UiT The Arctic University of Norway

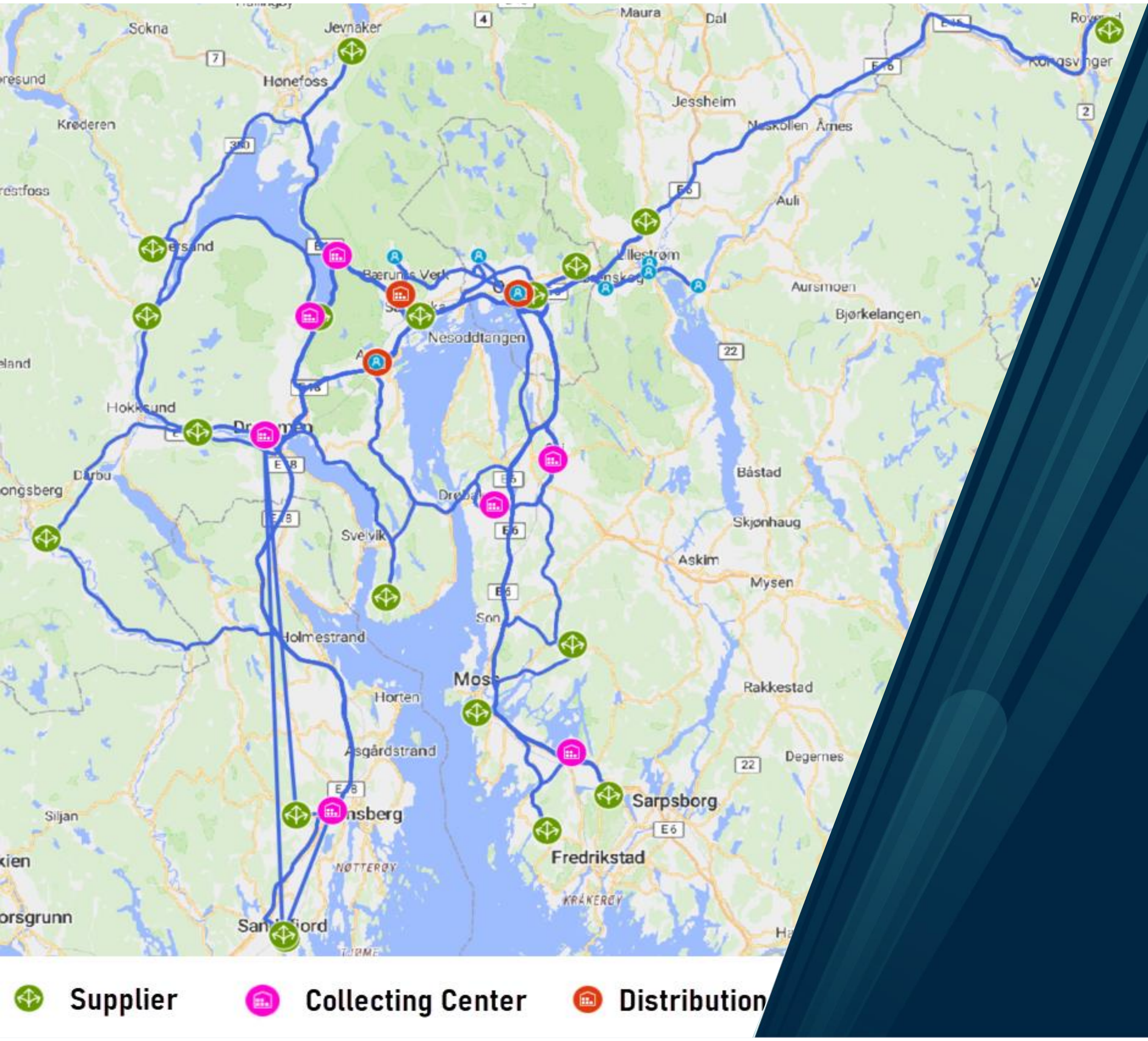
Department of Industrial Engineering

Industry 5.0 Enabled Smart Logistics

Optimization of Distribution Network in Food Industry

Niloofar Jafari

Master's thesis in Industrial Engineering, INE3900, May 2022



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Niloofar Jafari

UiT, Narvik, Norway

May 2022

Disclosure

This research in the first phase conducts a systematic literature review (SLR) in order to investigate the implications of Industry 5.0 for smart logistics. In this regard, I am privileged to state that this phase, which majorly covers Chapter 2, facilitated the development of a research paper, and in this regard, the contents and results of this chapter were published in MDPI. In this research article, I benefited from the supervision of my supervisor, Dr. Hao Yu, to complete the conceptualization, conduct the analyses, and writing the first draft of the paper as the first author. The paper is published in open access journal of "Logistics" and further details about this paper are as follows:

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logistics

Review

Moving from Industry 4.0 to Industry 5.0: What Are the Implications for Smart Logistics?

Niloofar Jafari [1], Mohammad Azarian [2] and Hao Yu [1,*]

[1] Department of Industrial Engineering, Faculty of Engineering Science and Technology, UiT The Arctic University of Norway, 8514 Narvik, Norway; nja016@post.uit.no
[2] Department of Mechanical Engineering and Technology Management, Faculty of Science and Technology, NMBU Norwegian University of Life Sciences, 1430 Ås, Norway; mohammad.azarian@nmbu.no
* Correspondence: hao.yu@uit.no

Abstract: *Background*: Given the importance of human centricity, resilience, and sustainability, the emerging concept of Industry 5.0 has pushed forward the research frontier of the technology-focused Industry 4.0 to a smart and harmonious socio-economic transition driven by both humans and technologies, where the role of the human in the technological transformation is predominantly focused on. Several studies discuss the impacts of disruptive technologies on smart logistics operations in Industry 4.0. However, since Industry 5.0 is a new concept and still in its infancy, its implications for smart logistics have not been discussed. *Methods*: To fill this gap, this paper presents a comparative bibliometric analysis to show the connection and differences between Industry 4.0 and Industry 5.0 and their implications for smart logistics. A thorough content analysis is then given to illustrate the features of smart logistics in Industry 5.0 concerning four areas, namely intelligent automation, intelligent devices, intelligent systems, and intelligent materials. *Results*: The results show that, compared with Industry 4.0, the research of smart logistics in Industry 5.0 puts more focus on the interaction between humans and technology in the digital transition, with the increasing adoption of collaborative technologies, e.g., human-machine systems, collaborative robots, and human-robot collaboration. *Conclusions*: Finally, a research agenda is proposed for identifying future research directions of smart logistics in Industry 5.0.

Keywords: Industry 5.0; Industry 4.0; smart logistics; sustainable logistics; bibliometric analysis; literature review

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1. Introduction

Industrial revolutions, throughout history, are primarily driven by disruptive technological breakthroughs that change the manufacturing paradigms and the way of customer demand satisfaction. With the increasing adoption of advanced manufacturing technologies, digitalization, and information and communication technology (ICT), Industry 4.0, also known as the fourth industrial revolution, aims at achieving a higher level of automation and intelligence [1]. Through leveraging the effectiveness and efficiency of manufacturing processes, Industry 4.0 predominantly emphasizes the paradigm shift led by new technologies, but less attention has been paid to the human aspects [2–4]. This is, however, argued as a threat to the sustainable development of humans and society [5], which requires more attention and effort from both industrial practitioners and academia [6]. Although this concern can be partially addressed by incorporating Industry 4.0 within the context of sustainability [7], circular economy [8], green supply chain [9], and so forth, it is still important to have a systematic conceptual development to fill the missing points of Industry 4.0. Thus, given the importance of human centricity, resilience, and sustainability [10], the concept of Industry 5.0 is proposed to complement the existing Industry 4.0 [11] in order to better meet the industrial and technological goals without compromising the socio-economic and environmental performance [2,3]. Among others,

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Abstract

The fourth industrial revolution, namely Industry 4.0, has substantially impacted the supply chain and logistics operations which led to the introduction of Logistics 4.0. The incorporation of novel technologies in this context developed smart logistics; however, scholars raised the concerns about socio-economic aspects of these improvements. Industry 5.0 as a value-driven paradigm, in this regard, initiated the trinary concept of sustainability, resilience, and human-centricity to put forward the technological and conceptual developments of industry according to this framework. Given the recency of this industrial revolution, not many research works have focused on the implication of Industry 5.0 for smart logistics. Therefore, this research aims at bridging this gap by investing effort into accomplishing a thorough systematic literature review to compare the topic of smart logistics in Industry 4.0 and Industry 5.0. The results define integration and intelligence among the key features, and spot simulation and digital twin among the enabling technologies of this concept. To realize these findings, a digital model of a company's distribution network is created, and it facilitates the possibility of performing network optimization and simulation through an integrated platform. The results show that such approach has a remarkable contribution in performing the supply chain network optimization and determining the logistics performances of the redesigned network, e.g., optimal inventory level and capacity at each facility, shipping policy in individual transportation routes, etc. This approach enables the possibility of incorporating socio-economic aspects into logistics studies, e.g., CO2 emission, which are discussed as further research directions.

Keywords: Industry 4.0, Industry 5.0, Smart Logistics, Supply Chain Network Optimization

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Chapter 1.
Introduction

Industrial revolutions throughout the history of manufacturing are considered as important milestones that made phenomenal improvements and changes in various areas, i.e., manufacturing technology, production systems, etc. The fourth industrial revolution which is known as a technology-driven revolution, namely Industry 4.0, emerged in early 2010s based on two major fundaments [1, 2]: intelligent analytics and cyber physical systems. According to the technological foundation of Industry 4.0, it was initiated by nine key technologies, and it is now further extended to a list of 12 including: autonomous robots, simulation, horizontal and vertical integration, internet of things, big data analytics, augmented reality, additive manufacturing, cyber security, cloud computing, artificial intelligence, block chain, and unmanned aerial vehicle [3, 4]. Supply chain and logistics is one of the areas that has benefited from Industry 4.0 throughout the last decade to a large extent, and the incorporation of the outlined technologies in logistics led to the advent of Logistics 4.0 [5]. This paradigm, interchangeably known as smart logistics, in fact seeks to positively influence and improve the logistics operations by utilizing novel technologies introduced by Industry 4.0, i.e., digital twin, smart transportation, etc. [6, 7].

Studies in this regard show that while there is a significant effort from academia to further develop smart logistics from the technological aspects, there has been an attention from academia towards sustainability in this context throughout the recent years [8]. Meanwhile, the concept of Industry 5.0 emerged to address the inverse impacts of intense focus on digitalization and automation [9]. The fifth industrial revolution emphasizes sustainability, resilience, and human centricity, and known as a value-driven industrial revolution [10]. Hence, this research primarily puts forward to comprehensively study this newly introduced industrial revolution in the context of smart logistics; afterwards, it attempts to investigate the possible approaches that are enabled by Industry 5.0 in order to address logistics network design problems.

1.1 Problem Description and Research Questions

The development of novel technologies throughout the last decade has been expedited and industries are experiencing a high-tech era that requires quick adaption. Although scholars have raised some fundamental topics, e.g., sustainability, society 5.0, etc., which are further promoted by Industry 5.0, it is essential to interpret and comprehend these topics not as a limitation but more importantly as a framework for improvements. Thus, this research is framed into two phases; the first phase seeks to study the implications of Industry 5.0 for smart logistics and find out the conceptual and technological solutions that satisfy the main objectives of this paradigm. The second phase benefits from the findings of its preceding phase and attempts to address the logistics network design problem according to the enabling tools and concepts in the era of Industry 5.0. In this regard, the following research questions shape the framework of this study:

- How could smart logistics be differentiated in Industry 4.0 and Industry 5.0?
- What are the implications of Industry 5.0 on smart logistics?
- How can we characterize Industry 5.0 and technologies in this era?
- How can Industry 5.0 tools improve logistics operations?

1.2 Research Objectives

The designed research questions are to be addressed from two approaches, and basically in two phases. The first three research questions shape the first phase, and they are addressed by a systematic literature review. This approach assists in conducting a quantitative and qualitative research using the literature concerning Industry 4.0 and Industry 5.0 in the context of smart logistics to follow the below objectives:

- To compare the previous studies regarding Industry 4.0 and Industry 5.0 from the viewpoint of smart logistics and highlight the similarities, and majorly, the differences of these two subsequent industrial revolutions in this context.
- To characterize and categorize the smart logistics operations in the era of Industry 5.0.
- To give insights about the enabling technologies that facilitate smart logistics with respect to the goals of Industry 5.0.

To accomplish the second phase, which focuses on the fourth research question, the aim is to perform a logistics network optimization study by benefiting from the methods and enabling technologies that contribute to Industry 5.0 and smart logistics. To approach this goal, this study utilizes the information of a logistics company, so-called Dyrket, that is located in Oslo, Norway. The firm is engaged in the food industry which majorly supplies organic food to private and business customers. The current distribution network of Dyrket constitutes of various local suppliers and it is facilitated by only one distribution center located in Sandvika, Bærum. Given the fact that the company provides delivery to customers, as well as pick-up service at the distribution center, there is massive number of trips throughout the congested area of Oslo pertaining to both inbound and outbound transportation. In this regard, the aim is to study and evaluate the possibility of adding collecting centers which form as an intermediary storage facility which bridge the connection between suppliers and distribution center. Hence, the main objective is to optimize the Dyrket's distribution network based on a set of alternative locations for distribution centers and collecting centers.

1.3 Summary and Overview of Research

In this chapter the primary research questions and research objectives were outlined, which were accompanied by the considered approach and methods in order to complete this study. According to the scope of the research, a brief overview regarding the two phases of this project was provided, and in this regard, the corresponding case study was also briefly described.

The remainder of this document includes elaboration of the research objectives, background studies, required materials, methodologies, experiments, and results which are organized in separate chapters as follows:

- **Chapter 2. Background Study and Literature Review**
  This chapter majorly deals with the first phase of the research that was explained in section 1.1. It comprises a systematic literature review study that was considered to complete this phase and highlights the results in response to the first three research questions of this study.
- **Chapter 3. The Problem, Data, and Methodology**
  This chapter initially gives insights on food supply chain and locally produced food. Afterwards, it completely describes the case study, Dyrket company, and highlights the refined data that are necessary to accomplish the optimization study. More importantly, the methodology that was inspired by the literature study will be thoroughly explained which includes two major aspects:
  - ✓ *Network optimization*: perform the network optimization study in order to redesign the Dyrket's distribution network.

- ✓ *Simulation*: accomplish a simulation experiment according to the inventory and shipping drivers as a mean of contributing to the optimal logistics performances of the redesigned distribution network.

- **Chapter 4. Experiments, Results, and Discussion**

  The chapter begins with explaining the software and the capabilities it provides for user, so-called anyLogistix. Afterwards, it elaborates the steps required to both developing the digital model of the supply chain and performing the experiments associated with both aspects outlined in Chapter 3: network optimization and simulation. It is worthwhile to mention that important analyses and inferences are provided to derive the ultimate conclusion for the case study.

- **Chapter 5. Conclusion**

  This chapter wraps up the whole research and highlights some of the limitations that have impacted this study and sheds light on possible directions which can improve this project.

