chi, \\ \left\|\frac{w_5}{w_3}-1\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.62\right\| \le \chi, \left\|\frac{w_4}{w_5}-1\right\| \le \chi, \\ \left\|\frac{w_2}{w_3}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_2: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.79\right\| \le \chi, \left\|\frac{w_2}{w_5}-1\right\| \le \chi, \left\|\frac{w_5}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_4}{w_3}-1\right\| \le \chi, \left\|\frac{w_1}{w_5}-1.79\right\| \le \chi, \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_5}{w_3}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$
	DM_3: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.33\right\| \le \chi, \left\|\frac{w_2}{w_4}-1.22\right\| \le \chi, \left\|\frac{w_4}{w_5}-1\right\| \le \chi, \\ \left\|\frac{w_5}{w_3}-1\right\| \le \chi, \left\|\frac{w_1}{w_4}-1.70\right\| \le \chi, \left\|\frac{w_2}{w_5}-1.22\right\| \le \chi, \\ \left\|\frac{w_4}{w_3}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_4: Min χ $\begin{cases} \left\|\frac{w_1}{w_5}-1.88\right\| \le \chi, \left\|\frac{w_5}{w_2}-1\right\| \le \chi, \left\|\frac{w_2}{w_3}-1\right\| \le \chi, \\ \left\|\frac{w_3}{w_4}-1.84\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.88\right\| \le \chi, \left\|\frac{w_5}{w_3}-1\right\| \le \chi, \\ \left\|\frac{w_2}{w_4}-1.84\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$
	DM_5: Min χ $\begin{cases} \left\|\frac{w_3}{w_1}-1.33\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.48\right\| \le \chi, \left\|\frac{w_2}{w_5}-1\right\| \le \chi, \\ \left\|\frac{w_5}{w_4}-1\right\| \le \chi, \left\|\frac{w_3}{w_2}2.07\right\| \le \chi, \left\|\frac{w_1}{w_5}-1.48\right\| \le \chi, \\ \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_6: Min χ $\begin{cases} \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_5}-1\right\| \le \chi, \left\|\frac{w_5}{w_1}-1.33\right\| \le \chi, \\ \left\|\frac{w_1}{w_3}-1.22\right\| \le \chi, \left\|\frac{w_2}{w_5}-1\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.33\right\| \le \chi, \\ \left\|\frac{w_5}{w_3}-1.71\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1, w_j \ge 0, \forall j \end{cases}$
	DM_1: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.35\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.25\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.75\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_2: Min χ $\begin{cases} \left\|\frac{w_1}{w_3}-1.42\right\| \le \chi, \left\|\frac{w_3}{w_2}-1.34\right\| \le \chi, \left\|\frac{w_1}{w_2}-2.01\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$
	DM_3: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.33\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.22\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.70\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_4: Min χ $\begin{cases} \left\|\frac{w_1}{w_3}-1\right\| \le \chi, \left\|\frac{w_3}{w_2}-1.55\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.55\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$
	DM_5: Min χ $\begin{cases} \left\|\frac{w_1}{w_3}-1\right\| \le \chi, \left\|\frac{w_3}{w_2}-1.55\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.55\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$	DM_6: Min χ $\begin{cases} \left\|\frac{w_1}{w_3}-1.16\right\| \le \chi, \left\|\frac{w_3}{w_2}-1.19\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.44\right\| \le \chi \\ \sum_{j=1}^{3} w_j = 1, w_j \ge 0, \forall j \end{cases}$

$\boldsymbol{DM_1}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.62\right\| \le \chi, \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_1}{w_3}-1.81\right\| \le \chi, \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_2}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_3}-1.42\right\| \le \chi, \left\|\frac{w_3}{w_2}-1\right\| \le \chi, \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_1}{w_2}-1.42\right\| \le \chi, \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$
$\boldsymbol{DM_3}$: Min χ $\begin{cases} \left\|\frac{w_2}{w_3}-1.18\right\| \le \chi, \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.60\right\| \le \chi, \\ \left\|\frac{w_2}{w_4}-1.18\right\| \le \chi, \left\|\frac{w_3}{w_1}-1.60\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_4}$: Min χ $\begin{cases} \left\|\frac{w_2}{w_4}-1.34\right\| \le \chi, \left\|\frac{w_4}{w_3}-1\right\| \le \chi, \left\|\frac{w_3}{w_1}-1.59\right\| \le \chi, \\ \left\|\frac{w_2}{w_3}-1.34\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.59\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$
$\boldsymbol{DM_5}$: Min χ $\begin{cases} \left\|\frac{w_2}{w_3}-1.55\right\| \le \chi, \left\|\frac{w_3}{w_4}-\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.62\right\| \le \chi, \\ \left\|\frac{w_2}{w_4}-1.55\right\| \le \chi, \left\|\frac{w_3}{w_1}-1.62\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_6}$: Min χ $\begin{cases} \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_2}-1.33\right\| \le \chi, \left\|\frac{w_2}{w_1}-1.22\right\| \le \chi, \\ \left\|\frac{w_3}{w_2}-1.33\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.71\right\| \le \chi, \\ \sum_{j=1}^{4} w_j = 1, w_j \ge 0, \forall j \end{cases}$
$\boldsymbol{DM_1}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_2}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$
$\boldsymbol{DM_3}$: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.42\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_4}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$
$\boldsymbol{DM_5}$: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.55\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$	$\boldsymbol{DM_6}$: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.16\right\| \le \chi, \\ \sum_{j=1}^{6} w_j = 1, w_j \ge 0, \forall j \end{cases}$

Table 47 FUCOM model for each manager in different waste category of Deliver process in Food company

D-OPR	DM_1: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1.15\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.46\right\| \le \chi, \left\|\frac{w_3}{w_5}-1\right\| \le \chi, \\ \left\|\frac{w_5}{w_4}-1\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.75\right\| \le \chi, \left\|\frac{w_2}{w_5}-1.46\right\| \le \chi, \\ \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$	DM_2: Min χ $\begin{cases} \left\|\frac{w_5}{w_1}-1.15\right\| \le \chi, \left\|\frac{w_1}{w_2}-1.46\right\| \le \chi, \left\|\frac{w_2}{w_3}-1\right\| \le \chi, \\ \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \left\|\frac{w_5}{w_2}-1.75\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.46\right\| \le \chi, \\ \left\|\frac{w_2}{w_4}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$
	DM_3: Min χ $\begin{cases} \left\|\frac{w_4}{w_2}-1.34\right\| \le \chi, \left\|\frac{w_2}{w_1}-1.26\right\| \le \chi, \left\|\frac{w_1}{w_3}-1\right\| \le \chi, \\ \left\|\frac{w_3}{w_5}-1\right\| \le \chi, \left\|\frac{w_4}{w_1}-1.76\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.26\right\| \le \chi, \\ \left\|\frac{w_1}{w_5}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$	DM_4: Min χ $\begin{cases} \left\|\frac{w_3}{w_2}-1.55\right\| \le \chi, \left\|\frac{w_2}{w_1}-1.07\right\| \le \chi, \left\|\frac{w_1}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_4}{w_5}-1\right\| \le \chi, \left\|\frac{w_3}{w_1}-1.75\right\| \le \chi, \left\|\frac{w_2}{w_4}-1.07\right\| \le \chi, \\ \left\|\frac{w_1}{w_5}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$
	DM_5: Min χ $\begin{cases} \left\|\frac{w_2}{w_1}-1.33\right\| \le \chi, \left\|\frac{w_1}{w_4}-1\right\| \le \chi, \left\|\frac{w_4}{w_3}-1\right\| \le \chi, \\ \left\|\frac{w_3}{w_5}-1.22\right\| \le \chi, \left\|\frac{w_2}{w_4}-1.33\right\| \le \chi, \left\|\frac{w_1}{w_3}-\right\| \le \chi, \\ \left\|\frac{w_4}{w_5}-1.22\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$	DM_6: Min χ $\begin{cases} \left\|\frac{w_1}{w_2}-1\right\| \le \chi, \left\|\frac{w_2}{w_3}-1.79\right\| \le \chi, \left\|\frac{w_3}{w_4}-1\right\| \le \chi, \\ \left\|\frac{w_4}{w_5}-1\right\| \le \chi, \left\|\frac{w_1}{w_3}-1.79\right\| \le \chi, \left\|\frac{w_2}{w_4}-1.79\right\| \le \chi, \\ \left\|\frac{w_3}{w_5}-1\right\| \le \chi, \\ \sum_{j=1}^{5} w_j = 1 \ , w_j \ge 0, \forall j \end{cases}$

After running the FUCOM model 30 times (for 6 DM regarding all 5 different types of wastes in Source and Deliver process) by GAMS 24.1 the following relative weights have been obtained for each identified waste in each Lean waste category in Source and Deliver processes of food company (see Tables (48) and (49)). More details about the coding in GAMS are available in appendix B and also by asking from author. Similar to the results of Automotive company also here the obtained results in Tables (48) and (49) have been named as c_{ik} for Source process and c_{jk} for Deliver process. In fact, c_{ik} or c_{jk} show the obtained values for each identified waste in Source and Deliver by k^{th} DM as expert.

Table 48 Relative weights obtained by FUCOM for each waste in the Source process of Food company

DM	C1	c2	c3	c4	c5	DFC(x)
DM1	0,288	0,178	0,178	0,178	0,178	0
DM2	0,309	0,173	0,173	0,173	0,173	0
DM3	0,284	0,210	0,166	0,170	0,170	0,022
DM4	0,346	0,184	0,184	0,100	0,100	0
DM5	0,231	0,153	0,313	0,149	0,149	0,025
DM6	0,172	0,228	0,139	0,228	0,228	0,025
DM1	0,317	0,433	0,25	-	-	0,017
DM2	0,455	0,23	0,315	-	-	0,025

DM3	0,317	0,428	0,255	-	-	0,022
DM4	0,378	0,244	0,378	-	-	0
DM5	0,378	0,244	0,378	-	-	0
DM6	0,392	0,276	0,333	-	-	0,018
DM1	0,337	0,252	0,252	0,159	-	0
DM2	0,321	0,226	0,226	0,226	-	0
DM3	0,164	0,31	0,263	0,263	-	0
DM4	0,159	0,337	0,252	0,252	-	0
DM5	0,148	0,372	0,24	0,24	-	0
DM6	0,18	0,223	0,295	0,302	-	0,025
DM1	0,535	0,465	-	-	-	0
DM2	0,535	0,465	-	-	-	0
DM3	0,413	0,587	-	-	-	0
DM4	0,535	0,465	-	-	-	0
DM5	0,608	0,392	-	-	-	0
DM6	0,463	0,537	-	-	-	0

Table 49 Relative weights obtained by FUCOM for each waste in the Deliver process of Food company

DM	C1	c2	c3	c4	c5	DFC(x)
DM1	0,279	0,239	0,162	0,159	0,162	0,02
DM2	0,239	0,162	0,162	0,159	0,279	0,02
DM3	0,167	0,213	0,167	0,29	0,164	0,02
DM4	0,173	0,189	0,297	0,173	0,168	0,025
DM5	0,194	0,258	0,194	0,194	0,159	0
DM6	0,272	0,272	0,152	0,152	0,152	0

8.3 Analysis of experts' results for Food company

In this section the results of the experts' judgments have been explained for each waste category in Source and Deliver process separately for the Food company. It is worth mentioning that in the present section the results have been discussed without considering the importance or weight of each expert in the Food company.

8.3.1 Analysis of experts' results for Source process in Food company

As shown in the Figure (67), the most important waste for source process of the Food company is related to the activity for "Making decision for next year production". In particular, the waste is long time to make decision for next year production by collecting and integrating all data about demand from different resources and potential B2B customers (S-OPR1). Since, the business model of this company is a hybrid Push-Pull system. Therefore, for the first part, according to the Push system, they need to have a good estimation before beginning of the production in each year. Totally, this is the most significant (1st rank) Over Processing waste in Source process for majority of the experts including Marketing manager, Logistics manager, Financial manager, and Production manager. In fact, S-OPR1 can affect the performance of mentioned departments directly or indirectly.

For instance, Production manager to appropriately organize the production plan for the next year needs to have an enough precise estimation next year demand.

Additionally, for the Procurement manger the most important wastes are mainly related to the internal activities which are pure responsibilities of procurement staffs. In this regard, the most important wastes for Procurement manager are "Weekly collecting and analyzing samples from all farms in the season of harvesting" (S-OPR5), "Contact suppliers every time to inform them about olives quality" (S-OPR2), and "Following, inserting, and keeping the track of each treatment for each farm" (S-OPR4).

In addition, for the Warehouse manager the most significant waste in this type is "Analyzing quality parameters after conditional acceptance of olives for each arrived truck" (S-OPR3) due to the fact that warehouse staffs are responsible for doing such activities related to this waste. In fact, it takes a long time of the warehouse staff to do the manual and subjective procedure for initial evaluation of each truck loads.

On the other hand, the least important waste from the expert's perspectives are "Following, inserting, and keeping the track of each treatment for each farm" (S-OPR4), "and Analyzing quality parameters after conditional acceptance of olives for each arrived truck" (S-OPR3). It could arise from the fact that these are related to the pure internal activities in Procurement department and they have less direct connection or effect on the performance of the other departments like Production.