Chapter 2.
Background Study and Literature Review

In this chapter, the major goal is to study the recent industrial revolutions and their impacts on the smart logistics operations. This implies the investigation of fourth and fifth industrial revolutions, which are tightly engaged with digitalization era and recent technological advancements. On the other hand, this study sets the objective to accomplish a supply chain network optimization which benefits from the findings of this chapter.

2.1 Smart Logistics in the Digitalization Era

Logistics, as one of the key functions of a company, has been significantly affected by recent technological advancements and innovations [8]. Smart logistics operations are enabled by the increasing use of new technological solutions, which lead to the emergence of intelligent warehouse management [11], smart transportation [6], digital twin [7], and so forth. By comparing the development of logistics operations with the four industrial revolutions, Wang [5] proposed the concept of Logistics 4.0 which incorporates the Industry 4.0 technologies into various logistics operations to improve the intelligence and automation. This concept is further developed to adapt the characteristics of specific industries, e.g., food logistics [12] and forest supply chain [13]. Amid the progress of logistics operations thanks to the fourth industrial revolution, the fifth industrial revolution emerged to address the environmental and human issues stemming from automation and digitalization brought by Industry 4.0. In this context, there is a lack of literature to study the impact of this recent and exquisite industrial revolution on the smart logistics operations. To approach this shortage, a systematic literature review is conducted in this section following two major goals: highlighting the connection and differences between Industry 4.0 and Industry 5.0 within the scope of smart logistics; studying the features of smart logistics in Industry 5.0. In this regard, the first objective is set to be achieved through a comparative bibliometric analysis while the latter is fulfilled by a content analysis. It is worthwhile to mention, that the results of this section are substantially critical for this project since they facilitate answering the first three research questions devised for this study. As outlined in section Chapter 1, the aforementioned research questions are as follows:

- How could smart logistics be differentiated in Industry 4.0 and Industry 5.0?
- How can we characterize Industry 5.0 and technologies in this era?
- What are the implications of Industry 5.0 on smart logistics?

2.1.1 Industrial Revolutions since 2010

2.1.1.1 Industry 4.0

Industry 4.0 is undeniably one of the most important industrial phenomena in the last decade that has drawn significant attention from both industry and academia. The advent of this industrial paradigm has shaped the ground for extensive research topics since its introduction in 2011 at the Hannover fair by highlighting two major concepts: internet of things (IoT) and cyber-physical systems (CPS) [2, 14]. The high-speed internet connectivity within manufacturing and logistics systems, i.e., industrial internet of things (IIoT) [15], potentially favors these industries by improving their intelligence and integration level [16-18]. In this regard, combining automation and intelligence in a highly integrated CPS shows the maturity level of an Industry 4.0 system [19, 20]. Through a combination of disruptive technologies and intelligent analytics, e.g., IoT, CPS, big data, artificial intelligence (AI), etc., Industry 4.0 will not only change the manufacturing industry but also impact all sectors of economic cycles. Figure 1 illustrates the 9 most important enabling technologies of Industry 4.0, which are considered the pillars of the fourth industrial revolution.

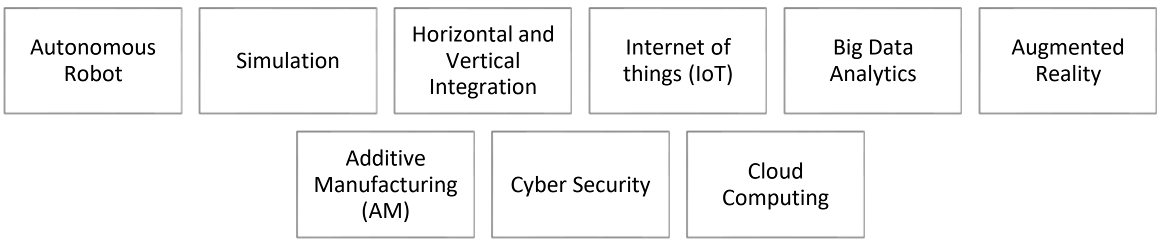

Figure 1. Nine pillars of Industry 4.0.

Integrating these technological pillars in an organized framework, Industry 4.0 is a technology-driven paradigm shift that aims at higher productivity through the better utilization of resources [1]. This technological framework incorporates all operational layers and streams of a factory and possesses a high level of intelligence as a human's brain. From a holistic point of view, this evokes a fully automated production system that is operated by internet-connected smart machines and robots with minimum human intervention. However, realizing such an objective needs the adoption of several enabling technologies through both vertical and horizontal integrations [20]. For instance, additive manufacturing (AM), e.g., 3D printing, has not only been used for the rapid prototyping complex designs but has also been widely adopted in the manufacturing processes in several industries, e.g., aviation [21]. It may change the manufacturing paradigm through direct digital manufacturing (DDM), which can better satisfy highly personalized demands. However, on the other hand, it may proportionally increase the sophistication of production management. To that aim, virtual technologies and simulation can be used to evaluate the operational aspects and performance of incorporating AM into a manufacturing plant [22], which can provide comprehensive insights into the technological updates. Thus, the technological integration in a CPS has been categorized into five levels to measure the maturity of an Industry 4.0 system, namely, smart connection level, conversation level, cyber level, cognition level, and configuration level. At the highest level, the system can achieve bi-direction communication and control, intelligent decision-making, and autonomous operations [19].

2.1.1.2 Industry 5.0

The primary focus of Industry 4.0 is a technology-driven industrial paradigm transition, but less attention has been given to the human aspects and society. One concern related to this industrial revolution is the possible layoff and job security with the increased adoption of autonomous systems [23]. Thus it is of great importance that the technological transition must be done in a sustainable way and comply with the socio-economic development goals [24]. The concerns of humans and society in the industrial transition led to the emergence of Industry 5.0, which was raised by Michael Rada [9] in 2015 to put forward the concept of "Industrial Upcycling". This idea emphasizes the corporation between human and new technologies, i.e., industrial robots, 3D printers, etc., in production with the purpose that "*we use these tools as tools, do not give them the function and brain to WORK FOR US, but WORK WITH US*" [9]. This concept is closely linked to the technological pillars that have already been employed, and thus studies are carried out to distinguish the scopes, goals, and approaches of Industry 5.0 as a new stage of the industrial revolution. Following the footprints of this paradigm shift, the Japanese government proposed "Society 5.0" based on the high digital transformations in society. This concept aims at protecting societal and environmental benefits along with the direction of economic growth by taking the advantage of technological improvements [10, 25]. It attempts to turn the novel solutions around for the benefits of society and humans' life.

With a predominant focus on the role of the human in the technological transition, substantial attention has been paid to the 'human-robot collaboration' in Industry 5.0 during the last couple of years [1, 24, 26-28]. In addition, several studies investigate the human's role from various perspectives, i.e., technical, ethical, operational, societal, safety, etc., which has become one of the mainstream research directions to shape this new industrial revolution [25, 29, 30]. Hence, Industry 5.0 aims at establishing a comprehensive framework by adopting disruptive technologies and innovative solutions to tackle the emerging human-and-societal-related challenges and to achieve sustainable development. In this regard, the European Commission (EC) officially defined the concept of Industry 5.0 in January 2021 [10], which presented a systematic approach in the context of technological and methodological improvements. It establishes a synergy between the main technological drivers and societal development in Industry 5.0, and six major categories are identified including human-machine interaction, bio-inspired technologies and smart materials, digital twins and simulation, big data analytics, artificial intelligence, and energy efficiency and renewable energies.

2.1.2 Systematic Literature Review

Considering the rapid advancement of industrial paradigms stemming from technological leaps and the significant socio-economic impacts, it is of significance to map out the status-quo of the literature and project the landscape of smart logistics within the context of Industry 5.0. In this section a systematic literature review is performed to thoroughly understand the main characteristics of smart logistics in the scope of Industry 5.0. Literature review studies could be distinguished by two taxonomies according to their domain of contribution [31, 32], namely, conventional and stand-alone literature review. The former is broadly known and used by scholars serving as a background study that highlights a literature gap as the basis of a research project. The latter, however, is a solid study that assesses the entire "body of existing knowledge" in a particular field to shed light on the current research status and frame the potential directions. This concrete method was reshaped by Fink in 2005 by outlining the main features of the stand-alone review study [33]: systematic, explicit, comprehensive, and reproducible. To be more precise, such a study ought to accommodate a solid methodology with clear notations on the procedures encompassing deep insights on the corresponding research materials, which can be reproduced by other scholars. Based on this framework, the systematic literature review (SLR) was defined as [31]: "*a systematic, explicit, comprehensive, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners*." An SLR can benefit from both qualitative and quantitative methods by exploiting the meta-analysis, which takes place prior to the qualitative evaluation of the selected articles, and thus, neutralizes the impact of selection bias pertaining to narrative literature review [31, 34].

The procedures of an SLR were initially developed by eight steps [31, 35]: formulating the problem, validated review protocol (eliminate the interest conflicts for studies including more than one reviewer), literature search, screening, quality assurance, data extraction, synthesizing the findings, and reporting. These steps were further aggregated into four logical categories to represent a more transparent overview of the stages involved in this research method [31, 36, 37]:

1. **Problem Formulation:** Entails the identification of the research goals and scopes by defining relevant research questions. It is worthy to note that, for studies including more than one reviewer, there should be a consensus over the questions to avoid evaluation bias.
2. **Literature Search and Screening:** This stage commences with precise search within the selected databases according to the identified keywords for each research question. The resulted papers are to be filtered out through the inclusion and exclusion of relevant criteria, which are further narrowed down by the screening procedure.
3. **Bibliometric Analysis:** According to the meta-data associated with the extracted papers, a quantitative analysis is conducted to reveal the relations between various characteristics of the research articles, i.e., publication trend, keywords focus, involved journals, etc.
4. **Content Analysis:** Qualitative analysis that aims at a thorough evaluation of the selected papers to explore the current status of the research area and highlight the future research agenda.

2.1.3 Problem Formulation and Literature Search

Formulating the research question is the primary step to conduct a systematic literature study. As also outlined earlier, the goal of this section is to establish a thorough understanding of the transition of smart logistics operations due to the advent of the fifth industrial revolution. To that aim, three research questions are defined to shape the ground of this SLR study. In this regard, it is remarkable to notice that the devised research questions pertaining to this particular phase are not specifically the same research questions that have been put forward for the entire of this research project; however, they are consistent and facilitating in finding the relevant answers to those.

- Research Question 1 (*RQ1*): What are the connection and differences of smart logistics in Industry 4.0 and Industry 5.0?
- Research Question 2 (*RQ2*): What are the main characteristics and enabling technologies of smart logistics in Industry 5.0?
- Research Question 3 (*RQ3*): What are the potential and important scopes of smart logistics in Industry 5.0?

After defining the relevant research questions, the second stage is literature search, which aims at finding and extracting the most relevant research articles for further quantitative (section 2.1.4. Comparative Bibliometric Analysis) and qualitative (section 2.1.5. Content Analysis) analyses. This stage consists of four steps, namely, keyword search, inclusion/exclusion of criteria, first screening (investigation of titles, abstracts, and keywords), and second screening (full-text investigation).

1. **Keyword Search.** This step employs two search techniques: (1) using a double quotation for an exact match with regards to phrase search; and (2) taking the advantage of Boolean operators (OR/AND) to combine various taxonomies of keywords. To thoroughly reveal the connection and differences of smart logistics in Industry 4.0 and Industry 5.0. The respective literature search is accomplished through two groups. The first group emphasizes the connection between Industry 4.0 and smart logistics, which primarily yields two contextual categories connected with "OR", as shown in Table 1. The second group is to explore the literature that discusses the characteristics, implications, driving factors, and definitions of Industry 5.0 enabled smart logistics. The primary database for literature search is Web of Science (WoS), which is the most extensively used platform [38]. However, due to the limited number of papers related to smart logistics and Industry 5.0 in WoS, Scopus is also used to yield a reasonable sample for analysis. The literature search was conducted in late December 2021, and the initial search for the first group yields 288 papers while it results in 247 for the second group (91 and 156 in WoS and Scopus, respectively).

Table 1. Identified keywords for smart logistics in Industry 4.0.

Main Category ('AND' Boolean Operator)	Sub-Keywords ('OR' Boolean Operator)
Smart Logistics	smart logistics; logistics 4.0; smart supply chain; supply chain 4.0; operator 4.0
Industry 4.0	industry 4.0; i4.0; fourth industrial revolution; cyber-physical system; internet of things; cloud computing; augmented reality; big data analytics; artificial intelligence; virtual technology; simulation; additive manufacturing; autonomous robots; cyber security; digital twin

2. **Inclusion/Exclusion of Search Criteria.** This procedure attempts to narrow down the collected papers from the previous step by either including or excluding particular criteria. Primarily, the language of the research items was selected 'English' to emphasize the international contributions. To ensure the quality of analysis, the papers were restricted to journal articles and conference proceedings. As also outlined, the introduction of Industry 4.0 was traced back to 2011 [2, 14], while the literature had recorded 2017 for Industry 5.0 despite its initial introduction being in 2015 [1, 39]. Thus, the next criterion was to set the publication years of the two groups of papers to be after 2011 and 2017, respectively. Another key filter that remarkably impacts the search results is the publication categories, which seek to eliminate articles with the least correspondence in terms of their scientific fields. Based on the applied filters, there were 114 and 146 in the two groups. Ultimately, a duplicate check for the second group is essential due to the use of two databases, which in turn, decreases the results to 110.
3. **First-Screening (investigation of titles, abstracts, and keywords).** The initial consideration in this stage was to exclude review articles, which were respectively recorded as 6 and 9 papers for the two groups. This was followed by a thematic investigation that aimed at filtering out the papers with weak conceptual relevance associated with the research questions. Throughout this process, the titles, abstracts, and keywords of the articles were investigated. This process led to the exclusion of 54 and 59 papers in the two groups.
4. **Second-Screening (full-text investigation).** During this process, the selected papers from the previous steps are entirely read to filter out the ones that are incapable of addressing devised research questions directly. After the full-text investigation, 12 papers were eliminated from the first group, and 10 papers were eliminated from the second group.