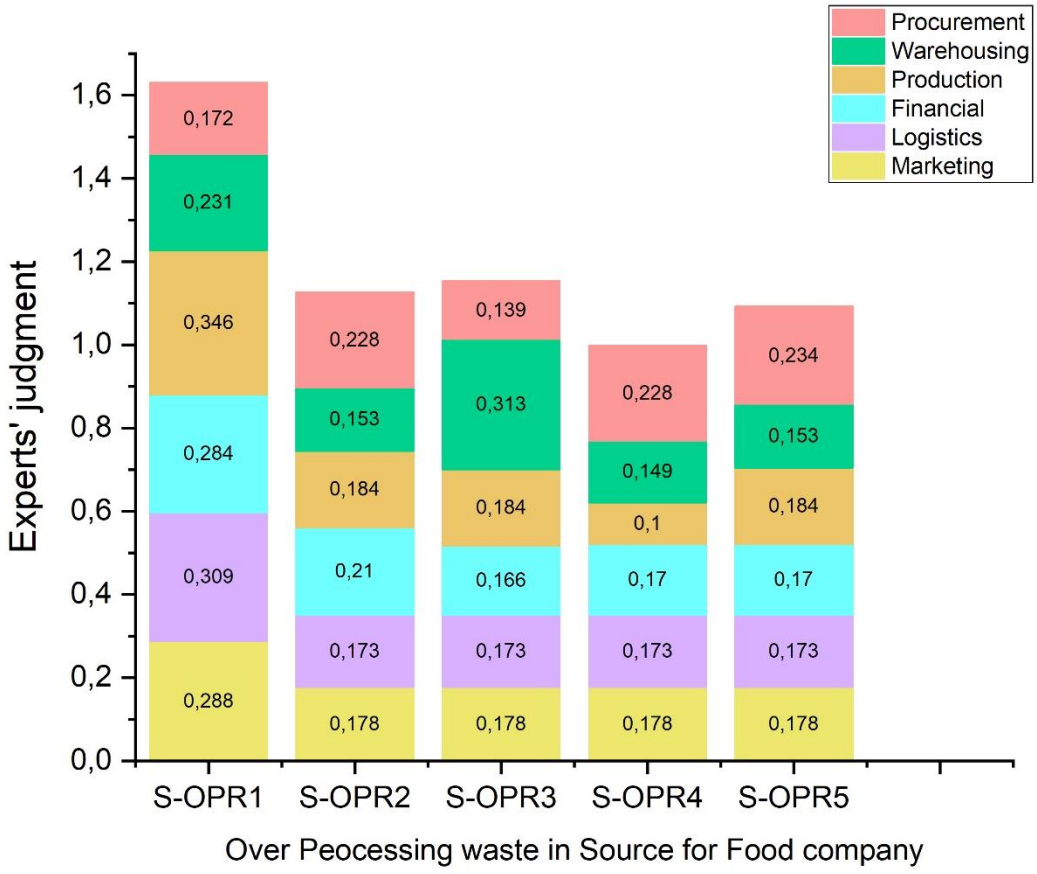


Figure 67 Distribution of experts' judgement for Over Process waste in Source process of Food company

In the Wait waste as described in the Figure (68), the most critical waste is

“Waiting each truck of olives to have an initial evaluation by observers” (S-WT1). It can be explained by the importance of doing the related task with minimum Wait waste in order to do the other following tasks with less delays. In fact, any problem in doing this task in a timely manner can be identified as a bottle neck for the next ones. In this regard, S-WT1 is the most important Wait waste in Source process of the Food company for Procurement manager, Warehousing manager, and Production manager thanks to the fact that this is a totally manual procedure based on subjective judgment of employees. Therefore, the performance of doing this activity can affect many departments such as Procurement manager, Warehousing manager, and Production manager. For instance, for the Production manager he prefers to receive the raw olives with minimum delay to process fresh olives for having better quality of final olive oil.

Moreover, “Waiting received olives for the results of the other analysis about quality of them” (S-WT3) is the first or second significant Wait waste for the same group of managers (Procurement, Warehousing, Production) since this task is a consequence of completing the results of the previous task (“Checking the quality of the olives on truck by employee’s observation”) more in depth. Therefore, performance of related activity to this waste can have direct effect on the next activities and related identified wastes (S-WT1 and S-WT3). In fact, because of the fact that the company cannot just rely on the results of checking quality of the olives on truck (S-WT1), the company should have more in depth analysis of the olives quality. Therefore, the Wait in the S-WT1 can directly affect the amount of waiting for S-WT3.

On the other hand, “Waiting for integration of selling information in the company system before the payment to the farmers” (S-WT2) is the least important Wait waste for majority of the managers as experts (Procurement, Warehouse, Production, Logistics). Nevertheless, it is the first rank Wait waste among the others from the Financial manager (0.428) because of the fact that the related activity to this waste is a task for Financial department. Hence, improving that can have a direct and great effect on the timing and performance of this department.

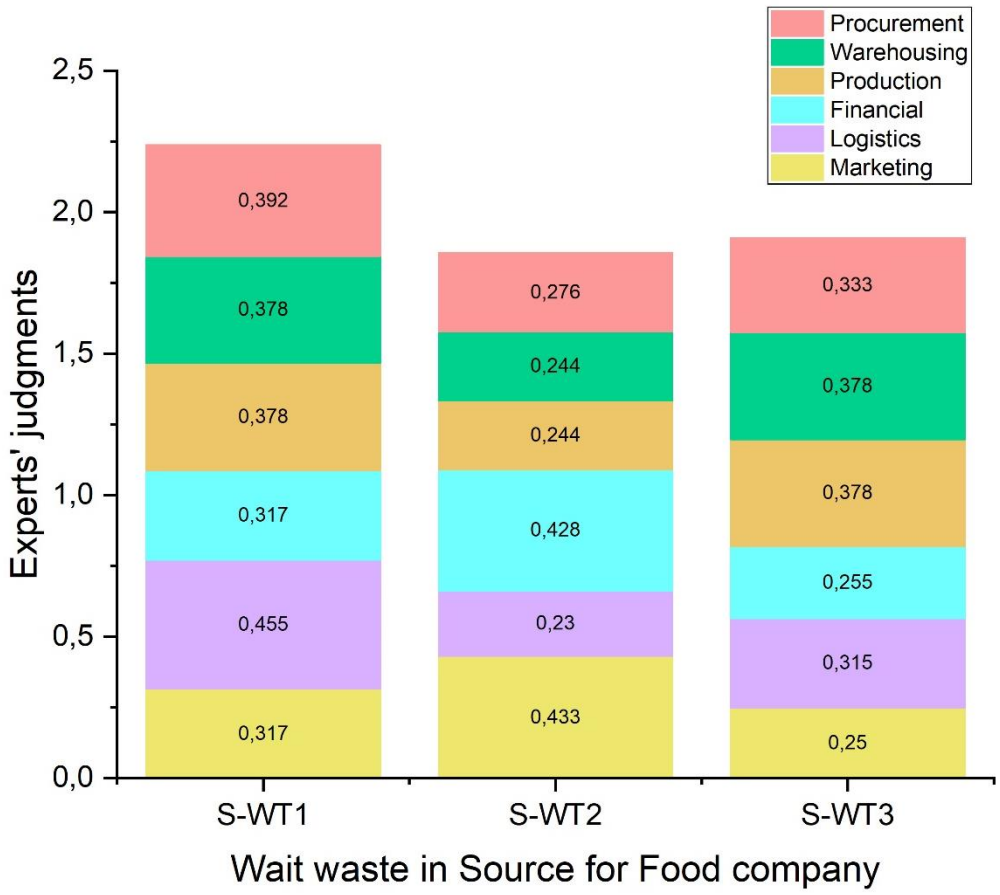


Figure 68 Distribution of experts' judgement for Wait waste in Source process of Food company

Figure (69) depicts the Experts' judgments about the Transportation waste in the Source for the Food company. As it can be concluded from Figure (69), the most important Transportation waste is "Going around the truck for checking the received olives on truck" (S-TR2). As a matter of fact, S-TR2 is the most significant waste for Warehouse manager (0.372), Production manager (0.337), Financial manager (0.310). For instance, Warehouse manager consider S-TR2 as the most important since the warehouse staff should do this investigation and checking before unloading the olives. Moreover, the performance of the warehouse staff in doing the related activity in the right way can directly affect the performance of the production department to produce higher quality oil in the following steps.

On the contrary, for the marketing department the transportation related to the "Going around to collect related information from different sources for estimating demand" (S-TR1) is the most important. Nonetheless, in general point of view S-TR1 is the least important one from the total overview of the other managers. This could be reasonable since the Transportation waste related to S-TR1 is a part of marketing staffs' activities for completing their tasks.

Moreover, for the Procurement department the most important Transportation waste is "Going to the farms and collecting samples for determining the time of harvesting every week" (S-TR4). In fact, going weekly to all the farms to collect the samples from them for analysis to decide about the harvesting time requires frequently trips to the farms and it means huge movements for the Procurement staff at the time of harvesting olives.

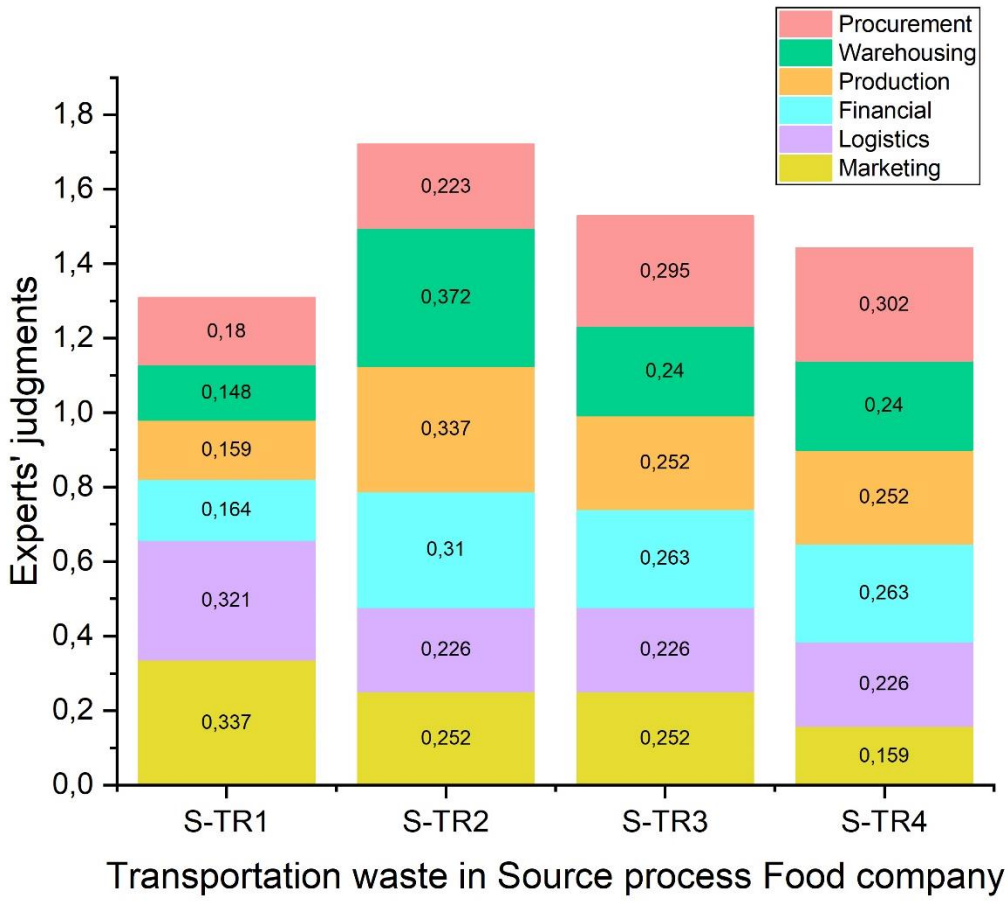


Figure 69 Distribution of experts' judgement for Transportation waste in Source process of Food company

Figure (70) demonstrates the importance of the two Defect waste in the Source process for each manager. For most of the managers the relative importance of these two wastes is more or less the same. However, for the warehouse manager it seems that "Human errors to determine right quality and directing to the right line for dropping the olives" (S-DF1) is pretty much more significant and critical than "Possible errors for estimating the time for harvesting and its effect on the quality of final product" (S-DF2). It can be explained by the fact that the Warehouse department is responsible for any errors which give rise to the defect in production if they do not have right evaluation by initial observation and checking the olives. Generally, it seems that the importance of S-DF1 is slightly higher than S-DF2 for all the departments manager involved in this study. Therefore, mainly aside from the Procurement manager (0.537) and Financial Manager (0.587), the other ones assigned slightly higher weight to S-DF1. In fact, the Procurement manager is more engaged with improving the possible issues and defects related to "Determine the time of harvesting and delivering to factory" as S-DF2.

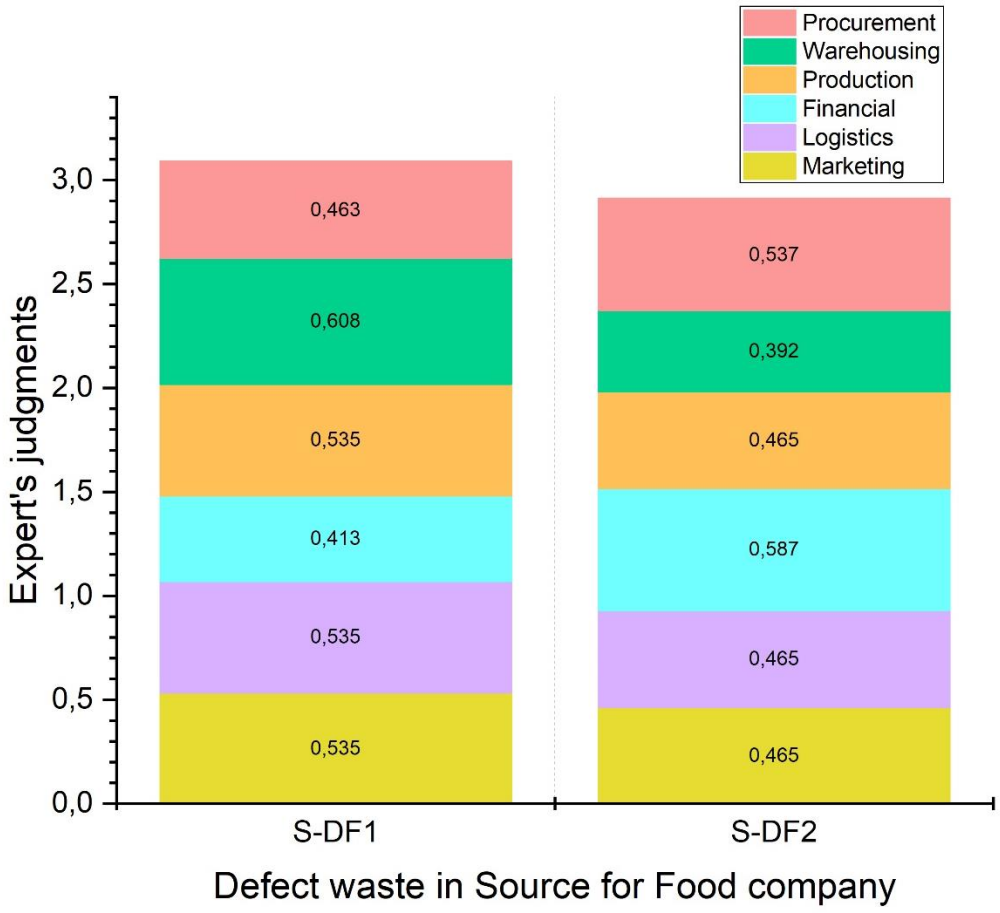


Figure 70 Distribution of experts' judgement for Defect waste in Source process of Food company

8.3.2 Analysis of experts' results for Deliver process in Food company

According to Figure (71), in the Over Processing of the Delivery for Food company the most important wastes to alleviate are as follows:

- "For each change in the customer order the marketing staff need to inform the customer about the availability of the requested products" (D-OPR1).
- "For each customer and each order, the information about the order should be register in the company information system" (D-OPR2).

In this regard, D-OPR1 is the most significant waste for the Marketing manager and the Logistic manager since they are directly connected with and affected by the performance of doing this activity. Moreover, "Communicate each time to order new bottle of products to the Production department" (D-OPR3) is the first rank waste among the remaining ones for the Production manager since for producing new orders and replenishing the warehouse Production department just relies on the information received from the finished products warehouse. However, in many cases it can lead to delays in production and delivery and consequently have a negative impact on the customer satisfaction.

Additionally, for the Financial department "Printing and preparing all shipment documents for each customer and each delivery" (D-OPR4) is the most critical task since the final B2B customers will not pay the company in case of lack in received documents from the company. Moreover, for the Logistic manager the most significant waste is "Spending time searching and defining the best possible

shipment group for delivery to customers" (D-OPR5). In fact, the company has various types of delivery contracts for different customers, and they do not use any structure method or tool to assist them in finding the best delivery provider. Nevertheless, still for Logistic manager D-OPR1 is one the main wastes preventing from providing high level of logistics service to the B2B customers of the company. In fact, the information provided to the customer is not timely and complete the logistic service outcome might be compromised.

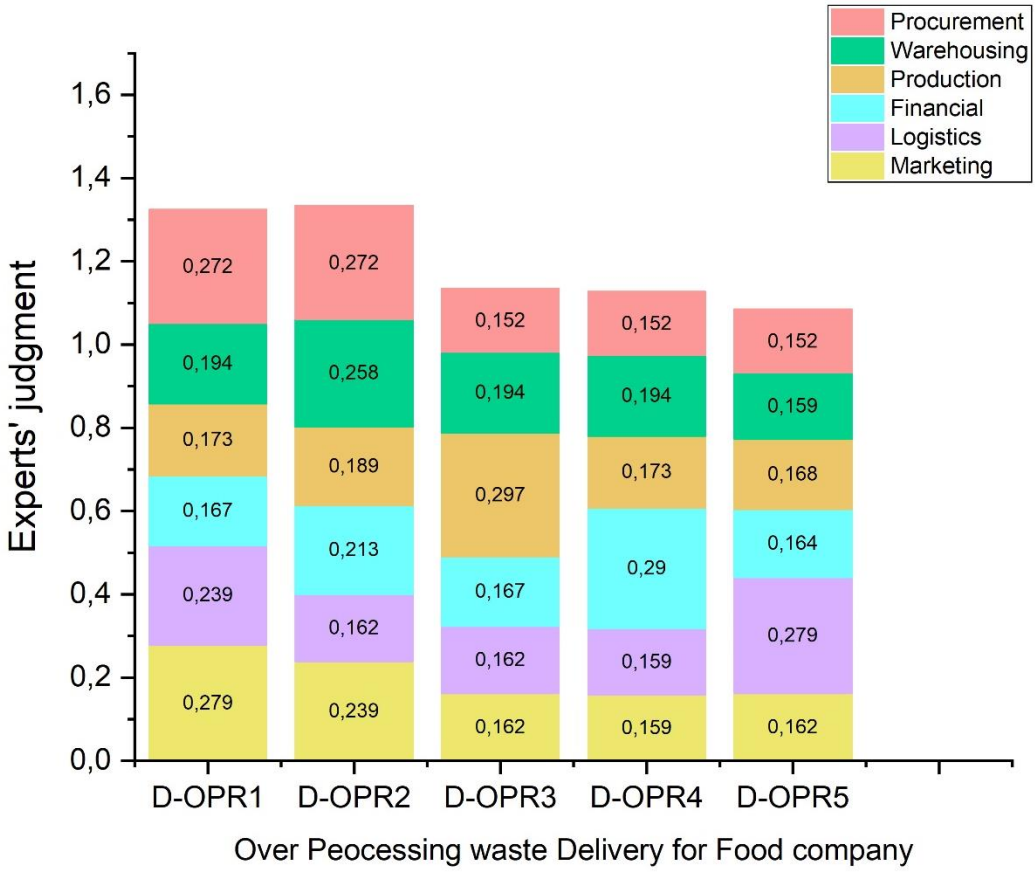


Figure 71 Distribution of experts' judgement for Over Process waste in Deliver process of Food company

8.4 Data aggregation for Food company

In order to construct and develop the final Lean DSC roadmap, it is necessary to combine the values coming from all involved experts throughout the company. This will allow for the integration of all the participating experts' viewpoints. Therefore, by adhering to the same process and formulas as discussed in section 7.3, the following findings have been obtained for the relative importance of various waste categories in the Food company for the Source and Deliver processes.

In the first phase, it is important to point out that the findings presented in sections 8.3.1 and 8.3.2 have been established from a variety of Lean waste types. As an outcome, for the final integration of results it is necessary to take into consideration the significance of each waste category from the Source and Deliver processes. The following equations have been used to determine how much weight should be assigned to each waste category in Source (W_{LCms}) and Deliver (W_{LCmd}):

$$W_{LCms} = \frac{\sum_{i=1}^{M_s} b_{im}}{\sum_{m=1}^{7}\sum_{i=1}^{M_s} b_{im}} \quad (23)$$

$$W_{LCmd} = \frac{\sum_{j=1}^{M_d} b_{jm}}{\sum_{m=1}^{7}\sum_{j=1}^{M_d} b_{jm}} \quad (24)$$

In equations (23), M_s represents the number of the identified wastes for the Source process. Therefore, as explained in section 7.4, (b_{nm}) indicates the n^{th} identified waste in the m^{th} Lean waste category when $(i \in \{1,2,i,\dots,M_s\})$ and $(m \in \{1,2,m,\dots,7\})$. Thus, $b_{nm} = 1$ if there is an identified waste in the investigated Lean category, otherwise, $b_{nm} = 0$. Also, the same explanation can be applied to expression (24) for the Deliver process when $(j \in \{1,2,i,\dots,M_d\})$ and M_d shows the number of the identified wastes in this process. Hence, the weights for each Lean waste category have been obtained according to the expressions (23) and (24). The results have been presented in Table (50) and under Level 1 in Figures (81) and (82).

Table 50 Relative weight of each Lean waste category for Source and Deliver processes of Food company

Wastes category (m)	Total number of wastes in each category ($\sum_{i=1}^{M_s} b_{im}$)	Weight of category (W_{LCms})
S-OPD1	1	0,067
S-OPR1	5	0,333
S-OPR2		
S-OPR3		
S-OPR4		
S-OPR5		
S-WT1	3	0,200
S-WT2		
S-WT3		
S-TR1	4	0,267
S-TR2		
S-TR3		
S-TR4		
S-DF1	2	0,133
S-DF2		

Wastes category (m)	Total number of wastes in each category ($\sum_{j=1}^{M_d} b_{jm}$)	Weight of category (W_{LCmd})
D-OPR1	5	0,714
D-OPR2		
D-OPR3		
D-OPR4		
D-OPR5		
D-WT1	1	0,143
D-DF1	1	0,143

According to the identified wastes in section 5.3.2, it is clear that they are related to the different departments. Therefore, as discussed in sections 7.4, this can affect the assigned weights to the wastes by experts according to their level of proficiency in predicting the possible consequences of different wastes. Hence, the relative weights of each expert should reflect the amount of connection among each waste and the level of proficiency of the responsible manager as expert for judgment about the final waste importance. As a result, by taking into account the responsibility matrix of the experts for Source and Deliver processes of the Food company (see Tables (51) and (52)) the following relative weights are obtained to

address the importance of each DM in Source (DM_{ks}) and Deliver (DM_{kd}) processes.

To be more precise, for the responsibility matrix in Table (51) the weight of each expert for Source process (DM_{ks}) is calculated according to the equation (25). Similarly, Table (52) has been considered for calculating the experts' weights in Deliver process (DM_{kd}) by equation (26). Therefore, the k^{th} DM's weight is obtained as follows for each Source and Deliver process separately:

$$DM_{ks} = 0.05 + (1 - 0.05 * E)\frac{\sum_{i=1}^{M_s} a_{ik}}{\sum_{k=1}^{E}\sum_{i=1}^{M_s} a_{ik}} \quad (25)$$

$$DM_{kd} = 0.05 + (1 - 0.05 * E)\frac{\sum_{j=1}^{M_d} a_{jk}}{\sum_{k=1}^{E}\sum_{j=1}^{M_d} a_{jk}} \quad (26)$$

In this regard, E shows the total number of DMs as experts in the Food company, and M_s and M_d represent the number of identified wastes in Source and Deliver process respectively. Accordingly, for the case of Food company, $E = \{1,2,k,\dots,7\}$, $i \in \{1,2,i,\dots,M_s\}, j \in \{1,2,j,\dots,M_d\}$. Therefore, $a_{ik} = 1$ if i^{th} waste in Source process is related to the k^{th} expert (manager), otherwise, $a_{ik} = 0$ the same explanation holds for a_{jk} in Deliver process.

Table 51 Responsibility matrix and relative weights of each manager as expert in Source process of Food company

	Marketing (DM1)	Logistics (DM2)	Financial (DM3)	Production (DM4)	Warehousing (DM5)	Procurement (DM6)
S-OPD1						
s-OPR1						
S-OPR2						
s-OPR3						
s-OPR4						
s-OPR5						
S-WT1						
S-WT2						
S-WT3						
S-TR1						
S-TR2						
S-TR3						
S-TR4						
S-DF1						
S-DF2						
Weight	0,18	0,05	0,09	0,09	0,27	0,31

Table 52 Responsibility matrix and relative weights of each manager as expert in Deliver process of Food company

	Marketing (DM1)	Logistics (DM2)	Financial (DM3)	Production (DM4)	Warehousing (DM5)	Procurement (DM6)
D-OPR1						
D-OPR2						
D-OPR3						
D-OPR4						
D-OPR5						
D-WT1						
S-DF1						
weight	0,40	0,14	0,05	0,05	0,31	0,05

As a result, according to the equations (27) and (28), the integration of the weights for each category of Lean waste in Source (C_{nsi}) and in Deliver (C_{ndj}) have been obtained by the weighted average of each waste regarding every single DM by considering their associated weights. Also, the results have been presented under Level 2 in Figure (81) for Source process and in Figure (82) for Deliver process.

$$C_{nsi} = \frac{\sum_{k=1}^{E} DM_{ks}.c_{ik}}{\sum_{k=1}^{E} DM_{ks}} \quad (27)$$

$$C_{ndj} = \frac{\sum_{k=1}^{E} DM_{kd}.c_{jk}}{\sum_{k=1}^{E} DM_{kd}} \quad (28)$$

Finally, to acquire the results of Level 3 (see Figures (81) and (82)), the following equations (29) and (30) are utilized for the final integration of the outcomes and prioritization of the Lean wastes. To be more precise, here the relative importance of the waste categories (Level 1) has also been addressed to establish the ultimate weights of each waste in Source (W_{Fsi}) and Deliver (W_{Fdj}) processes.

$$W_{Fsi} = \frac{b_{im}.W_{LCms}.C_{nsi}}{\sum_{m=1}^{7} W_{LCms}} \quad (29)$$

$$W_{Fdj} = \frac{b_{jm}.W_{LCmd}.C_{nsj}}{\sum_{m=1}^{7} W_{LCmd}} \quad (30)$$

8.4.1 Lean roadmap for Food company

According to the information that was presented in the section 7.4.1 for the Automotive company, Tables (53) and (54) contain thorough information for building the final Lean roadmap (these two tables will be discussed later on in more details in this section). Hence, it provides a solution for the Food company to aid strategic managers in understanding the most significant wasteful activities as non-value added ones. In this regard, the final ranking of the wasteful activities that occurred during the Source and Deliver processes of the Food company has been represented in Figures (72) and (73), respectively.

Therefore, based on the results represented in Figure (72), the first step to reduce waste in Source process should be alleviating S-OPR1 by doing the related actions. In fact, here Over Processing related to the activity which is the main issue for the Food company. However, on the other hand, the Transportation waste related to this related activity "Going around to collect related information from different sources for estimating demand" (S-TR1) can be identified as the least important one. It can arise from the correlation between these two wastes. In fact, to make a better decision in S-OPR1 the company needs more reliable data from the customer to predict next year demand. Hence, the company should also change the way of collecting and obtaining these demand data. As a result, improvement in S-OPR1 can lead to less transportation for collecting data in making it possible to reduce S-TR1.

Moreover, as depicted in Figure (72), among the three different wastes (S-TR2, S-WT1, and S-DF1) related to the same activity (Checking the quality of the olives on the truck by employees' observation), the most important one is the Transportation waste(S-TR2) from the aggregation of all the experts' judgments. In fact, it is a critical and time-consuming task for employees to move around the truck to have a precise evaluation of the received olives. Additionally, waiting for the trucks to be checked by the employees can give rise to defects in the final products in two ways. Firstly, long queues of trucks can lead to less precision of staff in the evaluation process to do it faster. Secondly, this waiting time in the queue can result in the deterioration of the fresh olives if not kept at an appropriate temperature. In fact, they arrive in standard not refrigerated trails. Therefore, the Wait waste (S-WT1) is more important than the Defect waste (S-DF1) since it could be a consequence of the long waiting time. In this regard, it is worth mentioning that since the performance of the activity related to S-OPR3 (Conditional acceptance of olives) is directly dependent on the previous one (Checking the quality of the olives on the truck by employees' observation) it is ranked after the wastes (S-TR2, S-WT1, S-DF1). It implies that by improving the wastes S-TR2, S-WT1, and S-DF1 also S-OPR3 might be improved, and the company does not need to have a conditional acceptance of olives and related Over Processing wastes.