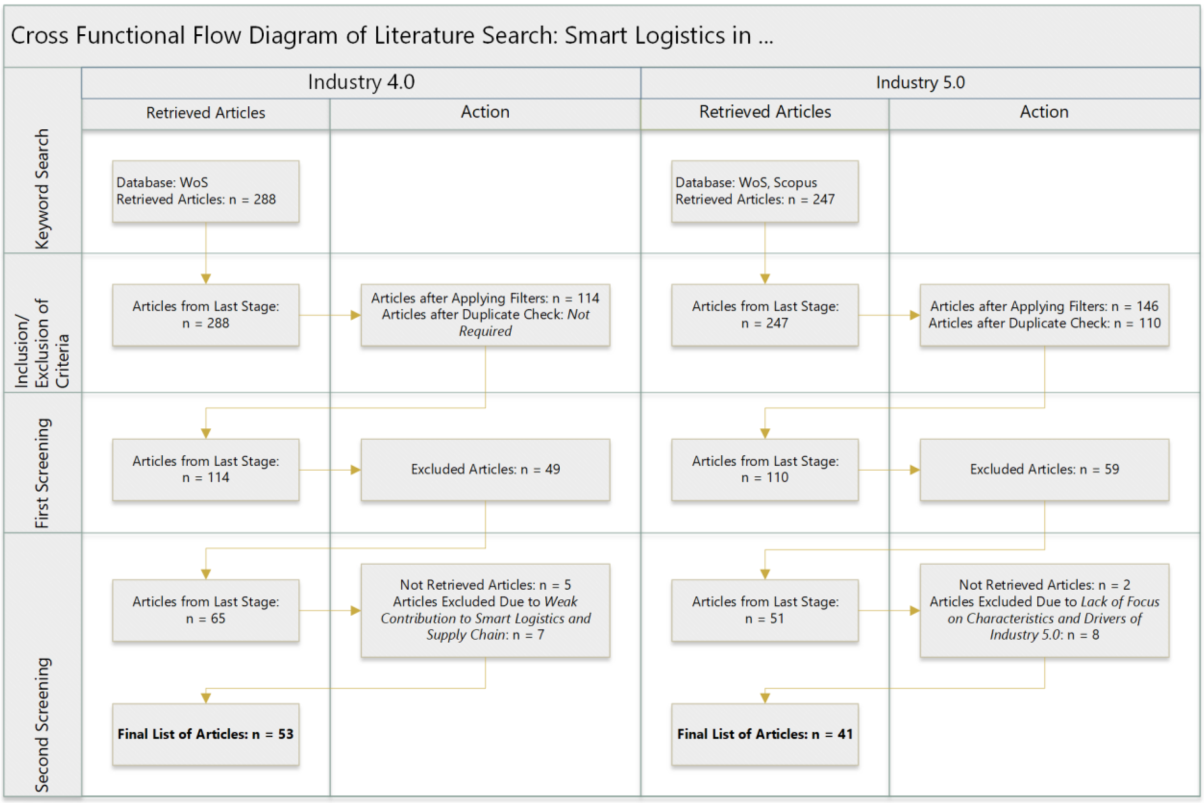

Figure 2. Flow diagram of literature search for systematic literature review.

As shown in Figure 2, the initial search associated with smart logistics in Industry 4.0 within WoS resulted in 288 articles. This figure through the filtering and screening procedures was then reduced to 53 research items. Combining both WoS and Scopus, 247 papers were yielded for smart logistics in Industry 5.0 in the initial search. After considering the inclusion/exclusion criteria, the duplicate check, and screening, the final set of research articles were narrowed down to 41 papers. It is noteworthy to mention, that during the second screening, 20 papers were identified as the relevant ones to understand the implications of Industry 5.0 in smart logistics.

2.1.4 Comparative Bibliometric Analysis

A bibliometric analysis also referred to as a meta-analysis [31], is a quantitative evaluation of the collected research articles, which enables scholars to statistically study the available bibliometric data from different perspectives. According to the scope of this research, the focus is on the connection and differences of smart logistics in Industry 4.0 and Industry 5.0. For this purpose, a comparative bibliometric analysis is performed based on the final set of articles pertaining to the two discussed groups, considering the *publication trend*, *sources contributions*, *interaction and co-citation analysis*, and *keywords co-occurrence analysis*.

2.1.4.1 Publication Trend

The publication trends are represented in Figure 3. For smart logistics in Industry 4.0, the numbers recorded affirm that increasing attention of academia has been drawn from 2015, and this figure was peaked in 2019 by 19 research items accounted for 36% of the accumulated articles. This trend reflects the incorporation of emerging Industry 4.0 technologies in logistics operations and decisions have become more attractive, which may largely affect this industry by adopting automated guided vehicles (AGVs), UAVs, AM, autonomous robots, etc. Although this rising trend is retrieved after a sharp decrease in 2020, the number of research items in 2021 is not comparable to 2019, which shows a shift of research attention to this area within the last couple of years. Contradictorily, the trend of research activities within the area of Industry 5.0 enabled smart logistics has drastically increased in this period, which has boomed in 2021 by 22 articles.

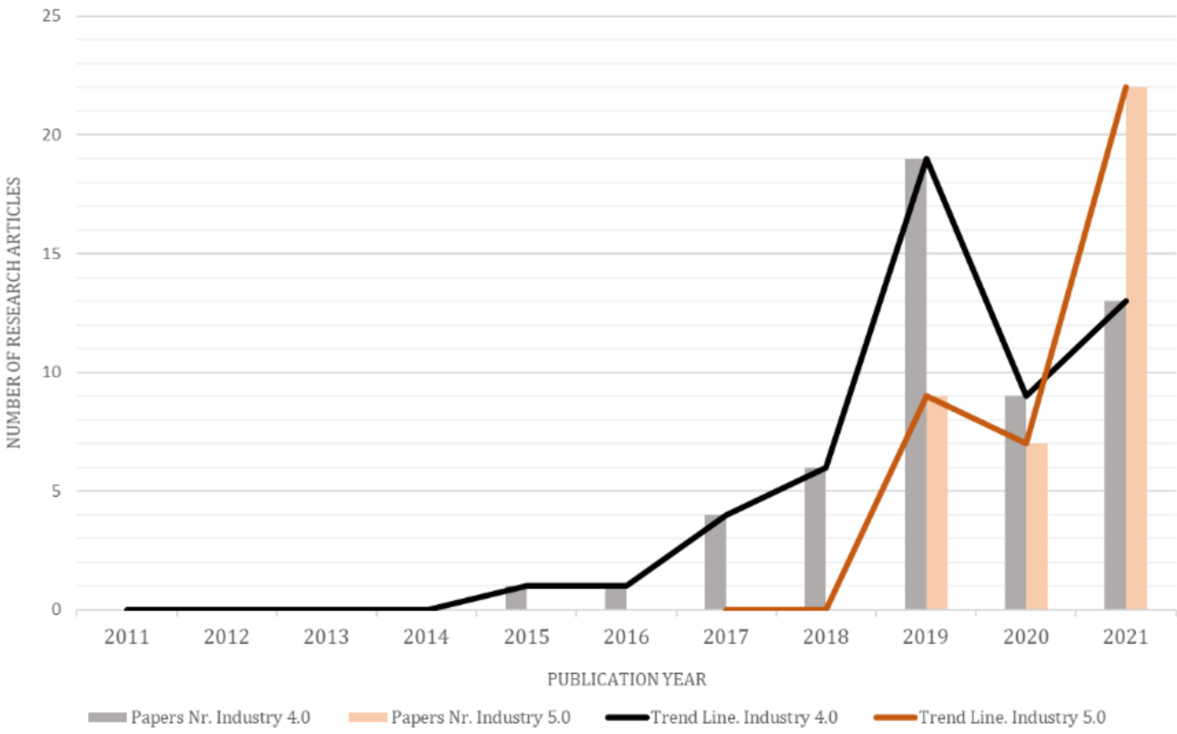

Figure 3. Publication trend of retrieved articles in SLR.

The most significant inference in this regard is the incorporation of sustainability, which has recently emerged in the main objectives of Industry 4.0 and the application of its technologies. Based on previous review studies [8], there is an increasing trend in sustainable logistics beginning from 2019. This trend is aligned with the general goals of Industry 5.0, which puts forward the significance of socio-economic and human-centric activities.

2.1.4.2 Sources Contribution

International journals and conferences are primary platforms that pave the way to foster innovative solutions and ideas. Therefore, it is of significance to evaluate the contributions and interaction of the sources within the sample set which, from a general scale, gives insights into the active and leading sources of a research topic. Table 2 shows the sources and the number of papers contributing to smart logistics in Industry 4.0 and Industry 5.0, respectively.

Table 2. Distribution of Top Contributing Sources.

Technological enabler of smart logistics	Source Title	Nr. Items
Industry 4.0	IFIP Advances in Information and Communication Technology	7
	Computers & Industrial Engineering	5
	IFAC-PapersOnline	5
	Procedia Manufacturing	3
Industry 5.0	Lecture Notes in Mechanical Engineering	4
	Applied Sciences Switzerland	3
	Sensors	3
	Journal of The Knowledge Economy	2

Table 2 highlights the respective four most important sources related to smart logistics in Industry 4.0 and Industry 5.0. With 7 articles published, ‘IFIP Advances in Information and Communication Technology’ is the most contributing source within the context of Industry 4.0 and Logistics 4.0 by signifying the technological topics, e.g., computer application in technology, systems modeling and optimization, artificial intelligence, etc. ‘Computers & Industrial Engineering’ is the following journal, which has contributed to 5 publications in this field and focuses on computerized approaches in response to industrial problems. In parallel, 5 research items are published in ‘IFAC-PapersOnline’ which tightly focuses on, but is not limited to, automation control. Given the importance of manufacturing processes, automation, robotics, and so forth, ‘Procedia Manufacturing’ is another important source that has contributed to 3 research items. The main focus of these sources is technological advances, e.g., robotics, automation control, etc., and advanced computerized approaches which not only are the inevitable components of Industry 4.0 but also, play an important role in developing smart logistics systems. On the other hand, Industry 5.0 is listed 4 times in ‘Lecture Notes in Mechanical Engineering’, which covers broad scientific topics including control, robotics, engineering design, automotive engineering, and engineering management. ‘Applied Sciences Switzerland’ and ‘Sensors’ are the following sources by publishing 3 papers each and majorly focus on computer science and engineering along with human-computer interaction. According to the significance of social and technological aspects of knowledge creation and innovation, 'Journal of The Knowledge Economy' has supported Industry 5.0-enabled smart logistics by publishing 2 research articles. The endeavor from these top four sources depicts that although technological subjects contribute to the development of Industry 5.0, the human-centric and social aspects must be emphasized.

It is worthwhile to note that the investigation of the entire list of sources reveals that smart logistics and the industrial revolutions are commonly studied in six of them, i.e., IFIP Advances in Information and Communication Technology, Computers & Industrial Engineering, Advances in Intelligent Systems and Computing, Journal of Industrial Information Integration, Lecture Notes in Mechanical Engineering, Procedia CIRP. The aims and scopes of these journals and book series are majorly technology-driven, which shows the connection between I4.0 and I5.0 from this perspective. In comparison with a recent review of technology-driven sustainable logistics operations [8], the result shows that Applied Sciences Switzerland, IEEE Access, Procedia CIRP, and Computers & Industrial Engineering serve as common platforms for this topic. This conjunction indicates the role of socio-economic and environmental factors within the roadmap of smart logistics in Industry 5.0.

2.1.4.3 Interaction and Co-Citation Analysis

The co-citation analysis intends to investigate the sources cited by the research items and their influence on the published documents. For this purpose, VOSviewer software assists to assess and visualize the interactions between the involved sources (see Figure 4 and Figure 5). The co-citation network is interpreted as a graph in which the nodes (vertex) represent the sources, and the link between the nodes (edge) shows the connection between them. Based on the visual variations in each network, the evaluation is twofold: (1) the size of nodes indicates the number of citations associated with each source; and (2) the thickness of links demonstrates the number of times each pair of sources are cited together. In addition, the aggregation of the links associated with each node is called total link strength (TLS), and this analysis implies the influence of each source on the published articles. To prevent a substantially congested network formed by all the sources, the minimum number of citations a source received needs to be implemented to eliminate the insignificant ones. This figure was set to be 10 and 5 for the two groups of papers, which yielded 25 and 21 sources, respectively.

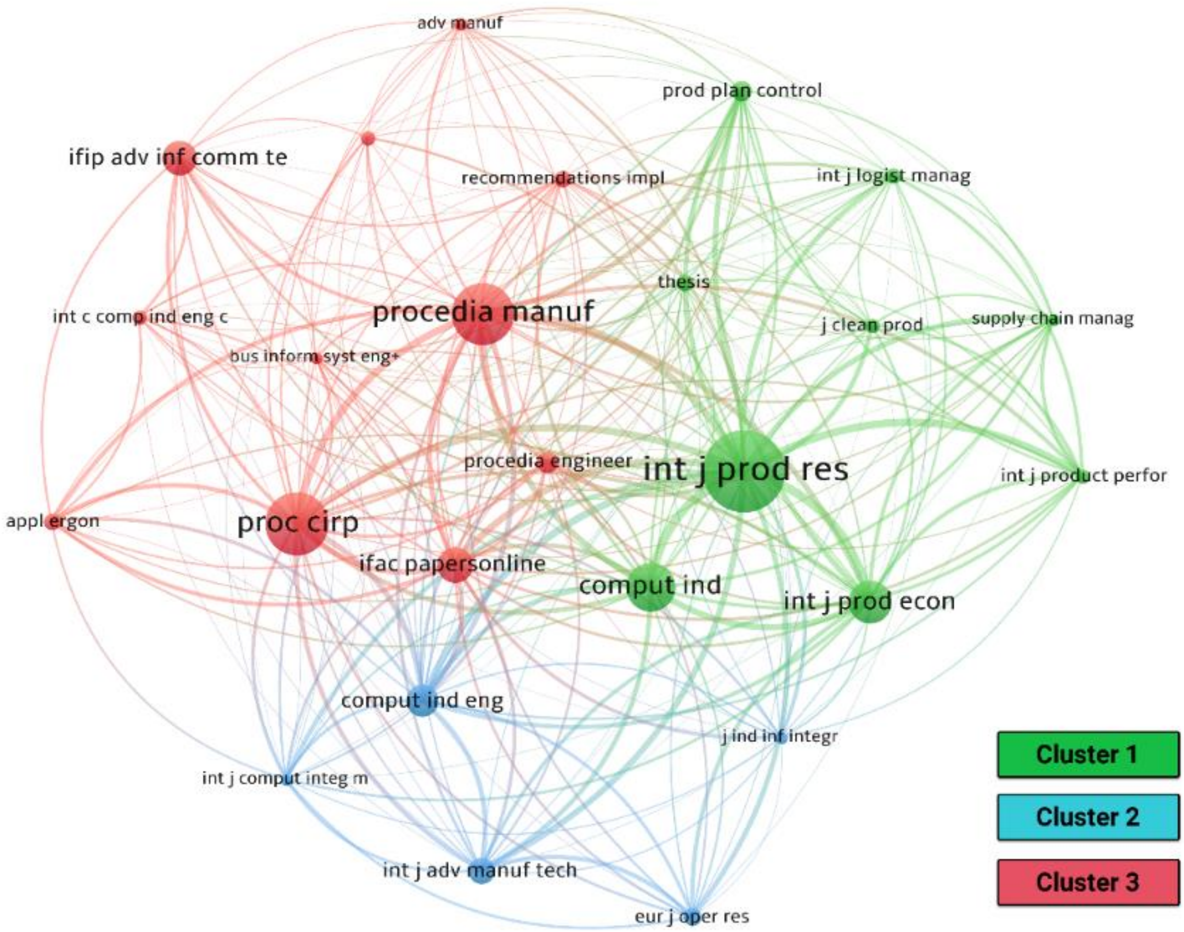

Figure 4. Co-citation analysis network of smart logistics in Industry 4.0.

Figure 4 reveals that the most influential source for smart logistics in Industry 4.0 is 'International Journal of Production Research' which yields 65 co-citations, and its TLS weight equals 1176. Given TLS as the comparison criterion, the impact of six more sources is determined to be significant including 'Procedia Manufacturing' (780), 'Procedia CIRP' (671), 'Computers in Industry' (641), 'International Journal of Production Economics' (625), 'IFAC-PapersOnline' (544), and 'Computers & Industrial Engineering' (541). Table 3 shows the clusters of these highly influential journals related to smart logistics in Industry 4.0 and their primary focus areas. Based on the features of the sources in each cluster, there is an interweaving connection between sources, which emphasizes the role of technological methods and drivers to advance the smart logistics paradigm in Industry 4.0.

Table 3. Co-Citation clusters of smart logistics in Industry 4.0.

Cluster	Source Title	TLS	Features
Cluster 1	International Journal of Production Research	1176	The application of computerized technologies in manufacturing and operation research
	Computers in Industry	641	
	International Journal of Production Economics	625	
Cluster 2	Computers & Industrial Engineering	541	Role of technology in manufacturing and logistics
	International Journal of Advanced Manufacturing Technology	390	
Cluster 3	Procedia Manufacturing	780	Manufacturing engineering, processes, and automation
	Procedia CIRP	671	
	IFAC-PapersOnline	544	

The newly emerged topic of Industry 5.0 enabled smart logistics, however, yields different attributes through the quantitative analysis of the sources. Based on the co-citation analysis, 'Assembly Automation' entails the highest TLS value, which is equal to 241. This is followed by 8 sources, which generate considerable influence according to their TLS weight including 'Journal of Industrial Information Integration' (224), 'Journal of Industrial Integration and Management' (217), 'Sensors' (195), 'Industrial Robot' (192), 'IEEE Access' (184), 'Sustainability (Switzerland)' (171), 'Kybernetes' (166), and 'Management Decision' (156).

Table 4. Co-Citation clusters of smart logistics in Industry 5.0

Cluster	Source Title	TLS	Features
Cluster 1	Assembly Automation	241	An inter-disciplinary com-bination of manufacturing technologies and information management
	Journal of Industrial Information Integration	224	
	Journal of Industrial Integration and Management	217	
	Industrial Robot	192	
Cluster 2	Sensors	195	An inter-disciplinary readership with a focus on engineering, social, human, eco-nomic, and environmental aspects.
	IEEE Access	184	
	Sustainability (Switzerland)	171	
Cluster 3	Applied Sciences Switzerland	102	Manufacturing engineering and technology management
	Procedia CIRP	69	
	Computers & Industrial Engineering	66	

In the outlined list, 'Sensors' is the source that is also involved in Table 2 amongst the most contributing journals. Additionally, it is the most referred source in the literature. This applies also to 'Sustainability (Switzerland)' and 'IEEE Access', both of which are the second most cited sources with a record of 16. This reveals the inter-disciplinary nature of the research and the importance of socio-economic and sustainability in the direction of Industry 5.0. Another finding from this list is that six sources (out of nine in total), as shown in Table 4, are crossfunctionally with a primary focus on manufacturing technologies and information systems and management. Similar to that of Industry 4.0, these sources have shown that technological advancements and innovation also play a significant role for smart logistics in Industry 5.0 through the adoption of big data analytics, AI, simulation, etc. Figure 5 shows the interaction and influence of these clusters. As demonstrated, there is a weak connection between cluster 1 and cluster 2, while they have intensive cooperation with cluster 3. This indicates that there is an interest to improve manufacturing technologies and information systems with a major focus on social, economic, environmental, and sustainable issues. Through the comparison of the co-citation analysis of articles between the two groups, it shows that the paradigm-change of smart logistics, from Industry 4.0 to Industry 5.0, must meet the socio-economic and sustainable requirements. In this regard, journals with this feature seem to play an increasingly important role.

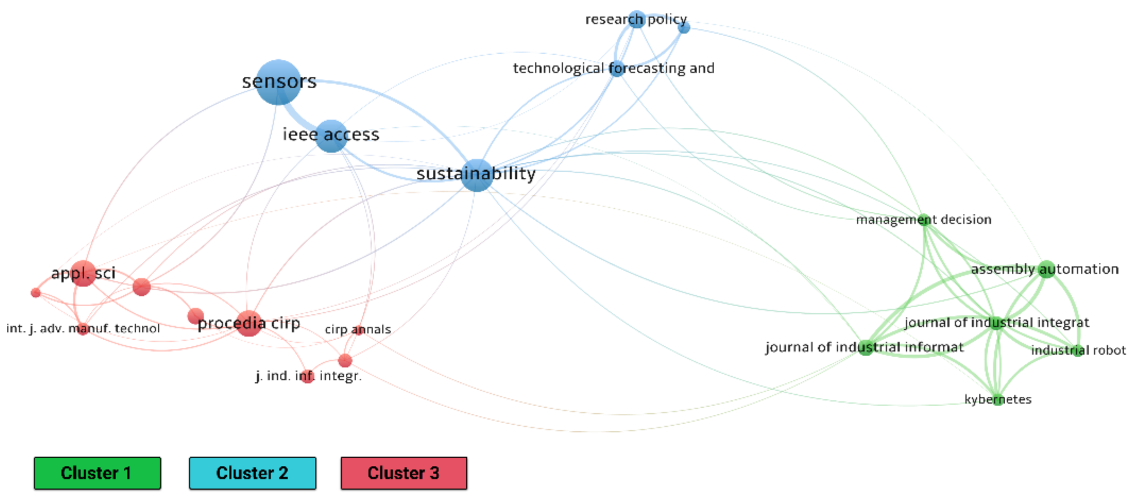

Figure 5. Co-citation analysis network of smart logistics in Industry 5.0.

2.1.4.4 Keywords Co-Occurrence Analysis

The co-occurrence analysis of keywords calculates the number of times each keyword is used along with the interaction between pairs of keywords. This examination is visualized in Figure 6 and Figure 7, where the keywords are represented by nodes and their size is dependent on the number of occurrences of the respective keyword. The links correspond to the interaction between keywords and their thickness indicates the usage frequency of each pair of keywords together. Thus, TLS in this context is the accumulation of links magnitude associated with each keyword. To yield sufficient and reliable results 'all keywords' is considered for network generation, which includes indexed keywords as well. Last but not least, the minimum number of occurrences 2 is used to generate the visualization, which leads to 46 and 42 results for the two groups.

Table 5. Top 15 Keywords.

Nr.	Industry 4.0			Industry 5.0		
	Keyword	**Occur.**	**TLS**	**Keyword**	**Occur.**	**TLS**
1	Industry 4.0	32	123	Industry 5.0	33	116
2	Internet	13	58	Industry 4.0	20	84
3	Operator 4.0	13	42	Industrial Revolutions	6	30
4	Big Data	5	31	Robotics	5	29
5	Future	4	30	Artificial Intelligence	6	25
6	Design	5	27	Manufacturing	4	25
7	Industry	4	27	Smart Manufacturing	4	23
8	Logistics 4.0	10	26	Internet of Things	5	22
9	Internet of things	6	24	Human-Robot Collaboration	4	21
10	Things	6	24	Industrial Research	4	18
11	Logistics	6	23	Collaborative Robots	3	16
12	Framework	3	21	Design and Development	3	16
13	Performance	4	21	Man-Machine Systems	3	16
14	Smart Logistics	6	19	Manufacture	2	16
15	Augmented Reality	3	17	Technology	3	16

Table 5 shows the top 15 keywords related to smart logistics enabled by both Industry 4.0 and Industry 5.0. Concerning Industry 4.0 and smart logistics, the top referred keywords are Industry 4.0, Internet, Operator 4.0, and Logistics 4.0, which identify the general framework of conceptual development. The other keywords, however, show the bond between new concepts and new technological drivers, i.e., big data, augmented reality, internet of things, etc. On the other hand, the keywords from the second group of literature highlight the significant role of Industry 4.0 as well as its enabling technologies within the roadmap of Industry 5.0. The primary finding is that, from the technological perspective, smart logistics in Industry 5.0 is concretely based on Industry 4.0. It is worthy to note that apart from a single technological perspective, socio-economic and sustainable issues are better considered and embedded in the smart logistics enabled by Industry 5.0 through the inclusion of human-robot collaboration, collaborative robots, and man-machine systems.

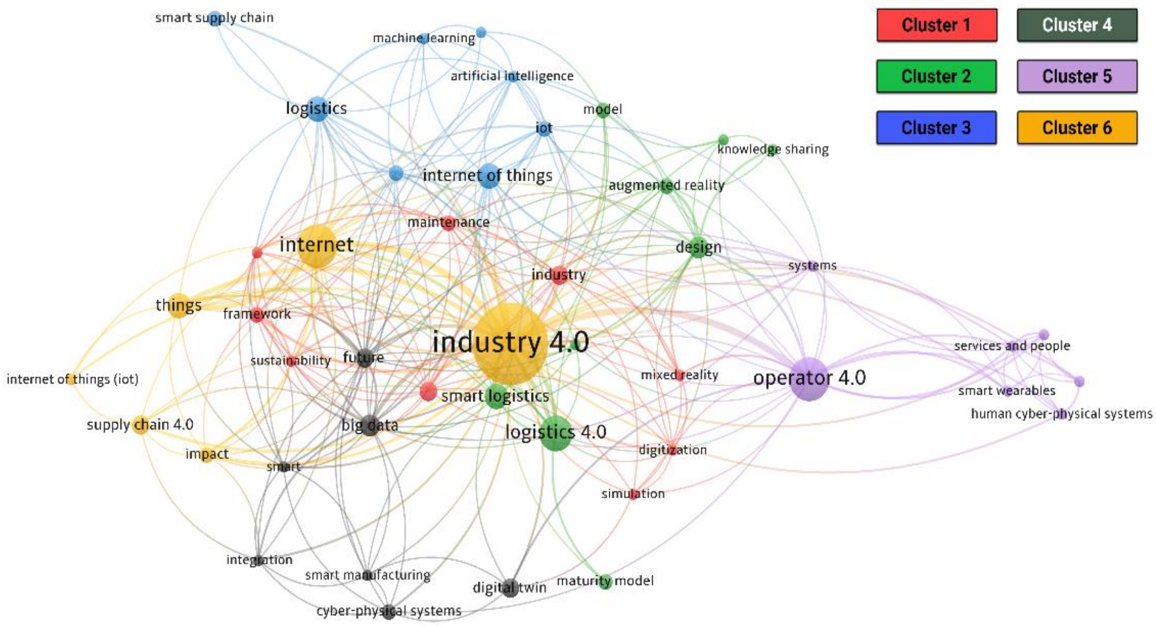

Figure 6. Keyword co-occurrence analysis of smart logistics in Industry 4.0.

Figure 6 illustrates the six clusters of keywords related to smart logistics in Industry 4.0. The most influential one is cluster 6 which shows a strong connection between the internet of things (IoT) and Industry 4.0. Cluster 2 addresses the main focus of Logistics 4.0 and smart logistics as well as some main enabling technologies, i.e., AR, etc. Cluster 3 indicates the importance of internet-based AI and machine learning in smart logistics and smart supply chains. Cluster 5 has remarkable interaction with cluster 6 and signifies the role of the smart logistics transition, which yields the concept of operator 4.0. Cluster 1 emphasizes digital tools, i.e., simulation, in manufacturing operations and sustainability. Cluster 4 depicts the importance of Industry 4.0 technologies in smart manufacturing and logistics, i.e., cyber-physical systems (CPS), big data, digital twin, etc. In general, the keyword co-occurrence network of these clusters shows that the research focus has been predominantly given to the technological drivers for smart logistics solutions in Industry 4.0. However, cluster 5 shows that increasing effort has been given to the connection between technology and human, which shows the motivation of a transition from Industry 4.0 to Industry 5.0. Finally, it is obvious that several advanced technologies, i.e., digital twin, simulation, AI, etc., have major contributions to this concept.

Figure 7 illustrates the four clusters related to smart logistics in Industry 5.0. Cluster 3 is by far the most influential category, showing the root of Industry 5.0 is from Industry 4.0. As discussed earlier, these two concepts have an interweaving connection in which the technological drivers play an undeniably important role. However, the elaboration of the links associated with smart logistics in Industry 5.0 reveals the footprints of social and environmental issues in this context. Cluster 1 comprises topics that immensely study CPS and smart manufacturing based on industrial robots according to the social impacts. Cluster 2 shows the links between the concept of society 5.0 and intelligence systems, human-robot collaboration, and collaborative robots. Cluster 4 evokes the existence of operator 4.0 and elaborates the significance of human factors, human engineering, personnel training, and so forth, in Industry 5.0 enabled smart logistics. On one hand, Industry 5.0 is tightly linked to the technological drivers of Industry 4.0 in the current digital era, while on the other hand, Industry 5.0 places predominant attention on socio-economic development, sustainability, and human issues. To that aim, the result of the keyword co-occurrence analysis shows the potential for smart logistics in Industry 5.0 by adopting new technologies while considering the human side in the transition, e.g., enhancing human-robot collaboration.

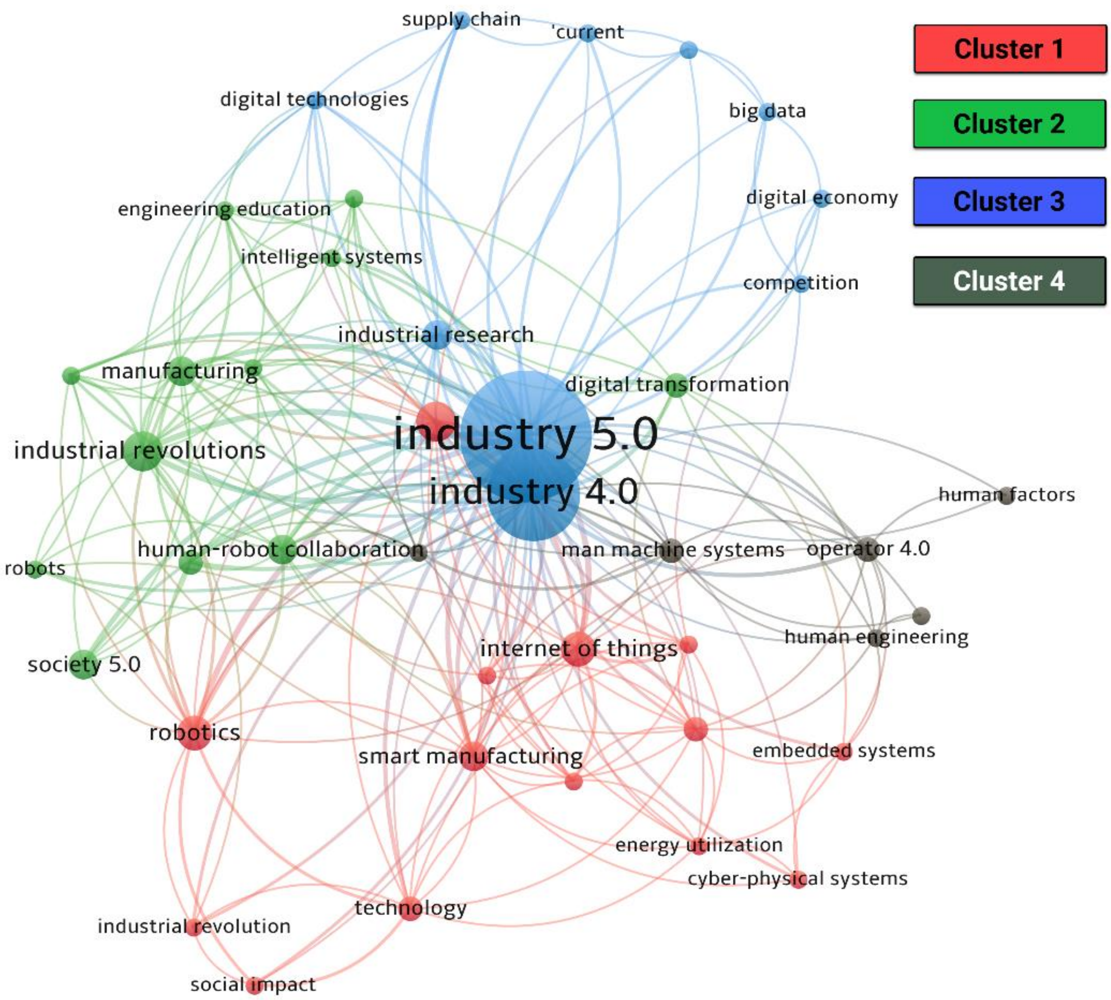

Figure 7. Keyword co-occurrence analysis of smart logistics in Industry 5.0.