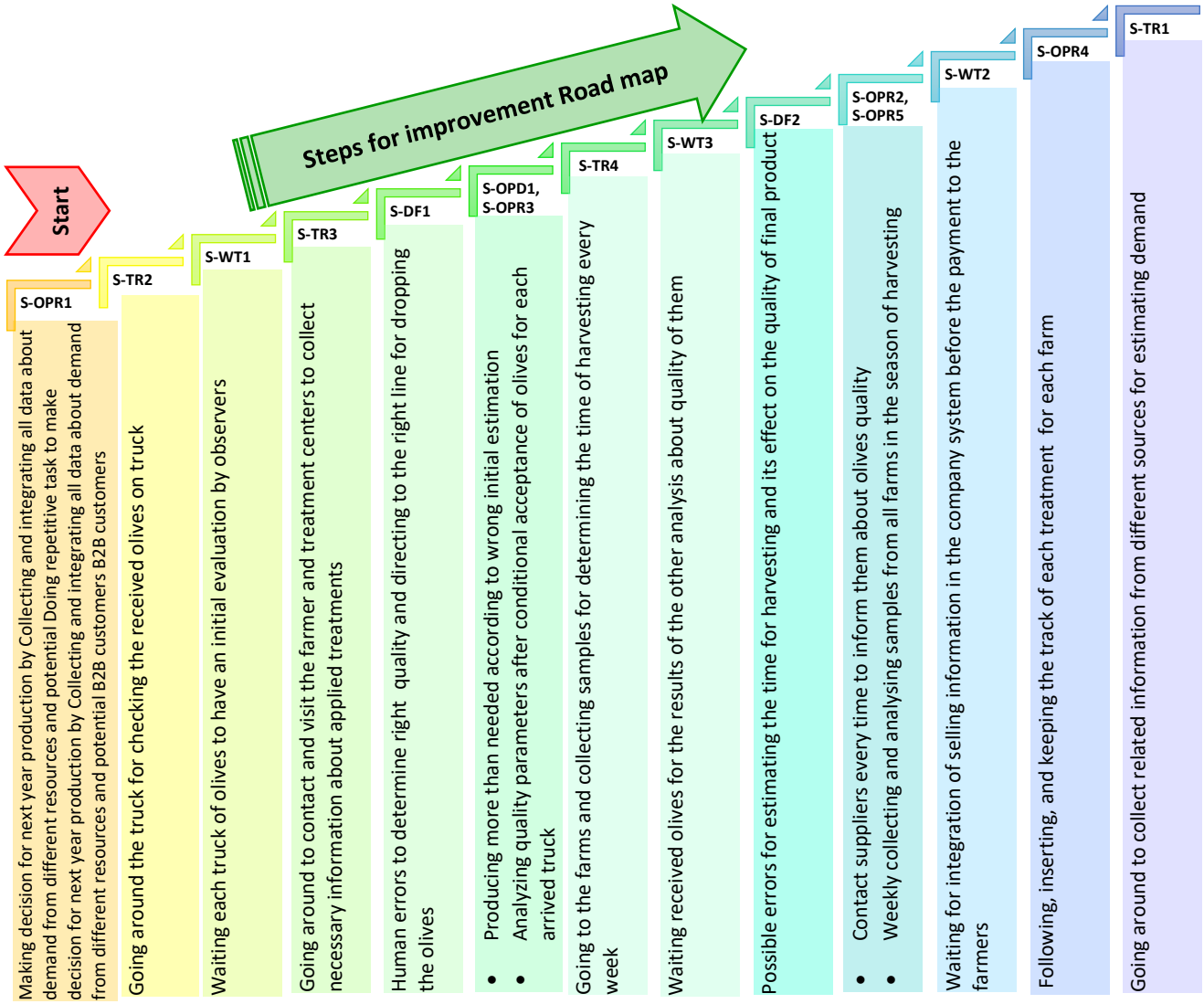


Figure 72 Wastes improvement for Source process in Food company

Figure (73) describes the importance of the identified wastes in the Deliver process for the Food company. According to this figure, the most two significant wastes are D-OPR1 and D-OPR2. It can be due to the importance of initial communications with the customer compared to the waste without need to communication with out of the company like D-OPR3 and D-OPR4.

In addition, the two first wastes as starting points for improvement (D-OPR1, and D-OPR2) are related to the over-processing. It implies that in the same activities (Inform customer about availability of items or changing the arrival time and Register orders in the information system) with more than one type waste ((D-OPR1, D-WT1) and (D-OPR2, D-DF1)) the importance of the Over Processing can be higher than other types such as Wait (D-WT1) and Defect(D-DF1). It means that by reducing over-processing in the activities (Inform customer about availability of items or changing the arrival time) and (Register orders in the information system), the company can also reduce the associated Wait and Defect wastes as

consequences of the over-processing wastes.

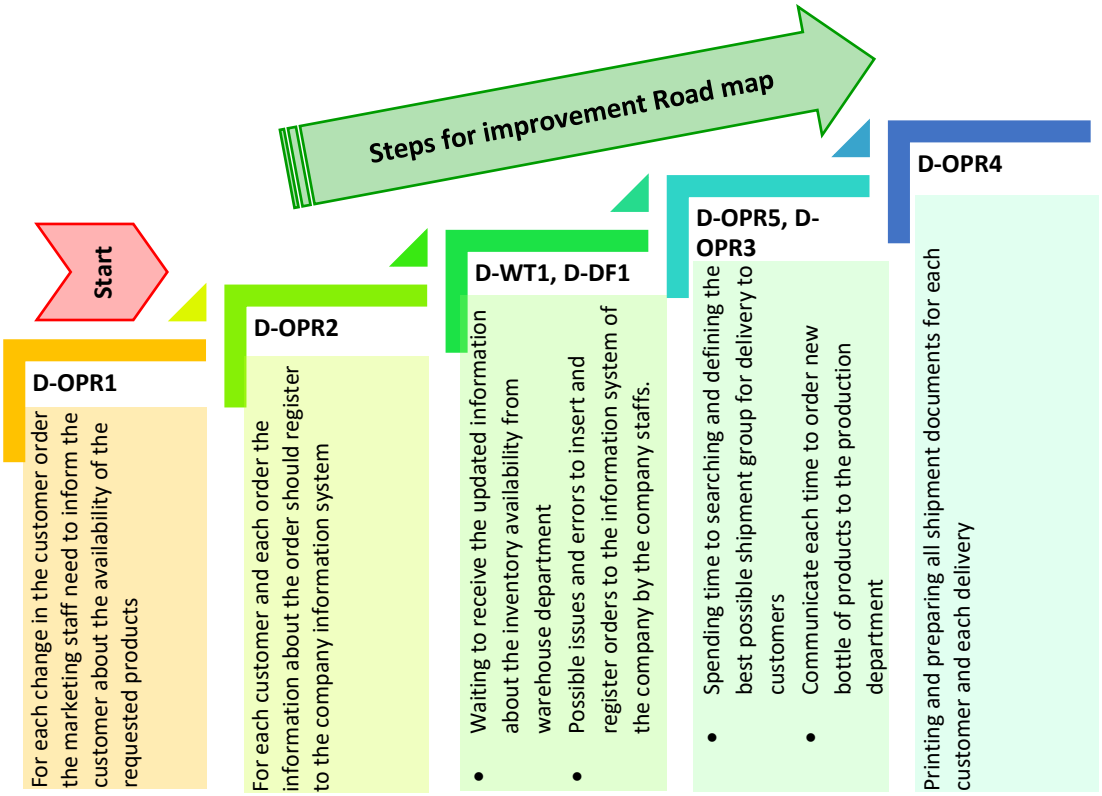


Figure 73 Wastes improvement for Deliver process in Food company

In order to construct the Lean roadmap for reducing waste, all of the final weights assigned to the identified wastes have been integrated for each activity. Based on the final integration, Figure (74) depicts the Lean roadmap for the Source process in the Food company. According to the results of Figure (74), the company should start by alleviating the waste related to Checking the quality of the olives on truck by employee's observation as the most critical activity to remove non-value-added time. This activity is the first one in the Lean roadmap since it can bring about many wastes also in the next steps of the Source process. For instance, any improvement in doing this activity can either reduce or remove the waste in Conditional acceptance of olives as the third important activity. In fact, the company needs to consider Conditional acceptance of olives since the results of the initial evaluation in Checking the quality of the olives on truck by employee's observation might not be enough reliable. Also, making a decision about next year production plan is one of the two most important tasks that should be improved first. It can be explained by the size of the company and the related sector. To be more precise, the company adopts hybrid push-pull production strategies. Because of the nature of the agricultural product that can be obtained just at a specific time of the year, the company uses a push system in the first part for estimating the amount of the required raw materials by collecting data from potential B2B customers. However, due to its small size, the company prefers to work according to a pull system for the final bottling of the olive oil according to the received orders from B2B customers. In fact, considering the small size of the enterprise from the economical side, they need to minimize the holding cost by applying a pull system

for the final delivery to the customers. To this end, making a decision about next year production plan can be one of the main concerns of the company to have a better prediction for obtaining the raw materials (olives) by initial estimation of customer demand in the push strategy.

Table 53 Final relative weight of each activity in Source process of Food company

Wasteful activity	S-MT	S-OPD	S-OPR	S-WT	S-TR	S-IV	S-DF	Activity weight
Making decision about next year production plan		S-OPD1 (0.067)	S-OPR1 (0.081)					**0.148**
Collecting samples from the farm and analyzing			S-OPR5 (0.063)		S-TR4 (0.066)			**0.129**
Pay to supplier				S-WT2 (0.061)				**0.061**
Collecting the information about demand and estimating size of market					S-TR1 (0.054)			**0.054**
Checking the quality of the olives on truck by employee’ s observation				S-WT1 (0.074)	S-TR2 (0.077)		S-DF1 (0.069)	**0.220**
Conditional acceptance of olives			S-OPR3 (0.067)	S-WT3 (0.065)				**0.132**
Notifying the farmers about the quality of the olives			S-OPR2 (0.063)					**0.063**
Update information system with the information about the farmers and land			S-OPR4 (0.059)		S-TR3 (0.070)			**0.129**
Determine the time of harvesting and delivering to factory							S-DF2 (0.064)	**0.064**

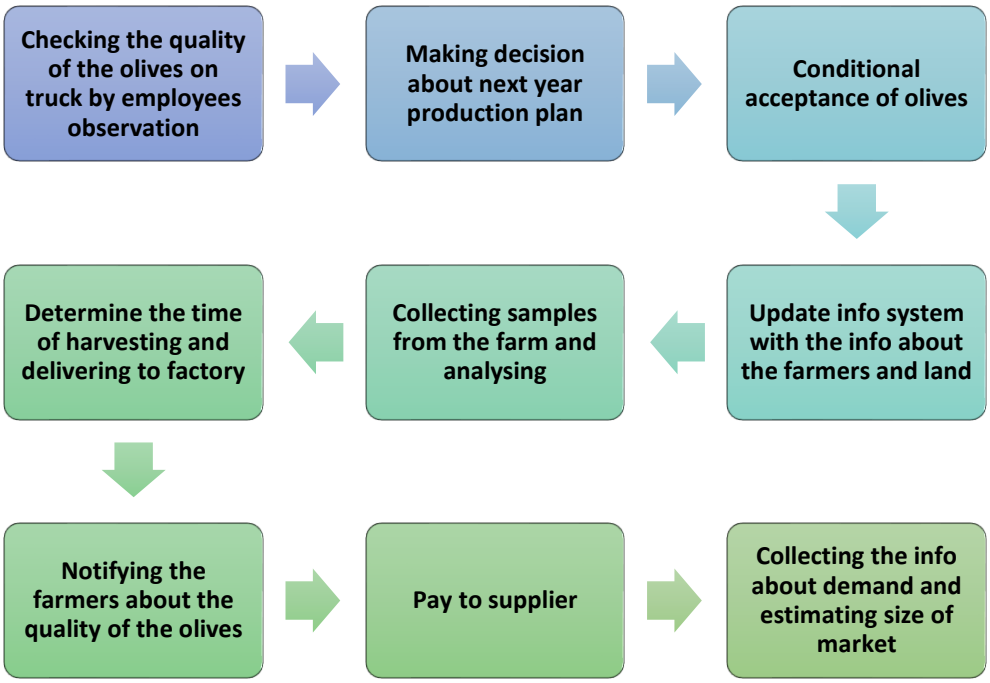


Figure 74 Roadmap based on prioritizing the identified wastes in Source process of Food company

In the Delivery process of the Food company (see Figure (75)), the most critical activities are Informing customers about the availability of items or changing the arrival time and Registering orders in the information system, since the consequences of any weak performance of these two activities can directly or indirectly involve more than one department in the company. For instance, weak communication between the Production and the Marketing departments in Informing customers about the availability of items or changing the arrival time can affect the total performance of the company and its final market share in general, especially in the long run. In fact, weak communication among internal departments of the company can give rise to weak communication with the final B2B customers, which might lead to losing them and thus decreasing the market share of the company.

Generating documentation for customers can still be related to more than one department and associated to customer satisfaction. However, the process associated to this activity is more standardized compared with the other ones since the main contents of documents, in terms of types of products and associated quantities, should be determined according to the customer requirements at the time of ordering. Therefore, the experts assigned the least total importance to the related waste. Nonetheless, still there is some room for improvement of the Over Processing waste associated with such a task.

Table 54 Final relative weight of each activity in Deliver process of Food company

Wasteful activity	S-MT	S-OPD	S-OPR	S-WT	S-TR	S-IV	S-DF	Activity weight
Issue order to production department			D-OPR3 0.127					**0.127**
Register orders in the information system			D-OPR2 0.166				D-DF1 0.143	**0.309**
Make decision about best possible groupings for transportation			D-OPR5 0.127					**0.127**
Inform customer about availability of items or changing the arrival time			D-OPR1 0.168	D-WT1 0.143				**0.311**
Generate documentations for customer			D-OPR4 0.126					**0.126**

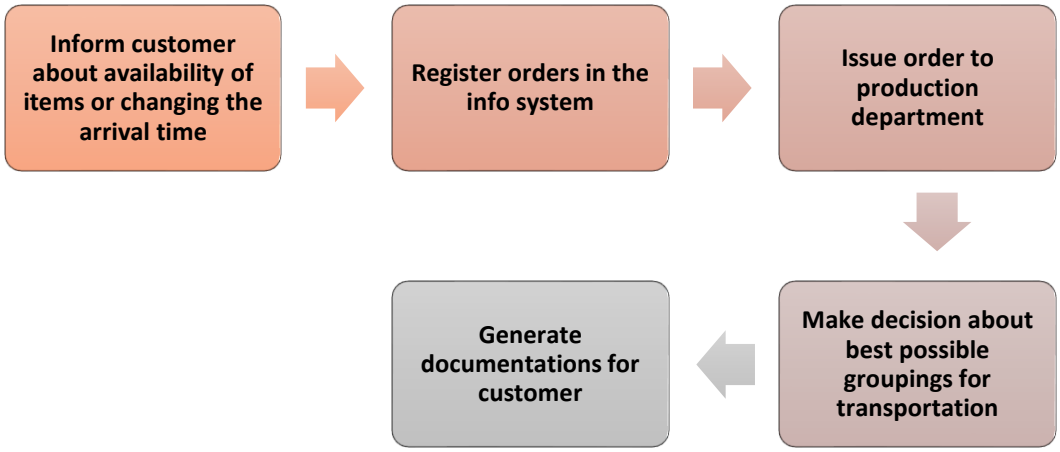


Figure 75 Roadmap based on prioritizing the identified wastes in Deliver process of Food company

8.4.2 Lean DSC roadmap for Food company

In Figures (81) and (82), based on the lines connecting each identified waste in Source and Deliver process to the related digital technologies, the weight of each technology has been determined. Table (55) represents the results of the aggregation of all the weights assigned to each technology. Therefore, according to Table (55) the most important technology in the Source process for the Food company is BDA, followed by Drones. To be more precise, BDA is the first technology in the Source process due to its great impact on improving various activities. The role of BDA can range from pre-harvesting (Collecting samples from the farm and analyzing) to harvesting (Determining the time of harvesting and delivering to the factory) and post-harvesting activities (Checking the quality of the olives on truck by employee's observation). Meanwhile, Drones is the second most important technology in the Source process for the Food company due to the fact that it is so beneficial to provide precise information for analysis by BDA algorithms in harvesting time (Determining the time of harvesting and delivering to the factory). Also, improving harvesting activities can have an effect on improving post-harvesting activities (such as Conditional acceptance activities). Therefore, Drones can have a great role as a complementary technology for BDA.