2.1.5 Content Analysis

The results of the comparative bibliometric analysis of the two groups of literature demonstrate that there is an increasing trend in addressing the societal, human, and sustainability aspects, which are the key elements of smart logistics in Industry 5.0 [29] to highlight the harmony between technological development and human-centric socio-economic transition. The evaluation of the most extensively used keywords reveals that smart logistics in Industry 4.0 focuses purely on the technological pillars. However, on the other hand, Industry 5.0 not only emphasizes the adoption of new technologies in smart logistics operations but also substantially stimulates the interaction among humans, technology, and the environment through human-robot collaboration, collaborative robots, man-machine systems, etc.

2.1.5.1 The Three Key Elements of Industry 5.0

As rooted from Industry 4.0, Industry 5.0 embraces similar technologies and a clear distinction between these two industrial revolutions is thus of significance. The official introduction of Industry 5.0 underpins the evolution of this novel paradigm with respect to a trinary concept to pinpoint its corresponding core values [10]: human-centricity, resilience, sustainability.

- **Human-Centricity.** Conveys the fact the production and logistics system must be improved with solid attention to human benefits and needs by which the human is transformed from ‘cost’ to ‘investment’ [1]. From the operational aspect, this urges the promotion of hybrid alternatives in response to the industrial challenges, where the human power and human brain are involved not only to maintain the surveillance but also, to incorporate more intelligence and innovation, and to some extent, making decisions [24, 26]. Industry 5.0 emphasizes research and development (R&D) activities to translate the information to knowledge and meet sustainable social goals by upskilling humans through formal education or training schemes [1, 27, 29, 40, 41]. From the social and economic point of view, Industry 5.0 shapes the ground to not only prevent the elimination of human labor engaged manufacturing industry but also create more job opportunities in the supportive industries, which provide technological solutions, i.e., robot manufacturing, sensor manufacturing, etc. [24, 25, 27]. Hence, based on these objectives, Industry 5.0 is a human-centric paradigm that transfers the human back to the center of production cycles.
- **Resilience.** Represents the flexibility and agility that a production plant needs to maintain in response to the market change [27, 42]. Today, customers are strikingly

bombarded with high-tech innovations and products, and according to the constant changing of the market, personalized demands are one of the most significant challenges to the manufacturing industry [26]. To a larger extent, manufacturing systems are expected to transform from mass customization to mass personalization [27]. From a tactical perspective, this is realized by incorporating the customers in the design phase to build up the personalized product from scratch [25, 43]. To improve the operational flexibility in this regard, human-robot collaboration has a significant potential, that conducts versatility of fabrication in a more efficient time [27, 28]. It is worthwhile to highlight that while the main task is accomplished by the robot, human collaboration facilitates the problem solving of the work and process flows, and improves intelligence and innovation [26, 28].

- **Sustainability.** The concept of sustainable development was initially introduced by Brundtland in 1987 and defined as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [44]. While the social-and-human-related issues are an integral part of this concept, they are merely discussed within human-centricity in the context of Industry 5.0. This approach emphasizes reverse logistics [45, 46], circular economy [1], value chains, and so forth [47]. Sustainable development seeks the protection of the environment by sustainable products and logistics systems to approach the zero waste objective [25]. In addition to waste prevention, the manufacturing processes must be environmental-friendly, for example, by using renewable resources and green computing [28].

2.1.5.2 Smart Logistics in Industry 5.0

The core elements of Industry 5.0 show that following the technology-centric transition of Industry 4.0, the societal, environmental, and human perspectives require more attention, which will yield significant impacts on logistics operations and management. For instance, the personalization of demands implies a personalized delivery system [40]. Incorporating customers in the design requires highly intelligent CPS and system integration [28]. Human-machine interaction triggers the interaction of various topics such as safety, human behavior, etc. [26]. Thus, there exist various challenges and approaches to addressing smart logistics issues in Industry 5.0. With a focus on the interaction between technology and human in smart logistics, a thorough discussion is presented through a quadripartite intelligence framework [24, 27], namely, *intelligent automation*, *intelligent devices*, *intelligent systems*, and *intelligent material*.

Intelligent Automation

The major focus of Industry 5.0 is human centricity which, from a pragmatic aspect, puts forward the presence and high importance of the human in a system. However, there is a trade-off between human integration and automation to satisfy the goals of Industry 5.0, and this concern resides in the context of intelligent automation [26, 27], e.g. human-robot collaboration. It impacts the resilience of a logistics system and thus requires special attention and intelligence to achieve a lean collaboration [48-50]. The human's role in a logistics system was initially investigated in 2016 under the concept of 'Operator 4.0', which aims, by taking the advantage of technological advancements, at maximizing the human's contribution from three functional aspects [51, 52]: assisted work, collaborative work, and augmented work. The first function highlights the tasks that are mainly completed by human operators with the help of assisting technologies. The second requires collaboration between machine/robot and human. The last relies on technologies that could extend human's physical and visional capabilities. Considering logistics operations at different stages, e.g., production, warehousing, etc., two operational categories are significantly benefited from these applications are material handling and information flow [53].

Industry 5.0 paves the way to extend this framework by considering both resilience and human centricity. Romero and Stahre [54] introduce the concept of 'Operator 5.0' as "*a smart and skilled operator that uses human creativity, ingenuity, and innovation empowered by information and technology as a way of overcoming obstacles in the path to create new, frugal solutions for guaranteeing manufacturing operations sustainable continuity and workforce wellbeing in light of difficult and/or unexpected conditions*". In the context of Industry 5.0, this paradigm encourages technological development in two main directions: self-resilience and system-resilience, respectively. Self-resilience emphasizes human sustainability from biological, physical, cognitive, and psychological dimensions and focuses on human centricity in the technological transition, i.e., work ethics, social impacts, legal issues, etc. [30, 55-57]. System-resilience, however, signifies the functional collaboration between humans and machines in terms of sharing and trading control [58].

Human-robot collaboration in Industry 5.0 also plays a vital role in reacting to highly unexpected events, e.g., the COVID-19 pandemic, which requires high production agility and flexibility to fulfill the rapidly increasing demands of medical supplies [54, 59, 60]. In this regard, collaborative robots (cobots) are one of the most discussed enabling technologies in Industry 5.0. However, two important issues, say, the human skill and the behavior of cobots, need to be taken into account when cobots are integrated into a production or logistics system. As the main lever of Industry 5.0, through proper training, humans must be capable of working together with cobots [23, 57, 61-63]. For this purpose, the use of several supportive technologies, i.e., virtual reality, augmented reality, and simulation, have been extensively investigated [24, 60, 64]. For instance, operators can learn and understand the cobot motions under specific conditions without compromising the safety measures and productivity [24, 60]. On the other hand, cobots can be programmed or trained to establish a lean collaboration with the operators, which may lead to an increase in the productivity and efficiency of the workflow [65]. Human-robot collaboration not only requires hardware capabilities, i.e., sensors, etc. but also implies the essence of cognitive and intelligent behaviors of the cobot [65]. In this regard, the latest computation methodologies, i.e., machine learning (ML), deep learning (DL), clustering, regression, etc., have become increasingly important for the development of versatile applications [24, 60, 66-70].

Intelligent Devices

Machines, robots, and other facilities that are used in the production and logistics systems must be improved and equipped with smart technologies to maximize *functionality* and *performance* through physical and cyber connections with high monitoring and controlling capacities [71-74]. Considering the scopes of Industry 5.0, this objective signifies the interaction between humans and robots/machines. On the one hand, these intelligent devices, e.g., intelligent machines, smart robots, cobots, etc., require cognitive capabilities for decision-making by themselves to not only perform operations alongside the human but also actively prevent undesired incidents. On the other hand, due to the operators' inherent physical and intellectual limitations, the shortcomings for accessing the information flow and augmented functional abilities can be resolved by intelligent devices [61]. The collaboration between robot and operator raises concerns about human constraints as opposed to machines, which requires extra effort to resolve their integration issues. In this regard, operators' conditions need to be constantly traced with capture motion and eye-tracking devices, wearable biometric equipment, etc., under various workload conditions from both physical and cognitive perspectives [75-77]. This helps to facilitate a resilient workplace in which the environment adaptability can be improved in varied conditions [76].

In addition, Industry 5.0 emphasizes human centricity through the use of technologies and hardware to improve and supports the operators' performance in logistics system and supply chain operations. In this regard, human wearable devices which boost cognitive and operational capacities have been increasingly being utilized and improved in manufacturing industries [77]. *Exoskeleton* refers to augmenter equipment that gives extra strength and physical capabilities to protect the operator from adverse effects of heavy workloads [78-81]. Benefiting from virtual technologies, i.e., smart AR glass, spatial AR projector, etc., are viable and novel gadgets that facilitate flexible operations and technical guidance through information transmission and virtualization [54].

Needless to mention the latest improvements in unmanned aerial vehicles (UAVs) have radically altered the intralogistics and material handling systems in a highly novel manner, and it additionally serves as a significant potential for personalized delivery systems [40, 82, 83]. Besides, Auto Identification (Auto ID) and RFID have been extensively investigated in smart logistics and supply chains, which support traceability, warehouse operations, and inventory management [62, 84].

Intelligent Systems

The systematic approach of Industry 5.0 requires information transmission for individualized and case-based tasks in the production system and enhanced interaction with better decision-making processes throughout the whole supply chain [85-89]. This feature urges improved data and information exchange among different stakeholders, which largely affects the agility and intelligence of a smart logistics system. This aim can be realized by a network of data interoperability, where sensors exchange and process information in a big data environment [24, 40, 90-93]. In the context of Industry 5.0, a Smart Cyber-Physical Systems (SCPS) can be established for promoting data transmission and sustainability of production and logistics systems [94, 95]. This digital transformation, however, must be energy efficient by taking into account green procedures, i.e., green production, green recycling/disposal, green IoT (G-IoT), etc., to facilitate a lean circular economy (CE) [96, 97].

A digital transition to Industry 5.0 and Society 5.0 triggers the development of blockchain computing [25, 98-102]. In addition, it benefits the supply chain by enabling demand customization and personalization through *recommender systems*, which capture customers' preferences using social networks, text recognition, and analytical techniques [103]. Benefiting from internet-based connectivity, the transparency of information and manufacturing traceability can be drastically enhanced [40, 62]. Real-time decision-making and high-quality visualization form the foundation of a virtual smart logistics system in Industry 5.0 [104], which facilitates the emergence of the smart digital twin for logistics systems [24, 92, 105-107].

Intelligent Materials

One of the revolutionary improvements in Industry 5.0 is the development of smart materials. The characteristics of these new materials may significantly impact the supply chain activities by serving multiple functionalities and capabilities under certain conditions. For example, manipulating the shape and properties of the material and/or product according to varying physical conditions, e.g., temperature, light, stress, etc. [107-110]. The primary implication is in additive manufacturing, where 4D printing method is drastically benefited from smart materials [27]. Compared with traditional 3D printing, 4D printing employs similar technology that fabricates parts and components through layer-wised adhesion of corresponding material. However, the major difference lies in the material type [108, 109, 111, 112]. By using smart materials, the products can maintain various shapes and functionalities according to the environmental condition to improve the durability, adaptability, and reliability of the product. Various examples exist in medical science, aerospace, semiconductors, etc.

2.1.6 Analysis of Enabling technologies in Industry 5.0 Era

Industry 4.0 has proposed a technology-driven evolution during the last decade with a major focus on networked connectivity, intelligence, and automation. However, the autonomous attribute of this industrial revolution disregards the role of humans from the operation loops, and thus, the new concept of Industry 5.0 is developed to use the technology in favor of humans, *not as a substitute*. According to the established automation level and massive utilization of industrial robots in manufacturing plants, human-machine/robot collaboration serves the best potential to approach this goal. The human and robot symbiosis, however, triggers various technological, operational, and strategical challenges which require particular attention from both industrial practitioners and academia to achieve a lean collaboration. Furthermore, Industry 5.0 embraces new technologies and platforms that facilitate the achievements of socio-economic and environmental objectives. In this regard, Table 26 (Appendix) summarizes the most extensively focused enabling technologies that are referred in the research articles related to smart logistics in Industry 5.0. In addition, Figure 8 illustrates and sorts the outlined technologies according to the frequency of their contribution.

As depicted, *artificial intelligence* has shown remarkable viability with being referred in 59% of the research articles. This innovative solution with broad applicability, i.e., human-robot collaboration, society 5.0, etc., is one of the most promising technologies that successfully fulfill the socio-economic requirements of Industry 5.0 within the context of smart logistics. Given the human centricity attribute of Industry 5.0 and the significance of the interaction between humans and machines/robots, 49% of the papers has highlighted the advantages of *cobots* which is unarguably the main technological driver in this regard. Although operators are empowered by a variety of new tools and equipment, cobots facilitate a resilient and sustainable logistics system. To improve the utilization of cobots, 24% of articles argue the importance of *sensor technologies* that not only favor better and safer human-robot collaboration but also improve the connectivity and intelligence of intralogistics and supply chain operations. Moreover, *machine learning* and *deep learning* (maintaining 16% of research activities) are emphasized methods to increase the intelligence and cognition level of either humans or cobots as well as the entire logistics system. To account for the sustainability and human centricity features, *biotechnologies* have been studied in 14% of articles. This category of technologies is enriched by machine/deep learning methods for better utility and applicability. It is noteworthy that smart materials are also included in this category. *Additive manufacturing* and *mobile transportation* are the least discussed topics. Given 8% and 5% for AM and UAV/AGV, respectively, there is a lack of attention from scholars to these categories considering their potential impact on smart logistics in Industry 5.0.