In the Deliver process, the most important technology is CC. It can arise from the nature of delivery activities since they mainly involve more than one department or parties (e.g., Marketing and Warehousing departments or final customer). Hence, they need to share information with each other in a timely manner. Therefore, in delivery activities, CC has a prominent role compared to other technologies like BDA and Drones. According to the company experts' opinions, in deliver activities Drones is not applicable and the role of BDA is just limited to providing some analyses as a decision support system for internal activities of departments, with less effect on the performance of the other departments.

As a result, to provide the final DSC roadmap, the company needs to decide on

the most significant technology to maximize the reduction of non-value-added activities for the whole organization. Therefore, based on the integration of the obtained relative weights for each Industry4.0 technology, the last column of Table (55) represents the final rank of the technologies for consideration by the company in both Source and Deliver process. This rank suggests that for the whole company it might be most beneficial to first start applying CC. In fact, CC can provide better communication for doing activities inside and outside of the company by providing real time data and information. Since the company is based on the hybrid Push-Pull system, it should rely on having perfect communication with its B2B customers. In fact, they need it for the push system to initiate production planning, and in the pull system for bottling oil according to the real-time final orders from customers. Moreover, BDA is the second technology to consider thanks to the fact that it can assist the different departments of the company to make more precise decisions with less effort at the appropriate time. Drones are the next technology to invest in since, according to the company experts, using Drones is a prerequisite for applying BDA in many cases such as "Collecting samples from the farm and analysing". BC is the last technology for applying in the Food company since however by using BC the company can improve the trust in some activities like Generate documentations for customer and Update information system with the information about the farmers and land, but these activities are not so critical for the total performance of the company form the experts' point of view. Therefore, based on the Industry4.0 roadmap that have been presented in Figure (76), after implementing other technologies like CC, BDA, and Drones, applying BC can help the company to promote and focus on other strategic goals like brand loyalty and sustainability. These benefits will be explained in more detail below.

Table 55 Final rank of Industry 4.0 technologies for Food company

Tech	Source	Deliver	Final weight	Rank
CC	0.468	0.873	0.670	**1**
BDA	0.693	0.447	0.570	**2**
Drones	0.545	-	0.272	**3**
BC	0.186	0.126	0.156	**4**

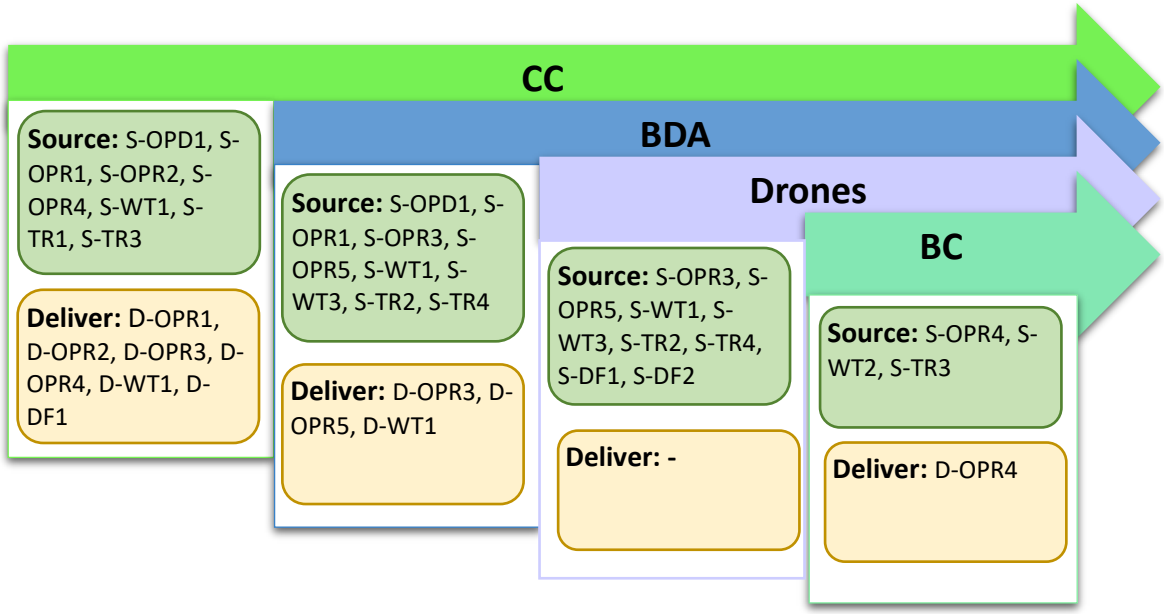


Figure 76 Lean DSC roadmap for implementing Industry 4.0 technologies in Food company

Figure (76) shows the Industry 4.0 roadmap for implementing DSC in the Food company. CC is the basic technology to be applied by the company thanks to its huge usefulness in both the Source and Deliver process. As mentioned before, BDA has a great role in improving waste in the Source process rather than in the Deliver process for the Food company. Also, Drones are applicable in the Source process to collect real time information about olives by flying above the farms. Totally, BC as the last technology can be useful for enhancing the brand of the company to obtain more market share by improving the trust through providing reliable data about the cultivation and harvesting process of olives. It can show the real attitude of the company to the social and environmental aspects of the triple bottom line to be more sustainable by providing more transparent information for customers. In this regard, applying BC to pay to the supplier faster can improve both social and economic aspects of the company. For instance, in the social aspect it can provide more information about the workers' conditions, also it can promote the brand by showing to be strict about the other social and environmental concerns. Moreover, providing reliable and trustful information about all the treatments that have been applied to the cultivation process of the olives can improve the environmental aspect of the company.

Figure (77) describes the distribution of the different Industry 4.0 technologies for alleviating the various types of waste. BDA is the most prevalent technology in all the types of waste. It can be explained by the criticality of the decisions that should be made in the process of cultivation and harvesting in the agricultural sector rather than the other sectors like Automotive. In fact, in the agricultural sector there are many parameters that should be controlled and analyzed during the cultivation and harvesting of olives to make the best decisions. However, in the Automotive industry, the parameters are more deterministic with less change after finalizing the contract. CC and Drones have the same situation in the number of alleviated waste categories. However, CC cannot be useful for avoiding Defect wastes related to products, since it is more related to the internal activities of the company, and information sharing technologies cannot directly alleviate Defect waste. On the other hand, drones are not useful in avoiding Over Production waste thanks to the fact that this type of waste can arise from the wrong estimation of demand in the initial steps. Thus, having better communication among SC members can reduce this waste by sharing information real-time. Moreover, BC is just applicable for limited types of wastes in specific situations.

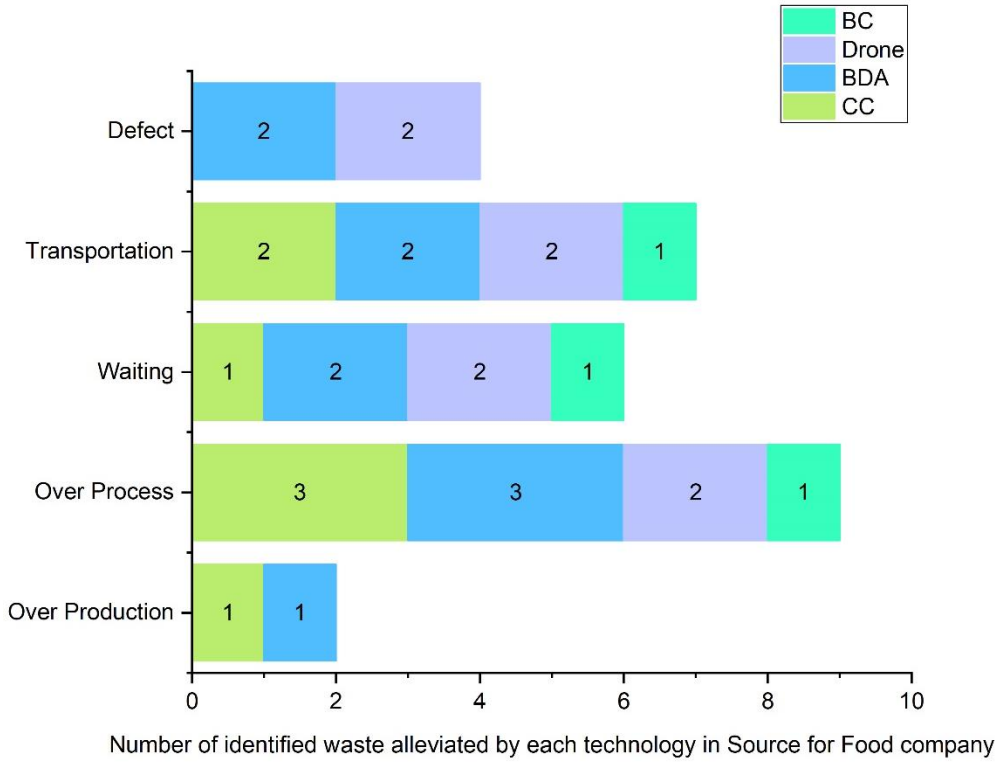


Figure 77 Application of Industry 4.0 technologies to wastes for Source process of Food company

As depicted in Figure (78), , CC is the most predominant technology for all the types of the identified wastes for the Deliver process of the Food company. In this regard, CC is also useful for Defect waste in the Deliver process since here Defect is arisen from weak real time communication with customers to register orders directly. Therefore, without using CC the registration by the employees can make mistakes in inserting the amount of the order or other associated data and information related to the customer. Hence, CC can remove defects in recording

customer orders. BDA is used here as a decision support tool to reduce the Wait and Over Processing wastes in the Delivery process. Also, applying smart contracts based on the BC platforms it can assist to reduce the Over Processing waste in the activity Generating documents for the customers by automatically producing and sharing these documents as soon as the products are shipped to the customer without any human efforts.

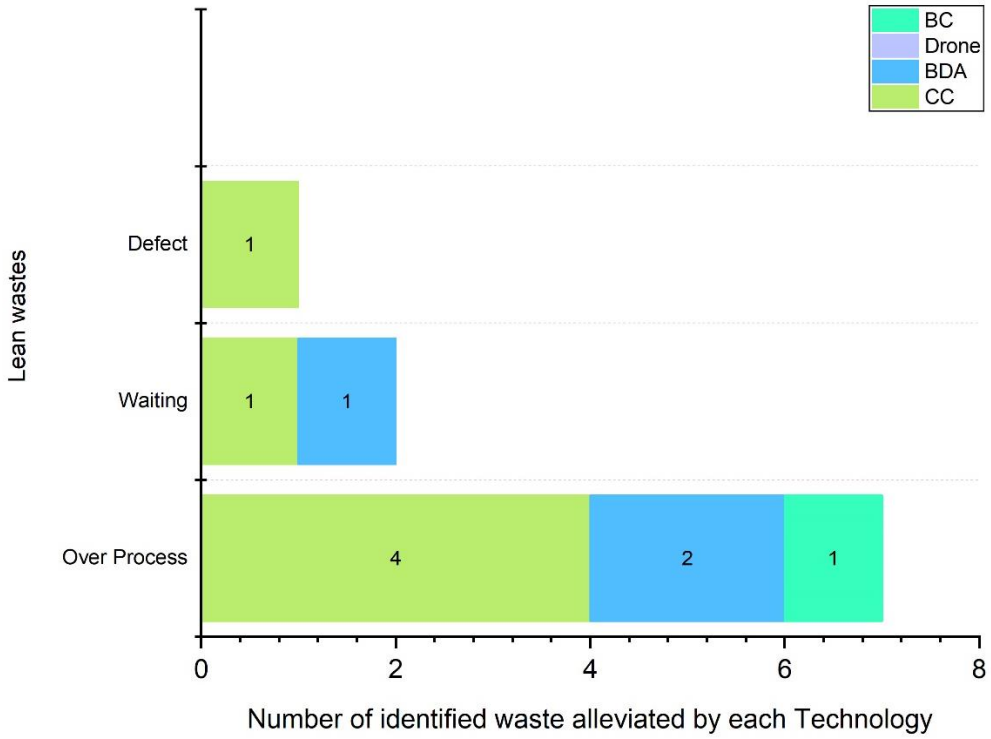


Figure 78 Application of Industry 4.0 technologies to wastes for Deliver process of Food company

Figure (79) and (80) represent how different Industry 4.0 technologies can be combined with each other to alleviate the identified wastes in Source and Deliver processes. According to Figure (79), in Source process BDA and Drones apply together. It means they are two complementary technologies for the case company. In fact, BDA relies on the data collected by Drones to perform analyses to provide better decision making. To this end, mainly Drones flying over olive farms can collect the images of olives as input for image processing by BDA algorithms to decide about the ripening of olives for determining the best harvesting time.

CC can be individually used when it applies to collect or share data with the other SC members (S-TR1, S-OPR2). However, when the activity is related to making decision based on the collected information, CC should be combined with BDA to provide real time inputs for BDA algorithms (S-OPD1, S-OPR1). Aside from that, when the shared data should be trustful and tamper proof, in order to use them for other purposes, CC should be combined with BC to avoid any manipulation in the recorded data (S-OPR4, S-TR3). Also, BC can be applied

individually in S-WT2 since in the associated activity BC is used as a trustful platform for inserting smart contacts to pay farmers.