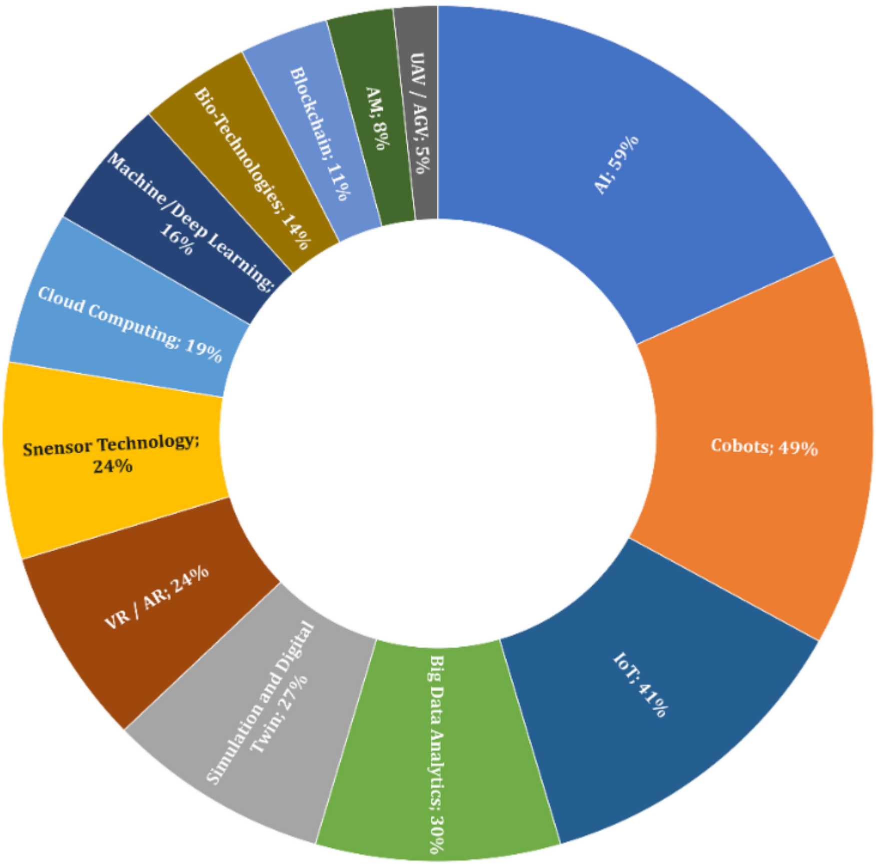

Figure 8. Supporting technologies in smart logistics of Industry 5.0.

IoT, *big data analytics*, and *cloud computing* which are the most important Industry 4.0 enabling technologies, have drawn academia's attention by 41%, 30%, and 19%, respectively, which imply the significance of digital transition in the fifth industrial revolution. These components, which are widely discussed in various topics, i.e., operator 5.0, society 5.0, and so forth, not only establish connectivity and intelligence but also improve the information transparency throughout different actors in a logistics system. In addition, *blockchain* is discussed by 11% of the research, which has a notable role in achieving socio-economic goals. Given this digital transition, smart logistics operations have shown a strong connection with virtual technologies in recent years, where 51%, 27%, and 24% of research highlight the role of *simulation, digital twin*, and *virtual reality* and *augmented reality*, respectively.

2.2 Scientific Contribution

The systematic literature review of this study thoroughly analyzed the smart logistics within the framework of two recent subsequent industrial revolutions and highlighted various aspects of Industry 5.0 to provide a comprehensive framework for smart logistics in this context. To answer the research questions devised in this regard (section 2.1.3), a comparative bibliometric analysis was initially conducted to reflect the differences and connections of Industry 4.0 and Industry 5.0 within the framework of smart logistics. This was followed by a comprehensive study concerning the newly emerged industrial revolution, Industry 5.0, to highlights the goals, ambitions, and drivers associated with this paradigm. This part was further extended according to the concept of smart logistics and a concrete structure for smart logistics in this era, along with major required and important technological drivers were identified. The knowledge acquired in these stages paves the way to highlight the major dimensions of smart logistics in Industry 5.0 era in terms of future research directions, i.e., mobile transportation, additive manufacturing, intelligent materials and supply chain, etc., among which this research particularly focuses on *smart and sustainable logistics network design*.

This concept, from tactical point of view, aims at addressing the human-centric and sustainability issues which, from technical perspective, puts forward to satisfy *intelligence* and *integration* within the logistics operations and supply chain design. This important goal triggers the utilization of technological components of Industry 5.0; needless to say, that majority of them were developed in Industry 4.0 era and they are not solely attributed to Industry 5.0. The review of such advancements (see Figure 8), show that intelligent quantitative techniques, e.g., artificial intelligence, machine learning, deep learning, etc., along with virtual technologies, i.e., simulation and digital twin, virtual reality, augmented reality, etc., are amongst the most contributing technologies in the context of smart logistics. Given the importance of digital transition, *simulation and digital twin* in this regard have a determining role that not only favor scholars to conduct versatile and thorough analyses of a real-word system but also, shapes the ground for incorporation of other smart tools, e.g., ML algorithms. As a matter of fact, this approach fulfils intelligence and integration as the principals of smart logistics within the context of Industry 5.0.

Digital twin of a logistics network shapes the ground to integrate various players of a supply chain into a virtual environment that is significantly beneficial to the decision-makers from a strategical point of view. The combination of this novel platform with optimization and simulation features leads to establishment an intelligent virtual platform that can best serve the challenges within the supply chain network design and logistics operations. This approach enables the academicians and practitioners to get more insights about the current, desired, and optimal supply chain network with considerable visualization possibilities. In addition, the simulation favors in conducting more rigorous evaluations through experimenting various feasible scenarios to analyze the performance of a logistics network. Last but not least, due to the considerable integration and intelligence embedded with this approach, one may carry out research regarding the environmental and sustainability aspects of a particular decision. Hence, simulation and digital twin have considerable potentials to accomplish research objectives associated with smart logistics under the influence of recently emerged industrial revolution, Industry 5.0. This research, therefore, opt this approach to model and optimize the distribution network of a logistics company, and benefits from the simulation capabilities to give more insights about the performance indicators of the optimized network in order to obtain more thorough and inclusive results.

Chapter 3.
The Problem, Data, and Methodology

The performance of supply chain network is critical to a company's success from a strategical perspective and companies majorly seeks the efficient frontier of *efficiency* and *responsiveness*. Approaching this objective has become even more challenging within the last decades and particularly during the post-Industry 4.0 era. The logistics systems, on one hand, have been significantly impacted by the technological improvements introduced under the shadow of fourth industrial revolution, and on the other hand, they have become more sophisticated due to the rapid market changes and high level of competitiveness. Logistic 4.0, operator 4.0, to name a few, are amongst the widely discussed topics in this era that address the supply chain and logistics issues by taking the advantage of recent novel technologies [5, 51, 52]. The outlined concepts aim to favor companies in facilitating more profound, intelligence, and integrated foundations to resolve the complex logistics issues that they encounter, such as robotized manufacturing lines, digitalized computational techniques, smart material handling systems, and so forth. Although considerable progresses have been achieved and experienced by industries and academicians, the recent industrial revolution evokes the concerns regarding human aspects and sustainability: fifth industrial revolution. Industry 5.0 is majorly driven by a trinary framework, i.e., human-centricity, resilience, and sustainability, which seeks to keep the human in the production cycle amid the automation and digitalization era [10]. Industry 5.0 in addition, aims at addressing the socio-economic pitfalls of its preceding revolution through better utilization of technologies and resources. In order to assess the implications of this industrial phenomenon to supply chain and logistics operations, a thorough systematic literature review was conducted in Chapter 2 and the results revealed four major areas corresponding to the smart logistics in this era: intelligent automation, intelligent devices, intelligent systems, and intelligent materials. Concisely speaking, this quadruple structure sheds light on *intelligence* and *integration* from technological perspective. In this regard, section 2.1.6

highlighted the major technological drivers that assist in promoting the smart logistics operations within the context of Industry 5.0, based on previous research works. This collective list reveals that Industry 5.0 not only inherits the novel technologies pertaining to Industry 4.0 but also, it facilitates the incorporation of recent exquisite developments. From the intelligence perspective, artificial intelligence, machine learning, deep learning, etc., are amongst the major technologies that are put forward within the context of smart logistics. In addition, simulation and digital twin, virtual technologies, and so forth, favors in realizing the system integration. Needless to mention the existence of other technological drivers are important in this regard, such as cobots, additive manufacturing, and so forth.

According to the today's complex environment of logistics systems, simulation and virtual technologies could be highly beneficial due to their potential in dealing with dynamics of a system and favors companies in better decision-making processes. The abilities of such approaches in modeling a real-world system helps scholars to get more insights about a logistics system through the integration of various components of the supply chain. In this regard, the current research puts forward to benefit from this novel technique and aims at addressing the supply chain design challenges within the locally produced food (LPF) business. To complete this study, a food logistics company, named Dyrket, is selected as the case study and the main goal is to redesign and optimize the distribution network of this firm, within the region of Oslo, Norway. Hence, an integrated optimization study and simulation experiment will be carried out in order to redesign the configuration of the current distribution network and overlook the logistics performance of the optimized solution.

To follow the explained objective, this chapter primarily discusses the locally produced food (LPF) and supply chain design in this context, which is followed by describing the problem and the case study. In the remainder, the required data for accomplishing the study are discussed. Finally, the chapter will be concluded by elaboration on the main methodology of this phase which is founded on two major stages: network optimization, and simulation.

3.1 Logistics in Food Industry

The supply chain strategies in the food industry may differ depending on the sectorial segment, i.e., fresh food industry, organic food industry, processed food industry, livestock food industry, etc. [113, 114]. The *local food* industry is a sub-category in this regard whose supply chain generally constitutes of farmers, distribution company, retailers and consumers as local chain actors [115].

3.1.1 Local Food Systems and Locally Produced Foods

Food systems in general, are expected to be responsive to overcome the issues stemming from the population growth, as well as being resilient and sustainable [116]. In an ideal form, food systems are to guarantee the customers accessibility to the safe and nutritious food while preserving the natural sources and addressing the climate change issues [117]. Local food systems (LFS) seek high degree of resilience in order to address uncertainties and combat unfortunate and unexpected situations, e.g., COVID-19. [118, 119], and it is shaped in various forms and structures, e.g., farmers market, farmgate sales, vegetable box delivery schemes, etc., which majorly, not always, provide unprocessed food supplies with transparent and traceable origin [120]. LFS around the world may accordingly be practiced based on the market, and thus, various definitions and interpretations is found in this regard. According to the US 2008 Food, Conservation, and Energy Act in the United States of America (USA) local food product is "less than 400 miles (approx. 644 km) from the origin of the product, or in the State in which it is produced" [121]; in Canada it is referred as "food produced in the province or territory in which it is sold, or food sold across provincial borders within 50 km of the originating province or territory" [122]; in European Union (EU), according to EU Joint Research Center LFS is "a food system in which foods are produced, processed and retailed within a defined geographical area (within a 20 to 100 km radius approximately)" [120]. Thus, LFS is neither limited to an abstract definition nor constrained by the local geographical scale [120]. Nevertheless, locally produced foods (LPF) refer to the items that are produced, processed, traded, and consumed in a defined geographical district and associated with social and supply chain characteristics [120, 123]. In recent years, LPF has provided high quality products and acquired an ideal position in the traditional food sector and received high interest from market [115, 124, 125].

Consumers have shown a high tendency of buying the LPF items [115]. The motivations in this regard are, but not limited to, taste and freshness, supporting the local community, sustainability, provenance, health benefits, and authenticity, and the only barriers for the consumption of local foods are the price and their availability due to the seasonal constraints [115, 126]. Thus, governments around the globe have attempted to facilitate this industry though legal frameworks and other schemes [123]; for instance, USA has supported community food project grant program, senior farmer's market nutrition program, federal state marketing improvement program, etc. [123]. In Sweden, different systems have been developed for local food marketing, distributing, and selling which aim at increasing the social interaction and supporting the LPF [127]. In this regard, farm shops and farmer's market are the two existing means of raising the LPF profile and establishing tighter connection between farmers and consumers.

3.1.2 Supply Chain in LFS/LPF

Within the context of LFS, customers know where the food exactly comes from and farmers maintain higher share of added value [120]. Indeed, in comparison with the most global food systems that the relation between producers and consumers are remote and anonymous, in LFS there is a direct and instant connection between the suppliers and customers [128]. In this scenario, the number of intermediaries between farmers and consumers is reduced and leads to a stronger sense of trust and social connection between actors [115, 129]. In general, there are two major types for local food market, “direct to consumer” and “direct to retail/foodservice”. In the first form, there is a direct connection between farmers and customers, while in “direct to retail/foodservice”, farmers sale the products to the restaurants, retail stores and institutions like government entities, hospitals and schools [123]. Although nowadays LPF is mainly offered to retail stores, hotels, restaurants, and so forth, it seeks other food service channels for gaining wider geographical area to increase the rate of sale [123, 124, 130].

Supply chain in LFS is arranged in different ways, by various types of selling arrangements between producers and buyers, different forms of interaction between consumers and producers, and different levels of commitment from consumers [121]. From practitioners and researchers’ point of view, short food supply chain (SFSC) is the main and most used channels in LFS that referring to a reduced number of intermediaries (usually at maximum one) among producers and consumers [121]. Herein, “sales in proximity” and “sales at distance” are highlighted as different types of LFS/SFSC that operate in the EU [120]. It is worthwhile to mention, that in aforementioned scenarios farmers act individually or collectively, however, the product is traceable back to the named farmer [120]. In general terms, *small farmers, diverse products,* and *short supply chains* are the pillars or main characteristics of local food markets [123]. According to previous studies [131, 132], face-to-face, spatial proximity, and spatial extended are three main types of SFSC that establishes the connection between producers and consumers. In this regard Table 6 summarizes and demonstrates the diverse local food distribution channels.

Table 6. Local food distribution channels [121].

Distribution Channel		Producer-buyer selling arrangement	Producer-consumer interaction	Consumer commitment
Direct-to-consumer SFSC	Farmers' markets	Spot market; relational contract	Face-to-face	Low
	On farm sales (pick-your-own, shop)	Spot market; relational contract	Face-to-face	Low
	Food boxes (home delivery, pick-up point)	Relational contract; formal contract	Face-to-face; proximate	Low to high[a]
	Community supported agriculture (CSA)	Formal contract	Face-to-face; proximate	High
Direct-to-retail SFSC	Consumer-owned retail food cooperative	Relational contract; formal contract	Proximate	Low to high[b]
	Local independent retailers	Relational contract; formal contract	Proximate	Low
	Restaurants, caterers	Relational contract; formal contract	Proximate	Low
	Institutions (schools, hospitals, prisons)	Formal contract	Proximate	Low
Conventional supply chains	Supermarkets, large food retailers	Relational contract; formal contract	Proximate; spatially extended	Low

a. Some food box schemes require consumers to subscribe, others do not.
b. Some consumer-owned retail cooperatives require consumers to subscribe or become a member of the cooperative, others do not.

With closer look, LFS/SFSCs have socio-economic and environmental impact that are [120]:

- Social impact
    - ✓ Social interaction, trust, social embeddedness
    - ✓ Sense of community
    - ✓ Increased knowledge/ behavioral change
- Economic benefit
    - ✓ Rural development and Economic Regeneration
    - ✓ Farm level economic impact
- Environmental impacts
    - ✓ Energy use and carbon footprint
    - ✓ Other environmental impacts: sustainability and SFSCs

3.2 Problem Description

Dyrket is a logistics company in the region of Oslo, Norway which is engaged in the food supply business and it is responsible for storage and distribution of food products. The notable issue in this regard is the suppliers of this company which are merely local producers, i.e., small farms, in order to provide organic food. The company has a distribution center (DC) at the west part of Oslo[1], and as a mean of flexibility, it provides both delivery and pick-up services. According to the information provided on the website of the company, the suppliers are distributed from north to south of Norway[2]. However, as depicted in Figure 9 by red pins, the company has a few suppliers on the northern and central part of Norway and the majority of them are distributed in the southern districts, and the Oslo area is the most congested region. It is noteworthy to mention, that the supply chain network of Dyrket is supported only by one DC which is marked by green pin in the magnified section of Figure 9. Needless to say, that the DC serves the customers in the region which is highlighted by green.