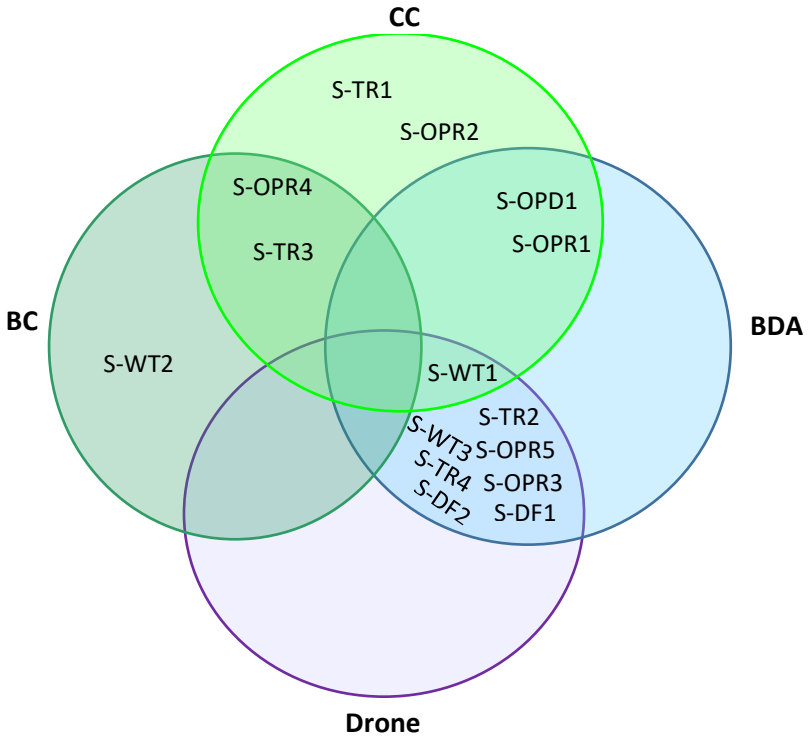


Figure 79 Analysis of combination of Industry 4.0 technologies in Source process in Food company

Figure (80) addresses the combination of applicable Industry4.0 technologies for the Deliver process of the Food company. Most of the technologies can be applied individually in the Deliver process. It can arise from the less complexity of the Deliver process of the case company compared to the Source process, since the activities are more deterministic and do not depend on the uncertain nature of the agricultural process. However, mainly for the activities that are related to the outside of the company such as harvesting the olives or delivery to the final customer, they still need to use more than one technology. For instance, CC and BC should be combined together to provide tamper proof documents about the quality and the status of final delivery to the B2B customers (D-OPR4). As another example, to provide more precise and real time information about the product availability for B2B customers, the company could apply CC in combination with BDA (D-WT1). Moreover, in some cases, like when addressing the D-OPR3 waste, combining more than one technology can alleviate the possible conflicts among departments. For instance, in D-OPR3 applying BDA as a decision support tool can help experts in the company to determine the best time to produce and the appropriate size of the production lots. However, here combining BDA with CC by providing real time data can assist decision makers in Warehousing and Production departments to make their decisions based on a clear vision about the amount of the final products available in the finished products warehouse.

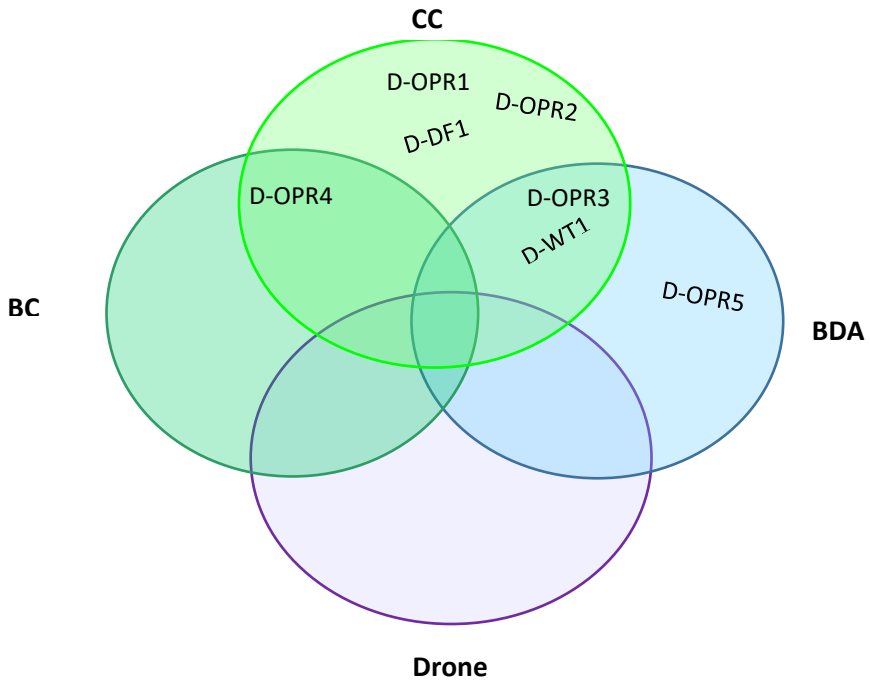


Figure 80 Analysis of combination of Industry 4.0 technologies in Deliver process in Food company

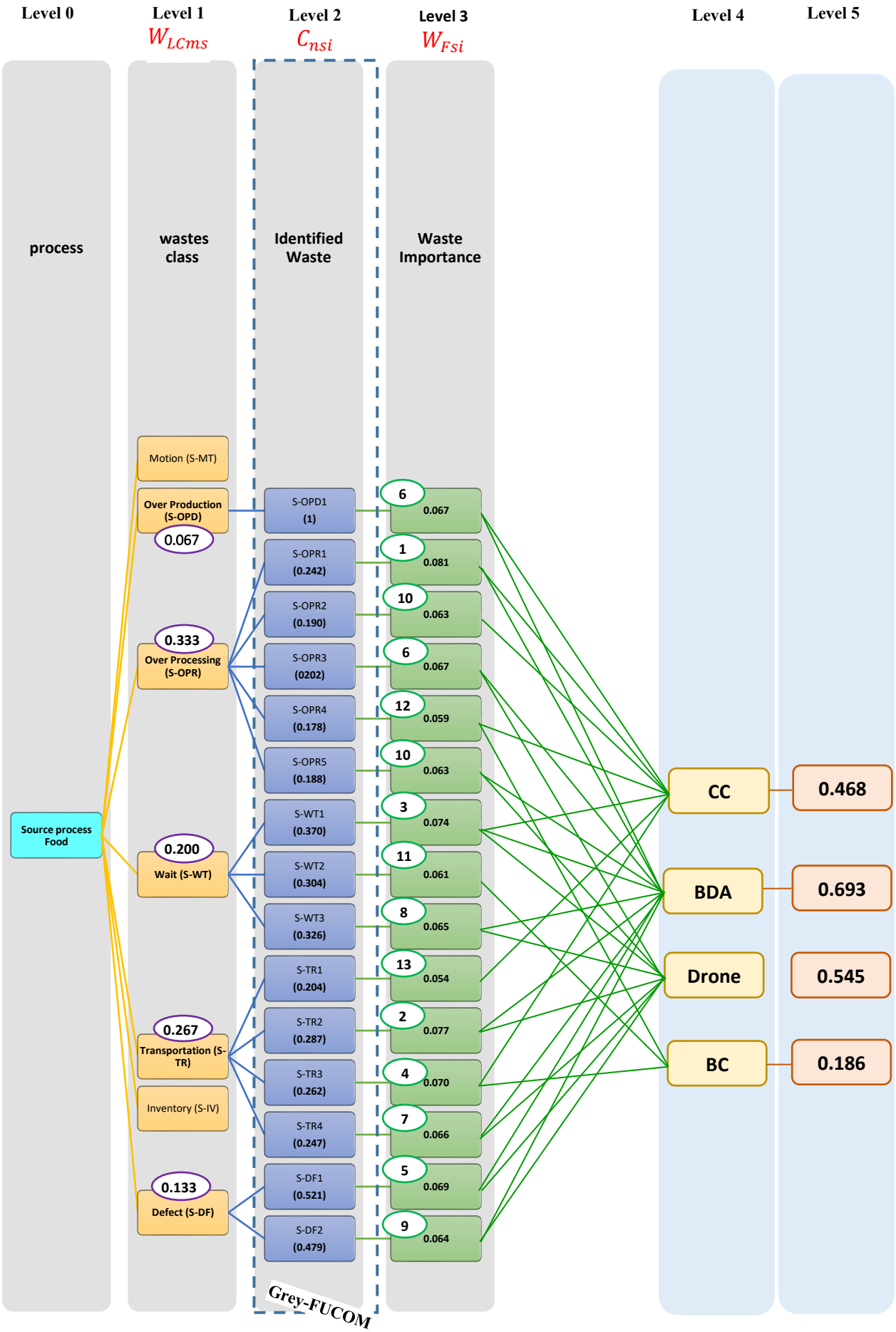


Figure 81Computational structure of the Source process for developing Lean DSC roadmap in Food company

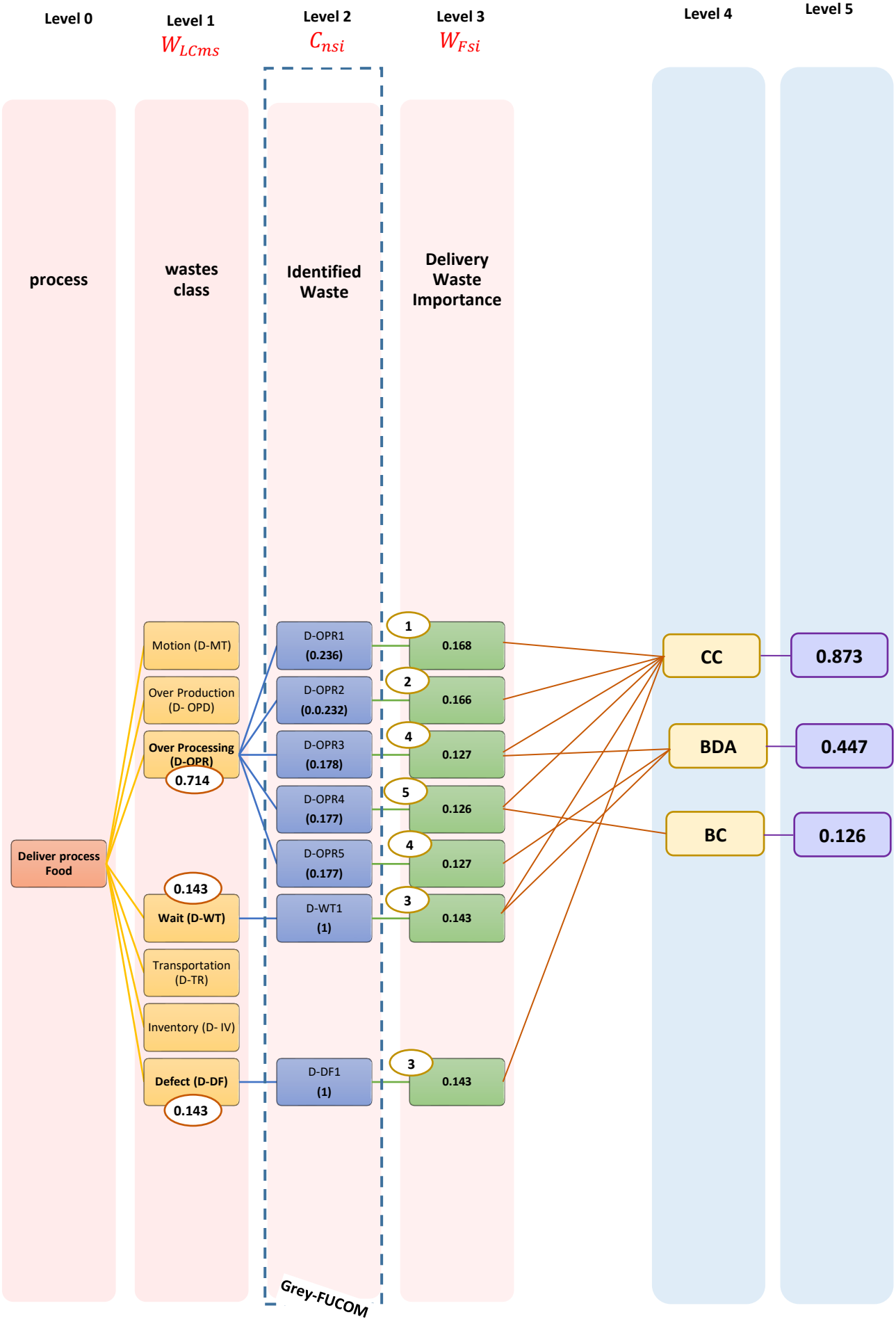


Figure 82 Computational structure of the Deliver process for developing Lean DSC roadmap in Automotive company

Chapter 9

Discussion and Conclusion

In this last chapter, the author will go deeper into the case study findings and summarize the key conclusions. As such, the chapter is split into two parts. In the first section, the author will go further into comparing the main differences between the two case studies and discuss the most important practical and theoretical implications of the present work. The second part presents a summary of the research and its main findings. Finally, the author provides suggestions for future research that may be conducted to expand this study and overcome the associated shortcomings and limitations.

9.1 Discussion

This part starts with a comparison of the most important findings from the two case studies, which demonstrates that the developed framework is flexible and has the potential to be applied by companies operating in different sectors. In fact, it was possible to define a unique roadmap for the Industry 4.0 transition of SC processes in each case study. Such a roadmap is developed through an in-depth analysis performed according to the specific requirements of each company. Afterward, the most significant academic and practical implications have been derived in section 9.1.2.

9.1.1 Lessons learned from the comparison between the two case studies.

According to Figures (40) and (48) presented in chapter 5, the number of wastes in the Source and Deliver process is a key different between the two cases from the Automotive and Food industry respectively. In fact, 68% of the Food company's total wastes originate from its Source process. However, only around 39% of waste in the Automotive company are associated with the Source process. This is because the raw materials used in the Food industry typically come from the agriculture sector, making this phase potentially more critical than the Deliver process. More specifically, the Food industry has a great difficulty in controlling all of the various parameters to acquire raw materials with high quality in the Source process because it is dependent on agricultural factors. For instance, in the branch of the Food industry considered in the case study, certain guidelines must be observed when

growing olives. Precipitation and soil fertility, for example, are two variables whose values might fluctuate over time and affect the quality of final olives as raw materials. Because of this, it is significantly more challenging to maintain proper control over such aspects in comparison to the production parameters or the management of the suppliers as a part of the Source process in an Automotive company. Due to these characteristics, the tasks associated with the Source process in a Food company might lead to an increase in non-value-added activities connected to controlling the supplier variables. Therefore, the Food industry may greatly increase control over many factors by adopting a standardized Source process relying on Industry4.0 technologies.

However, the Deliver process in the Automotive company has been shown to have a higher percentage of detected wastes (about 61%) compared to its counterpart in the Food company (nearly 32%). Actually, the investigated Automotive company is a second-tier SC member. So, they can rely on long-term contracts with a limited number of suppliers to acquire the metals and other necessary components needed for their production. In reality, the Automotive company, due to the scarcity of the required raw materials such as metals can only collaborate with particular suppliers for its Source process. However, during the Deliver process, they may deal with B2B clients, who may be geographically dispersed and whose needs may change from year to year. As a result, the activities involved in the Source process might be more deterministic, and less subject to variability, than the Deliver process, which is more complicated since it also involves a larger number of customers. This is the reason why the number of reported wastes in the Deliver process of the Automotive company is larger than the number of wastes in the associated Source process and also larger than the number of wastes in the Deliver process of the Food company.

Figures (60) and (76) suggest that companies should adopt the appropriate technologies depending on the unique needs of their operations and the recognized waste categories. In reality, the two investigated companies do not share the same Industry 4.0 strategy and roadmap. The most beneficial digital technologies and their implementation priorities for the case company in the Automotive industry are IoT-CC-BC-BDA. Nonetheless, the olive oil company in the Food industry is different, due to the following Industry 4.0 roadmap: CC-BDA-Drones-BC. Given these findings, it is clear that the technique used to collect real-time data and its significance might differ from industry to industry.

In this regard, since IoT devices may collect data from each product or each batch, they can be quite useful for gathering real-time information in an Automotive company. However, it is more challenging to apply IoT devices in the Food industry, since farmers may have to spend a lot of money to acquire them for each tree. Furthermore, installing IoT sensors in production unit loads in the Automotive industry is simpler than in the agricultural one during the crop growing phase. In the agricultural industry, IoT sensors are exposed to a wide range of climatic conditions, making it more difficult and costly to implement the technology effectively. All of these issues, however, may be managed with the help of Drones gathering data real time. For such a reason, companies can take on responsibility

for purchasing Drones and operating them for longer time periods than IoT devices. Since drones may be used for an extended time period with relatively few issues, they can lead to lower maintenance costs and better investment returns compared to IoT devices.

Moreover, the function and significance of the BDA technology is different in the two case studies. In fact, BDA is the least crucial technology to be introduced in the Automotive company. It may result from the necessity for data analysis to support decision making inside the current SC position (tier 2) of the company. Precisely, in the considered Automotive company, the key decision-making parameters such as number of orders and delivery times are set by the customer at the time of the contract. As a result, the decisions regarding these parameters are less subject to revision in the future. However, the Food company must make a series of decisions during the olives' cultivation and harvesting to ensure the highest possible quality of the final crops as raw materials. Therefore, the BDA function for the Automotive company is limited to advising employees and managers on how to carry out their daily jobs more effectively. For example, it can help them to predict possible future adjustments in the production rate due to a change in customer demand. However, BDA plays a crucial role in the analysis of data collected during cultivation and harvesting at the Food company, which serves as a primary input to produce the finished product, olive oil.

Furthermore, BC is more likely to impact the Automotive company than the Food company. In fact, because there are more partners and SC levels in the Automotive company, it is necessary for it to create a trustworthy environment in which to get data and share them with the other actors. As an additional advantage, BC can help the Automotive company to communicate data and information reliably and automatically through the use of smart contracts on BC platforms. However, in the Food company, trust may be easier to be established because of the simpler, less bureaucratic structure of its SC. Nonetheless, the company may still decide to invest in BC due to its international B2B customers and the inherently perishable nature of its products. Putting BC into practice may truly be an asset for the Food company, as it will enable them to strengthen their brand and get reputation as a sustainable business.

It is important to point out that CC is one of the first two technologies both the companies might implement. This highlights the significance of such a technology to establish the foundation for a smoother and more efficient implementation of other technologies. Actually, there are activities for which CC is a necessary precondition. In fact, by creating a platform for real-time data sharing, CC may act as a link between the data acquired by drones and IoT sensors and the data to be used as input in business information systems such as the inventory levels in both raw materials and finished products warehouses. Also, the IoT sensors can provide the data analyzed by BDA such as data for prediction of replenishment time of inventory in the customer warehouse or ordering time of raw material which should be shared among SC members. Aside from this point, CC can give enough flexibility to businesses of various sizes and in different SC tiers to spend on it as one of the primary technologies in their Industry 4.0 roadmaps by providing a

variety of solutions to invest in. These solutions include cloud Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), and Function as a Service (Faas). IaaS gives customers an environment in which they can create their customized information systems, PaaS gives customers an environment in which they can build information systems, and SaaS gives customers an information system that is already set up and ready to go (Wulf et al., 2021).

9.1.2 Academic and practical implications

Numerous implications, relevant to both researchers and professionals in the field, may result from this study.

The following considerations are relevant for academics to take into account:

1. First of all, the present research work provides a valuable contribution for combining Lean Manufacturing and Industry 4.0 notions and tools, by providing a concrete way of performing such an integration. Thus, it can be the starting point for future studies aimed at advancing knowledge about how Lean and Industry 4.0 could be jointly applied.
2. The developed framework can serve as a starting point for further in-depth studies providing more tailored roadmaps for deploying digital technologies across the SC.
3. The present work can offer a comprehensive assessment of an effective way in which the Automotive and Food industries can implement the integration of different Industry 4.0 technologies. Hence, it can pave the way to future studies about how the combination of various technologies can be implemented to alleviate the waste in different industries.
4. This study provides a structured approach to obtain a comprehensive picture of the waste generated by manufacturing companies and their associated types. Therefore, it can assist academicians to suggest new effective methods to apply Lean Manufacturing principles to SCs, with the purpose of identifying and analyzing wastes.

In addition, for practitioners, the proposed Lean DSC framework offers them the opportunity to take advantage of the following benefits.

1. The framework can serve as a decision-support tool for managers, assisting them in developing both short-term and long-term strategies for incorporating the most useful digital technologies in their SC processes.
2. This study can provide a comprehensive picture of the most common types of waste generated by various manufacturing industries. Therefore, it can assist practitioners to become familiar with the most prevalent non-value-added activities and provide a better perception for them to propose related solutions for eliminating them.
3. By relying on the framework and the associated Lean DSC roadmap that can be created, the senior management of a company can be sure to primarily focus on the most significant wastes to be improved by introducing relevant technologies.

4. The proposed framework can be used as a guide for recommending the most effective Industry 4.0 technologies, but it can be also potentially applied to eliminate the identified wastes, without introducing such digital tools.
5. The Lean DSC roadmap built through the framework differs from the existing ones in several key respects. Most notably, it goes beyond just proposing broad insights about potentially valuable technologies for practitioners. Instead, it customizes the roadmap to reflect the actual activities and processes of each firm. As a result, it is able to offer a tool that is tailored to the needs of each individual company.

9.2 Conclusion

The goals of the following sub-sections are wrapping up the research discussed in this thesis and emphasizing its most significant contributions and achievements. In addition, the primary limitations of this study are discussed in Section 9.2.2, where some promising and interesting avenues for future research are also presented.

9.2.1 Final remarks

Practitioners across industries are struggling to keep up with the rapid evolution of Industry 4.0 technologies, which makes it difficult for them to determine when and how to use these innovations inside their own businesses and throughout the SC. Actually, they need to design their own policies in this respect, taking into account the impact of the applied technologies not only within the company but also on the other SC members. In fact, in order to be more competitive, they should facilitate the cooperation between upstream and downstream members of the SC, and one way to achieve this purpose is applying the Industry 4.0 technologies in their companies.

However, it is costly for companies to adopt the latest Industry 4.0 technologies. Therefore, it is really undeniable that there is a need to develop scientific frameworks to advise professionals on how to determine which technologies would be most beneficial to their company and how to implement them for obtaining the highest gain. In fact, they should have a defined and customized strategy that can ensure the greatest possible enhancement of SC activities, while simultaneously reducing the associated wastes by applying these technologies. Hence, such a strategy should be like a roadmap to provide a clear and comprehensive picture of what could be the most effective technologies and the appropriate implementation sequence to obtain a DSC according compliant to Lean concepts.

This research intends to improve manufacturing SCs by providing solutions to the aforementioned challenges by jointly applying Lean principles and Industry 4.0 technologies. As such, the term "Lean DSC framework" is used to describe a special structure that is developed in the present thesis as a solution for companies. In this respect, the wastes are identified in accordance with the principles of Lean

Manufacturing, with the primary emphasis placed on logistics operations, in particular Source and Deliver processes. Following this, a scientific method based on the SCOR model is used to identify and analyze the main elements of the mentioned processes. As a result, process mapping is used to depict the existing conditions of the processes, by relying on a theoretical development that is followed by the real observations from case studies. This leads to figuring out the activities without value added for customers according to the Lean concept. Thereafter, "5 why" technique is applied to identify the most significant underlying root causes for each waste. Finally, according to the main identified roots for each waste, the most advantageous Industry 4.0 technologies are suggested to eliminate them.

To complete the Lean DSC framework construction, the process is followed by workshops and interviews with executives from the two case companies, in order to create a strategy by ranking the most beneficial Industry 4.0 technologies to deploy them in each company. In this regard, a MCDM method named FUCOM is applied to first rank the most important identified wastes, according to the opinion of a selected group of company managers as DMs. Then, the results of all the managers' judgements are aggregated to provide a ranking to identify the Lean roadmap to reduce waste inside the logistic processes of the company. Then, the obtained weights for the wastes are mapped to the suggested Industry 4.0 technologies to develop the final Lean DSC roadmap.

As a consequence, the framework for the construction of the Lean DSC roadmap can guarantee that the technologies that are the most suited to either decrease or eliminate the crucial wastes in companies are implemented in the first steps. In addition, given that the framework is developed on the basis of actual observations from the activities carried out by each company, it is possible to recognize it as a strategy specifically tailored for each of them.

As already mentioned, two case studies have been investigated as part of this research in order to evaluate the development of the Lean DSC framework. Both the Automotive and Food industries, represented in the case studies, are essential to modern society, and both are. The findings from these two case studies demonstrate how the proposed framework can be easily modified and adjusted according to a variety of SC configurations. Also, the outcomes of the two case studies prove that the proposed framework is able to provide a tailored Lean DSC roadmap for each company. Therefore, each company has its own unique digital path, customized according to its wastes.

To sum up, the present research attempts to fill the gap for presenting a roadmap for implementing Industry 4.0 technologies to reduce the wastes in DSC by proposing a structured and practical SC analysis and decision support approach based on the actual needs of each company. In fact, the main aim is to show how to integrate Industry 4.0 technologies in the real processes of the company to reduce the waste of each process and create a real value added for the ultimate customers. Eventually, this aids companies in developing customized Lean DSC methodologies that help them streamline their day-to-day activities in line with Lean concepts and with the use of Industry 4.0 technologies.

9.2.2 Limitations and future research

In the end, considering all the efforts that have been made to accomplish the current study, nevertheless there are certain limitations as well as the potential for more research and development. The present research, and in particular the case studies that were carried out, focus mostly on companies that are classified as small and medium-sized enterprises. While addressing small and medium-sized businesses is important, looking at how the framework can be applied to big enterprises, with their more complicated SC structures and numerous upstream and downstream members, can uncover the hidden value added by implementing Lean principles and Industry4.0 technologies.

In order to achieve a higher level of generalization of the developed Lean DSC framework, it is essential to include additional industries in future validation studies. While this study focused on only two industries as primary examples, such as the Automotive and Food industries, it is important to explore the applicability of this framework in other industrial contexts. Industries for example the fashion industry, marine industry, and mining industry, among others, should be considered for inclusion in future validation studies.

Moreover, the Lean DSC framework can also be applied in other companies within the same industrial sectors explored in the present research, in order to perform sensitivity analysis of the obtained weights for each identified waste and related results. This will help to validate the robustness of the suggested decision-making approach to different companies' conditions and ensure that the framework can be applied effectively in a range of contexts. Additionally, using the framework in different industrial contexts and companies will provide more empirical evidence to further validate the effectiveness of the Lean DSC framework.

Therefore, future studies should focus on including a diverse range of industries and companies to further generalize the developed Lean DSC framework. In fact, the Lean DSC framework is designed to be a flexible and adaptable tool that can be applied to a range of waste reduction efforts in different industries and companies. By using a structured approach to identify and prioritize wastes, the framework provides a comprehensive understanding of the waste reduction potential within the supply chain. This information can then be used to develop targeted waste reduction strategies that can be implemented across the entire supply chain.

Furthermore, the Lean DSC framework can be easily integrated into existing organizational structures and decision-making processes. This makes it a highly practical tool that can be used by companies of all sizes and across a range of industries to achieve waste reduction targets and improve their sustainability performance.

Here we use process mapping as the starting point for this research. However, in the next steps other quantitative methods like VSM can be applied to identify the requirements of Industry 4.0 technologies to reduce the waste of specific products in the company.

Since the two case study companies are part of a SC network, it would be interesting to apply the developed framework also to their suppliers and customers in order to explore the synergies that can be among them regarding the deployment of different Industry 4.0 technologies. In fact, further development of these innovations into action will need cooperation between the focal company and the upstream and downstream SC members. For instance, in order to apply CC, a company should first get the agreement of the other SC members, who must all comply to adopt the new means of information sharing. Therefore, in order to build a more applicable Lean DSC framework that can attract different SC members, future studies should also include and incorporate the views of the other SC members regarding the significance of the detected wastes and the recommended Industry 4.0 technologies to remove them.

Furthermore, the present research basically constructs the DSC roadmap according to the significance of the waste detected in Source and Deliver processes. However, future studies may benefit from considering these technologies also from a financial perspective when developing the final roadmap. In fact, as was discussed in chapter 3, the incorporation of technologies related to Industry 4.0 might need large economic investments from companies. Consequently, an economic analysis can assist DMs in better implementing these technologies in future.

Moreover, the present work takes into account the perspectives of top managers across different company departments. However, the framework practical applicability may be enhanced by also incorporating the expertise of the company IT staff. In this light, it may be beneficial to validate the proposed digital technologies by taking into account the opinion of trusted IT specialists who are familiar with the company's key information and data gathering processes.

In addition, investigating how firms can use digital technologies to develop competitive advantages through waste reduction in their supply chain can be an interesting direction for the future developments. In this regard, the Resource Based View (RBV) can help firms to identify which digital technologies are most valuable for waste reduction efforts. By conducting a resource audit that includes digital technologies, firms can identify their key digital capabilities and how they can be leveraged to reduce waste in the supply chain. This can help to ensure that digital technologies are used in a strategic and effective way, and that they contribute to sustainable competitive advantages for the firm.