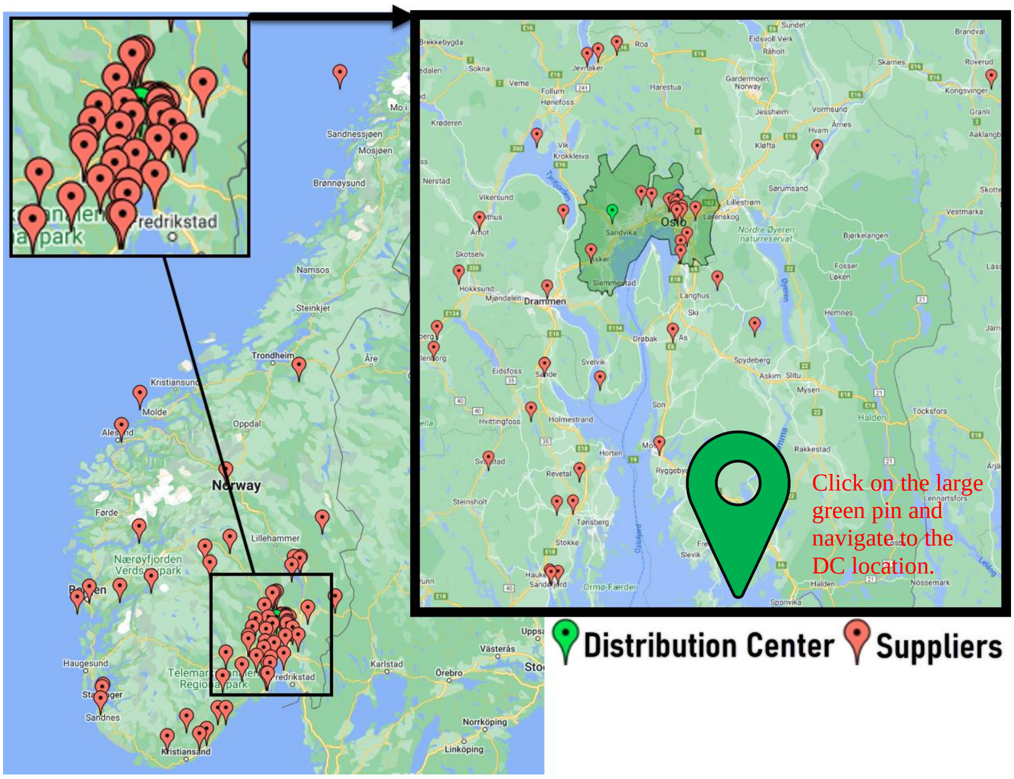

Figure 9. Dyrket supply chain network in 2022.

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[1] Rudssletta 54, 1351 Rud

[2] The provided list of suppliers (https://dyrket.no) reveals that the company is connected to 84 suppliers until April 2022. This number, however, is not conclusive and it is based on public information available on the website.

In order to get more insights about the logistics operations and network design of Dyrket, the company's website does not provide sufficient information required to address the optimization problem within the scope of this research. Thus, in order to collect the essential data, this study benefits from the thesis carried out by Thi Kim Le [133] who focused on investigating the supply chain network of Dyrket in 2020, and the study report from SINTEF research institute in which the customers' habit of Oslo area regarding online shopping is studied through phone surveys and statistical analyses [134].

This research, however, takes the advantage of utilizing more intelligent and integrated approach, in comparison to mathematical modeling, and seeks to achieve more rigorous results through a two-stage study: network optimization, simulation experiment. The former aims at redesigning and optimizing the distribution network, while the latter favors in investigating more dynamics and applying what-if analyses to find out the feasible and optimal operational policy of the redesigned network. Aside from the integration between these two successive stages, some of the advantages of this approach are as follows:

- Benefiting from graphical information system (GIS) embedded within the software and utilizing real routes between a pair of locations instead of straight lines.
- Applying various transportation policies according to the capacity of the transportation vehicle.
- Investigating various inventory policies of the redesigned network to favor decision-making regarding the capacity of the required distribution centers/storages.

A comparison between Dyrket in 2020 and 2022, reveals that the company has not modified the supply chain infrastructure and has maintained the only DC that was existed in 2020. The customer segments, however, are slightly changed by which Dyrket has shifted its focus from northern east of Oslo to the northern and western regions that are more in the range of its DC reachability. In addition, a notable growth in the suppliers' chain of the company is observable in 2022 in the district of Oslo by which they are close to the storage and distribution facility (DC). Figure 10 illustrates the distribution network of Dyrket in 2020 by highlighting its customer coverage area, suppliers (only the suppliers around Oslo area), and DC.

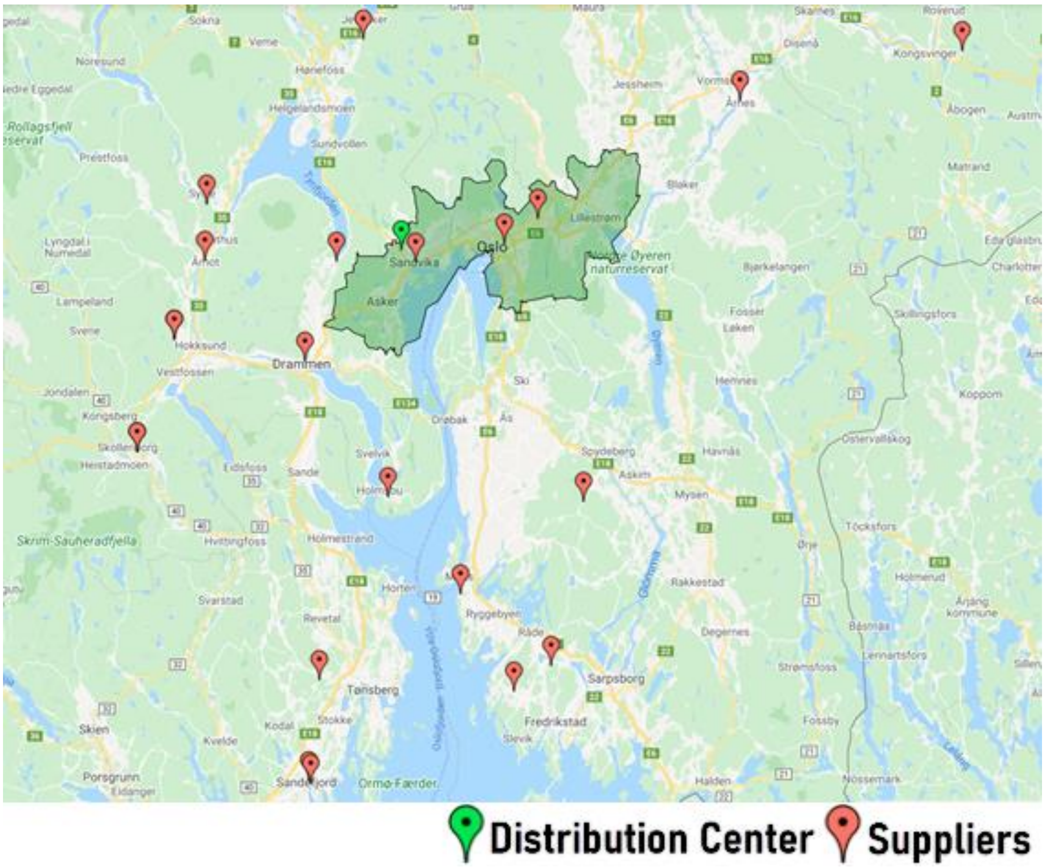


Figure 10. Dyrket supply chain network around Oslo area in 2020 [133].

Comparison between the supply chain network of Dyrket in 2020 and 2022, shows that company has considered cost reduction policies by adapting the customer segments and network of suppliers which mainly lead to the minimization of transportation costs, including both inbound and outbound deliveries. Although the 2022 status shows that the company has appreciated such policy, it might not be the optimal solution in the long run. Therefore, this research experiments another alternative by which the company is able to adjust and improve the supply chain performance through redesigning the distribution network and optimizing the logistics operational expenses. Such approach paves the way for further development of customer segments by considering more storage and distribution centers which will be elaborated in the remainder of this study.

3.2.1 Dyrket's Distribution Network

Due to the fact that the company has not modified the supply chain *infrastructure* in 2022, utilizing the information collected in 2020 are still practically valid to conduct the optimization experiment. therefore, as outlined earlier in this section, the information from 2020 will be utilized to fulfil the objective of this study. Thus, the current status of Dyrket in this report is equivalent to the company's situation in 2020.

Dyrket serves 5,600 private and 400 business customers and provides delivery service in Oslo (highlighted by green in Figure 10). Among the 200 suppliers, 20 have the highest impact on the customer segments which is due to the fact that 18 provide all of the groceries items and 3 are the largest producers that the company has commercial connection with. According to the previous studies regarding the customer segments [134], the company provides delivery services to 8 checkpoints which are within the 50 km radius of the DC, while the suppliers are located within the radius of 122 km of the DC. Thus, the current supply chain of Dyrket within the scope of this study encompasses 8 customer delivery points, 1 DC, and 20 suppliers which are illustrated in Figure 11.

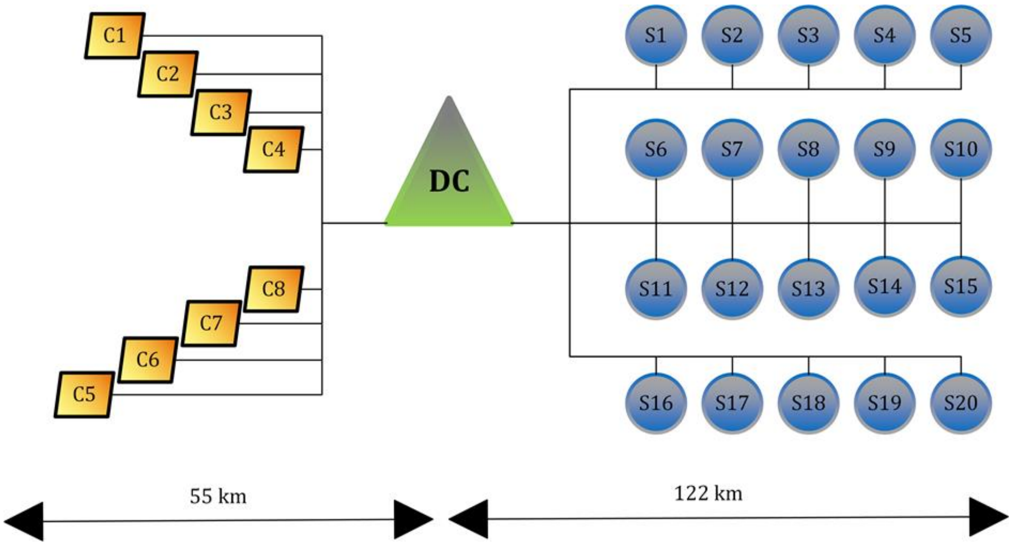


Figure 11. Current distribution network of Dyrket (C: Customer; DC: Distribution Center; S: Supplier).

The depicted distribution network does not lead to the optimal performance throughout the supply chain in terms of the transportation and inventory efforts and expenses. In such scenario, not only plenty of trips are required throughout the congested area of Oslo between suppliers and DC but also, one DC could potentially increase the inventory operations complexity. According to a research work regarding LPF in Sweden by Bosona, Gebresenbet [135], the distribution network of their case study was redesigned by adding *collecting centers* to the supply chain. In this approach, collecting centers (CC) are storage facilities that serve as the delivery points for the suppliers such that transportation between suppliers and DC will be eliminated. Thus, the internal flow of material is between CC and DC, while the customers/delivery points are still connected to the DC. According to the results of the study, improvements have been observed regarding the transportation distance, transportation time and number of trips. In this regard, this research takes the advantage of the outlined approach because it is a beneficial policy to reduce the transportation within the Oslo area by optimizing the transportation between suppliers and Dyrket facilities. The general framework of this policy associated with Dyrket company is demonstrated in Figure 12 to realize this approach within the scope of this research.

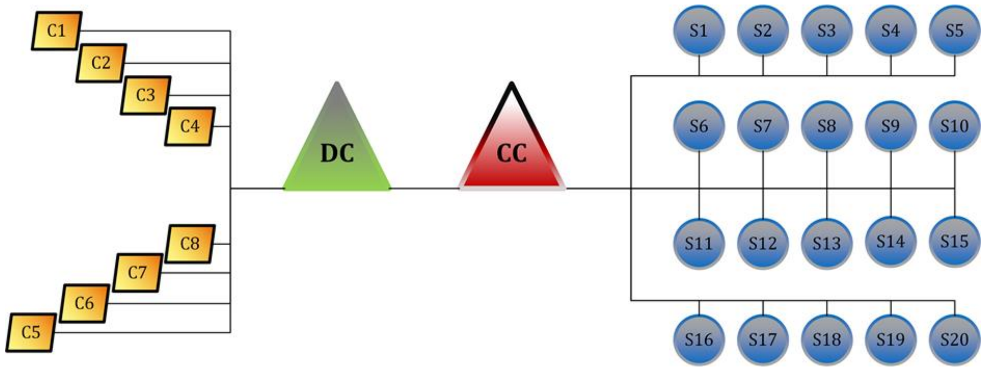


Figure 12. Proposal for Dyrket distribution network by adding collecting centers (C: Customer; DC: Distribution Center; CC: Collecting Center; S: Supplier).

According to the proposal explained and depicted above, the scope of this research is to investigate the optimal solution to improve the distribution network of Dyrket by considering potential candidates for DC and CC. In this regard, the aim is to determine the optimal collocation of CCs and DCs in order to best serve the customers within the distribution network by minimizing the inventory and transportation costs. Hence, this experiment assists in identification of the best CCs (out of 7 candidates) and DCs (out of 3 candidates) and optimizing the flow of material throughout the supply chain.

3.3 Collection and Refinement of Data

Designing the supply chain and distribution network of a company is majorly driven by satisfying the customer demand and, simultaneously, minimizing the overall logistics expenses. To complete this research, the availability of some particular information is critical. This section sheds light on the essential data in order to accomplish the experiment within the scope of this research project.

3.3.1 Customer Demand

In 2019 [134], SINTEF research institute conducted a survey through phone calls to people who have experienced online shopping and home-delivery services for grocery in the province of Oslo. During the survey procedure 501 customers were contacted, and according to the frequency of service utilization they were categorized into *low*, *medium*, and *high*.

- **Low**: using the home-delivery service for one time in the recent months
- **Medium**: using the home-delivery service for 2-5 times in the last two months.
- **High**: using the home-delivery service for more than 5 times in the last two months.