Last but not least, using digital technologies can significantly alter the SC power structure. Consequently, it might be beneficial to build a game theory approach to analyze the impact of the proposed Lean DSC framework for each company. By doing so, we may learn how the proposed framework might affect the distribution of power among SC members in order to facilitate their close collaboration to improve SC productivity. In addition, results of the given framework might be useful for analyzing how SC members should invest in adopting the different Industry 4.0 technologies in their companies by considering the importance of useful technologies in their specific processes.

As a further suggestion for future research, the impact of the developed Lean DSC framework should be studied in terms of its potential influence on

sustainability concerns, in order to determine how much it can assist achieving a company's sustainable goals in social, economic, and environmental aspects. In fact, the Lean DSC roadmap might vary as a result of prioritizing different technologies in light of a company's particular sustainable objectives. Also, the impact of the proposed Lean DSC framework on SC resilience is another potential interest for future studies.

Finally, the conducted case studies are based in Spain. However, it would be interesting to have an additional examination about the application of the developed framework in other countries, in order to have a greater generality on the obtained outcomes and completely validate the framework.

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Appendix A

Application of "5why" method and benefits of Industry 4.0 technologies

Here, for both case studies parts of the "5why" application to find root causes and how different Industry 4.0 technologies can be useful for alleviating root(s) of each identified waste have been showed.

A1 "5why" method and benefits of Industry4.0 technologies for Source process- Automotive company

		sS- Source(sS1 Source Stocked Product)- Automotive	
	why?	**Generate the receipt of verification [S-MT1]**	**Reading the barcode Of pallets and storage location to match them [S-MT2]**
Motion	**Waste description**	*to stamp and scan this document logisitics staff should go around to complete this task. Therefore, this activity contains unessecary motions for logisitics staff for providing this document to other parties.*	*the warehouse staff need to have some unnecassary motions to read the both barcode for updating the information system.*
	1st why?	because the logistics staff should give the stamp document as a proof of delivery to the driver and keep the scan of that in their documents for at least 5 years before discarding	because they need to match these barcodes by reading both barcodes by barcode reader.
	2nd why?	because there is no safe and automatic tool or system to generate and share these document among both parties without need to stamp and scan the documents.	because the process of reading and matching both barcodes is not autpmated.
	3rd why?		
	suggested technologies	IoT, BC, CC	IoT
	benefits of **BC** for alleviatng the waste and how it works	by applying BC among both parties(company and suplier), the related documents can be generated and verified as soon as the truck have been unloaded in the company. In fact, as soon as the truck has been uloaded by verifying the barcodes of received items in the company the related smart contract based on the BC can generate the verification of receiving items to the supplier and private key to access that. Therefore, there is no need to stamp and scan the document by the driver as a proof of delivery for supplier.	
	benefits of **CC** for alleviating the waste and how it works	CC by sharing the documents and related information among both parties can remove the unnesseccary motions for providing this document to driver. In fact, here CC is a complementary technology to facilitate the access to the BC verification in real time for all parties.	
	benefits of **IoT** for alleviating the waste and how it works	IoT can collect all related data to generated related verfication for both parties. In fact, For instance by using RFID tags it is possible to reduce the effort by employees to collect and insert the related information to the information system of the company. Also, Updated information is always available to the both parties to manage the receiving of items in the company. In this way, by using IoT and RFID tags all data for applying in BC and CC are available in timely manner.	by Applying RFID tags on products and using tag readers and sensors in the storage area and racks it is possible to read and match the barcode with the storage location as soon as the pallet put in the related storage area without need to further effort from the forklift driver or warehouse staff.

A2 “5why” method and benefits of Industry4.0 technologies for Deliver process- Automotive company

		sD- Deliver (sD1- Deliver Stocked Product)- Automotive
	why?	**Picking the items based on the scheduled delivery[D-TR1]**
	waste description	*if warehouse staff can not find and pick up the product based on the received information, they should go to logistic office to receive the new up dated plan and related information.*
transportation	1st why?	because they can not access to the updats of the picking plan
	2nd why?	because the information system is not complete and real time to integrate all the information about the picking items and their related positions. Therefore, the logistics staff should integrate all info from SAS with the Access file to provide complete picking plan with exact locations and information.
	suggested technologies	IoT, CC
	benefits of **IoT** for alleviatng the waste and how it works	IoT can remove the unnecessary transportation of warehouse and logistics staff for updating the picking plan. Because IoT can send real-time information about the stored items in the warehouse to the forklift driver, this information can be accessible to the forklift driver by connecting to the CC as a virtual area for storing and sharing these data.
	benefits of **CC** for alleviatng the waste and how it works	CC can store and share all send data from IoT to the logistics and warehouse staff. In this manner, the logistic staff can send the picking plan to the warehouse staff through CC, and warehouse staff can find and pick products by the data sent from IoT tags. Therefore, warehouse staff does not need to go to receive new updates from the logistic office.

A3 “5why” method and benefits of Industry4.0 technologies for Source process- Food company

Defect	**why?**	**Checking the quality of the olives on truck by employees observation [S-DF1]**	**Determine the time of harvesting and delivering to factory [S-DF2]**
	Waste description	*the process of investigation of the olives quality by employees can lead to some defect in the production process .*	this process can give rise to wrong estimation about the time of harvesting due to the some human errors in time of collecting or analysing samples
	1st why?	the observation by employees can not be reliable since it can be affected by human errors for different reasons like employees bias in their evaluation, effect of the various condition like the physical conditions about employees, other factors like the intense of light etc.	since the quality of olives can be affected by way of transporting or accuracy of the analyser or method of analysis or precision of the analyser tool.
	2nd why?	because the company does not have any prediction system to have first evaluation about the quality of olives before arival of trucks	because the system can not predict the harvest time without analysing the collected samples
	suggested technologies	BDA, Drone	Drone, BDA
	benefits of **Drone** for alleviatng the waste and how it works	by applying Drones there is no need to inspection from employees to direct the truckes to the right line. Due to the fact that company can have initial estimation of olives quality before arrival to receivig area. In fact, the PICUALIA by flying Drones above the olives farms before and in time of harvesting can take useful images for analysing by BDA before arriving the trucks to the company. As a result, the consequense and defects that are arising from biase or errors for evaluating the quality of olives can be removed by providing in time images from olives farms by Drones.	applying drones can remove the effects related to way of transfering and conditions for keeping the samples before analysing. Since in this way drones can collect the picture from the real state of the olives in real time.
	benefits of **BDA** for alleviatng the waste and how it works	BDA can analyse the images that have been sent from Drones to provide comprehensive and reliable initial evaluation from the quality of olives based on detecting their ripen, colore, estimation of oil percentage. Thereofre, the risk of wrong estimation or employees biase in evaluation can be minimized by using BDA and image processing algorithms.	BDA can remove the issues related to the analyser or analysing tool precision. That can rely on the real data collected from Drones and analysing different paprameters by image processing algorithms to estimate the ripeness of the olive. Therefore, it can reduce the defect in olive oil producing and final product.

A4 “5why” method and benefits of Industry4.0 technologies for Deliver process- Food company

		sD- Deliver (sD1- Deliver Stocked Product)-Food
	why?	**Inform customer about availability of items or changing the arrival time [D-WT1]**
Wait	**waste description**	*warehouse should approve the request from the marketing dep for each order. Therefore, for each order marketing dep should wait for the final information about time and product availability from warehouse to inform customer and finalize the order.*
	1st why?	because the marketing dep can not provide this info to the customer directly
	2nd why?	because the time estimation for the product availability or delivery time depends to the experience of warehouse employees knowledge and experience and need to communication
	3rd why?	because the estimation system is not supported by computer and integrated to access by all engaged related employees
	suggested technologies	CC, BDA
	benefits of **CC** for alleviatng the waste and how it works	applying CC can connenct all internal deps of the PICUALIA and provide timely info about related info without waiting for response from other deps. Therefore, in this case applying CC in the internal level can improve the response time to access the related info among production and marketing departments. in the higher level of developing Industry 4.0 technologies, it can possible to also integrate CC to access by all B2B customers to directly check the time availability and quantity of their orders through CC information system.
	benefits of **BDA** for alleviatng the waste and how it works	BDA can be complementary tool for supporting the info available from CC. In this regard, BDA can provide the estimation to produce enough olive oil orders or inform customer about the possible lead times to receive the olive oil orders.

Appendix B

GAMS codes

In the following Figures for each case study in Automotive and Food industry all GAMS codes have been provided for one of managers in all identified wastes in Source and Deliver processes of each company.

B1 GAMS code for Source process identified wastes in Automotive company (Logistic manager)

S-MT

```
sets
j index of criteria /1,2/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
cof
;

ObjectiveFunction .. z=e=x;
co12              .. abs((w('1')/(w('2')-0.0001))-1.62)=l=x;
cof               .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

S-OPR

```
sets
j index of criteria /1,2,3,4,5,6/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
co23
co34
co45
co56
co13
co24
co35
co46
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('6')/(w('4')-0.0001))-1)=l=x;
co23            .. abs((w('4')/(w('5')-0.0001))-1.62)=l=x;
co34            .. abs((w('5')/(w('3')-0.0001))-1)=l=x;
co45            .. abs((w('3')/(w('2')-0.0001))-1.81)=l=x;
co56            .. abs((w('2')/(w('1')-0.0001))-1)=l=x;
co13            .. abs((w('6')/(w('5')-0.0001))-1.62)=l=x;
co24            .. abs((w('4')/(w('3')-0.0001))-1.62)=l=x;
co35            .. abs((w('5')/(w('2')-0.0001))-1.81)=l=x;
co46            .. abs((w('3')/(w('1')-0.0001))-1.81)=l=x;
cof            .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

B2 GAMS code for Deliver process identified wastes in Automotive company (Logistic manager)

D-MT

```
sets
j index of criteria /1,2/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
cof
;

ObjectiveFunction .. z=e=x;
co12              .. abs((w('1')/(w('2')-0.0001))-1.16)=l=x;
cof               .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

D-OPR

```
sets
j index of criteria /1,2,3,4,5,6,7,8/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
co23
co34
co45
co56
co67
co78
co13
co24
co35
co46
co57
co68
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('5')/(w('6')-0.0001))-1)=l=x;
co23            .. abs((w('6')/(w('8')-0.0001))-1)=l=x;
co34            .. abs((w('8')/(w('3')-0.0001))-1.33)=l=x;
co45            .. abs((w('3')/(w('7')-0.0001))-1)=l=x;
co56            .. abs((w('7')/(w('4')-0.0001))-1.22)=l=x;
co67            .. abs((w('4')/(w('2')-0.0001))-1)=l=x;
co78            .. abs((w('2')/(w('1')-0.0001))-1)=l=x;
co13            .. abs((w('5')/(w('8')-0.0001))-1)=l=x;
co24            .. abs((w('6')/(w('3')-0.0001))-1.33)=l=x;
co35            .. abs((w('8')/(w('7')-0.0001))-1.33)=l=x;
co46            .. abs((w('3')/(w('4')-0.0001))-1.22)=l=x;
co57            .. abs((w('7')/(w('2')-0.0001))-1.22)=l=x;
co68            .. abs((w('4')/(w('1')-0.0001))-1)=l=x;
cof           .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

D-WT

```
sets
j index of criteria /1,2,3/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
co23
co13
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('1')/(w('2')-0.0001))-1.16)=l=x;
co23            .. abs((w('2')/(w('3')-0.0001))-1.39)=l=x;
co13            .. abs((w('1')/(w('3')-0.0001))-1.69)=l=x;
cof            .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

B3 GAMS code for Source process identified wastes in Food company (Marketing manager)

S-OPR

```
sets
j index of criteria /1,2,3,4,5/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
Co23
Co34
Co45
Co13
Co24
Co35
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('1')/(w('4')-0.0001))-1.62)=l=x;
co23            .. abs((w('4')/(w('2')-0.0001))-1)=l=x;
co34            .. abs((w('2')/(w('5')-0.0001))-1)=l=x;
co45            .. abs((w('5')/(w('3')-0.0001))-1)=l=x;
co13            .. abs((w('1')/(w('2')-0.0001))-1.62)=l=x;
co24            .. abs((w('4')/(w('5')-0.0001))-1)=l=x;
co35            .. abs((w('2')/(w('3')-0.0001))-1)=l=x;
cof            .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

S-WT

```
sets
j index of criteria /1,2,3/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
Co23
Co13
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('2')/(w('1')-0.0001))-1.35)=l=x;
co23            .. abs((w('1')/(w('3')-0.0001))-1.25)=l=x;
co13            .. abs((w('2')/(w('3')-0.0001))-1.75)=l=x;
cof            .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

S-TR

```
sets
j index of criteria /1,2,3,4/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
Co23
Co34
Co13
Co24
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('1')/(w('2')-0.0001))-1.34)=l=x;
co23            .. abs((w('2')/(w('3')-0.0001))-1)=l=x;
co34            .. abs((w('3')/(w('4')-0.0001))-1.59)=l=x;
co13            .. abs((w('1')/(w('3')-0.0001))-1.34)=l=x;
co24            .. abs((w('2')/(w('4')-0.0001))-1.59)=l=x;
cof           .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

S-DF

```
sets
j index of criteria /1,2/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
cof
;

ObjectiveFunction .. z=e=x;
co12              .. abs((w('1')/(w('2')-0.0001))-1.15)=l=x;
cof               .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

B4 GAMS code for Deliver process identified wastes in Food company (Marketing manager)

D-OPR

```
sets
j index of criteria /1,2,3,4,5/
;


variables
z
x
positive variables w(j)
;


equations
ObjectiveFunction
co12
Co23
Co34
Co45
Co13
Co24
Co35
cof
;

ObjectiveFunction .. z=e=x;
co12            .. abs((w('1')/(w('2')-0.0001))-1.15)=l=x;
co23            .. abs((w('2')/(w('3')-0.0001))-1.46)=l=x;
co34            .. abs((w('3')/(w('5')-0.0001))-1)=l=x;
co45            .. abs((w('5')/(w('4')-0.0001))-1)=l=x;
co13            .. abs((w('1')/(w('3')-0.0001))-1.75)=l=x;
co24            .. abs((w('2')/(w('5')-0.0001))-1.46)=l=x;
co35            .. abs((w('3')/(w('4')-0.0001))-1)=l=x;
cof            .. sum(j,w(j))=e=1;
model firstfucom /all/;
solve firstfucom using DNLP minimizing z;
display z.l, x.l,w.l ;
option limrow=10;
```

Doctoral Dissertation
Doctoral Program in Management, Production and Design (35th Cycle)

A Framework for Implementing Industry 4.0 Technologies to Improve Supply Chains Based on Lean Principles

by
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