The customer segments in the report of SINTEF constitute of three major regions including the downtown of Oslo, so-called *city*, the *neighboring municipalities*, and *other capital regions*. After projecting the area that covers the Dyrket delivery points (highlighted by dark green in Figure 10) on these regions, the customer segments corresponding with Dyrket according to the outlined classification are yielded as follows:

- Region A (City): Oslo, Holmenkollen
- Region B (Neighboring municipalities): Bærum, Lørenskog, Lillestrøm
- Region C (Other capital regions): Asker, Rælingen, Fetsund

Following this categorization, Table 7 represents the distribution of outlined demand categories in each region, which bases the ground to calculate the demand of each customer segment.

Table 7. The frequency of various demand groups across the delivery regions.

Customer Region	Demand Groups		
	Low (n = 112)	**Medium (n = 252)**	**High (n = 137)**
Region A	67 %	59 %	56 %
Region B	20 %	25 %	30 %
Region C	13 %	16 %	14 %

The calculations continue with converting the distribution percentages into weekly demand quantities according to the probabilities of each demand group as follows:

- Low demand: usage of home-delivery service once in two months
- Medium demand: usage of home-delivery service 4 times in two months
- High demand: usage of home-delivery service 8 times in two months

Considering 5,600 private customers, the ultimate amount of weekly demand of products (each order comprises minimum of 10 products) associated with eight customer segments of Dyrket are calculated [133], and represented in Table 8.

Table 8. Weekly demand of products associated with 8 customer delivery points of Dyrket.

Region A		**Region B**			**Region C**		
Oslo	Holmenkollen	Bærum	Lørenskog	Lillestrøm	Asker	Rælingen	Fetsund
3,587	3,587	1,124	1,124	1,124	613	613	613

3.3.2 Distribution Network Design

According to the proposal that was put forward earlier in section 3.2.1, the distribution network of Dyrket is going to be redesigned and optimized utilizing 7 alternatives for CCs and 3 candidates for DCs in order to satisfy the demand of 8 customer delivery points by 20 suppliers (see Figure 13).

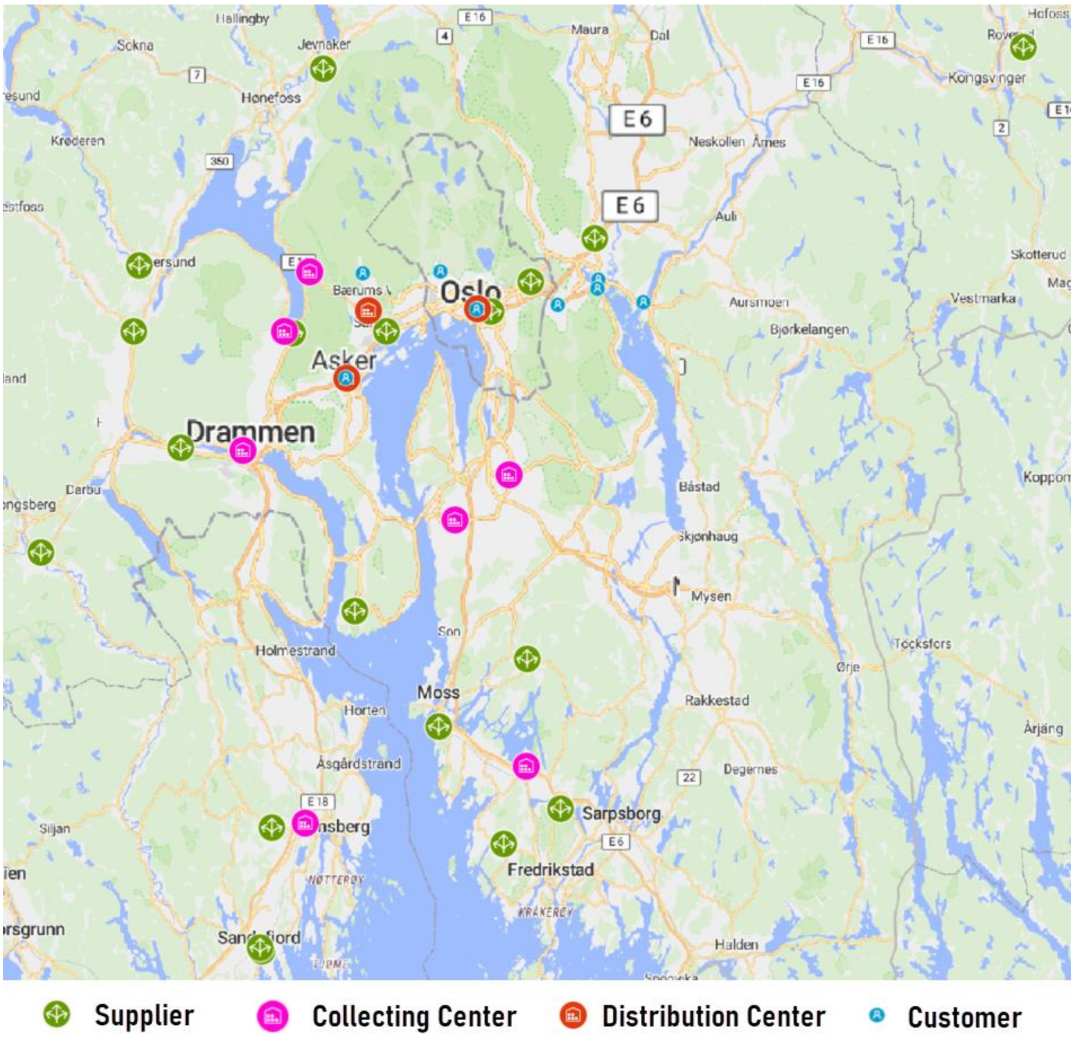


Figure 13. The proposal of Dyrket distribution network.

The locations of suppliers, facilities, and customer checkpoints are pinpointed by their coordinates. In this regard, the latitude and longitude corresponding with each location are utilized, and for this purpose, Google Maps platform is used to collect the respective data. These locations are represented in Table 27 (Appendix).

It is worthwhile to mention, that the products delivered by the considered suppliers in this study (S_1 to S_{20}) is accounted for 40% of the total amount of products that Dyrket receives from its suppliers' chain, and it is calculated as 12,386 products per week. Given the fact that 3 suppliers deliver twice the ordered quantity, the outlined figure is divided by 23, and *the weekly number of products produced and delivered by each supplier is calculated as 538*. This figure is interpreted as the number of weekly products that each supplier delivers to the CC that it is connected to. Hence, according to the assumption that each CC is linked to at most 8 suppliers, *the capacity of each CC is calculated by 538 × 8 which equals to 4,304 products per week*.

Distributions centers, however, are not solely supplied by CCs and they are also fed by other suppliers in order to fulfil the demand of Dyrket customers. Therefore, the *capacity of each DC is determined by the demand magnitude which is 30,965 products per week*.

3.3.3 Facility Costs

The issues surrounding facilities in this research have determining role and directly impact the supply chain performance according to the incurred expenses. Considering the research proposal, 3 DCs and 7 CCs are potential candidates that will be used to not only identify the best combination of required facilities but also, as the basis of facility cost calculations. According to the research previous study regarding Dyrket [133], *collecting and storage facilities (CC) has a fixed cost of 6,860 kr per week*, while this figure for *distribution centers (DC) is 49,349 kr per week*. The difference between the fixed costs associated with CCs and DCs is emanated from the quantity of products they operate each week which was explained in section 3.3.2.

It is notable to remind that as a cost reduction policy, the Dyrket company has considered renting facilities instead of purchasing a site corresponds to DC and/or CC. Thus, the calculated fixed costs are proportional to the renting, and yet, include other logistics expenses as well, e.g., insurance, taxes, etc. [136]. In this research, another cost driving factor that is considered to be incorporated into the experiment and modeling, is the *carrying costs* of the facilities pertaining to each unit of product. This figure according to previous research work, and based on an average between various product types, is computed as *6.4 kr per product per month* [133].

3.3.4 Delivery Schedule and Lead Time

According to the public information provided by Dyrket on the website, the customer order and delivery are not immediate subsequent events. In this regard, the lead time between receiving the customer order and delivering or picking up the order is 3 days at minimum for private customers. It is notable to mention, that this figure could increase for 1 or 2 days in a way that delivery scheme follows a schedule that each customer should pay attention to the deadline of submitting order for each individual delivery. Given the fact that deliveries or pick-ups are set for 2 times per week, Figure 14 elaborates this schedule.

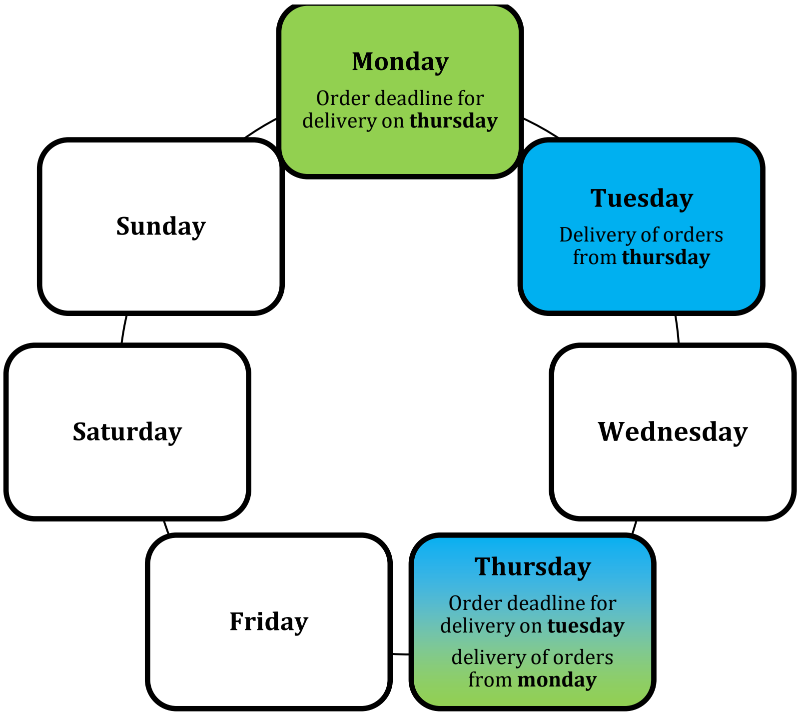


Figure 14. Order and delivery schedule for private customers.

3.3.5 Transportation Cost

The transportation cost could be assessed from two aspects [137]: time-dependent and distance-dependent. The former refers to the scheme by which the transportation cost is a function of the time that the batch of products require in order to be transported from point A to point B. The latter, however, takes the distance between point A and B into account and it is majorly driven by the fuel consumption as well as maintenance expenses. Needless to mention, that the time-dependent cost entails the time that is needed to load and unload the car. Moreover, time-dependent cost has a determining role in the logistics costs because it is a vital factor in calculation of salary, and similar variable expenses. According to the this discussion, the data associated with the transportation cost that will be useful for this research are as represented in Table 9 [133].

Table 9. Transportation costs expected for Dyrket distribution network for Van vehicle.

Cost Factor	Time-Dependent Cost	Distance-Dependent Cost	Average Speed
Van Vehicle	425 kr/hr	3.14 kr/km	60 km/hr

It is assumed that each customer's order entails 10 products on average, which are placed inside a bag for delivery purpose. Transportation of bags is accomplished by crates, and according to the volume of each crate, the transportation van is filled up by 16 crates. Whereas each crate has the capacity of 20 bags, it is equivalent to say that each trip between the facilities within the distribution network comprises 3,200 units of product (10 × 20 × 16).

3.3.6 Miscellaneous Data and Simplifications

Modeling a real-world system, in general, comprises various dynamics and complexities that are difficult to be measured or converted into a pure mathematical or computerized model. The remedy to this challenge is simplifying the uncertain factors and facilitate modelling from various aspects, such as converting stochastic parameters into determined/fixed factors, disregarding factors with least impact on the results, and so forth. To complete the modeling in this study, apart from the collected and refined data, some miscellaneous data and simplifications are taken into account to prevent from unnecessary sophistication for both modeling and analysis phases. The following items summarize the discussed information:

- The network optimization and simulation run for a period of 1 year.
- Due to the renting policy, there is no opening and closure costs associated with the facilities (DCs and CCs) in the experiment.
- There is a wide variety of selling prices for products, ranging from 10 to 90 kr. Whereas in this study the product variety is simplified into one item, so-called "grocery item", the selling price is considered as an average value of 30 kr.
- The penalty cost for unsatisfied demands for network optimization is 12 kr per item.
- Demand values pertaining to each customer segment are fixed and certain during the experiment period (no stochastic modeling).
- The processing costs of inbound and outbound articles are disregarded within the data collection, and thus the experiment phase.

- The transportation vehicle (Van) runs at 80% of the capacity during the network optimization.

3.4 Methodology and Experiment Approach

According to the findings and ultimate discussion represented in Chapter 2, simulation and digital twin are amongst the most discussed Industry 5.0 technologies that significantly contribute to smart logistics. It is earlier discussed that such approach has considerable potentials of intelligence and integration which aligns with general *technical* goals of the fifth industrial revolution. According to the wide span of elements and parameters involved in logistics operations and supply chain design, the application of simulation is remarkably beneficial to conduct more versatile studies. In addition, the advent of Industry 4.0 as a technology-driven industrial revolution facilitated and expedited the development of simulation tools, and research works have been benefiting from such technological leaps ever since. According to the available tools and the scopes of this study, the general goal is to initially perform the optimization of the distribution network associated with the selected case study. Afterwards a simulation experiment is to be conducted in order to highlight the performance indicators of the proposed logistics network. Thus, not only the optimized configuration of the distribution network is obtained but also, the simulation assists in making critical decisions regarding various performance indicators.

3.4.1 Network Optimization

From a holistic viewpoint, the goal of network optimization is to redesign the configuration of the existing logistics network of a company or even propose this network from scratch for a new-born business. Either case, the principals are to minimize the supply chain expenses and fulfil the customer demand at highest possible service level. This objective from one aspect, is highly related to the location and capacity of the facilities, particularly the *distribution centers*, that a company seize to meet the customer demand. Distribution centers (DC) have a high impact on both customer experience and logistics expenses according to the inventory size and required efforts in this regard. Thus, the inventory capacity of this facility potentially has a determining role in designing the logistics network, which is known as *capacitated* network optimization.

In the current research, the network optimization is based on the proposal that was explained in section 3.2.1, and the main goal is to come up with the best possible network configuration while minimizing the distribution network expenses. The underlying idea in this regard, is to reduce the transportation between the suppliers and company within the congested traffic areas and bridge this connection using collecting centers (CC) as the touchpoint of suppliers. To approach this, the initial proposal includes 7 CCs and 3 DCs and the goal of optimization is to select the facilities among the available candidates that lead to the optimal configuration of the distribution network according to the locations and capacities of the facilities. Thus, primarily in this section, the optimization objective will be elaborated which is accompanied by summarizing the required particular data according to the described information in section 3.3. In the following, the final stage of network optimization is explained which is based on two scenarios according to the geographical categorization of CCs.

3.4.1.1 The Objective and Overview of Essential Data

The main objective is:

> ***minimization*** *of the logistics* ***expenses*** which is equivalent as ***maximization*** *of the* ***profit*** while redesigning the distribution network of Dyrket company according to the alternative locations associated with CCs and DCs.

The main drivers in this regard are expenses incurred by **transportation** and **inventory** activities; however, the company aims at high responsiveness and customer experience for which a **penalty cost** is considered for unsatisfied demand. The expected outcome from this stage is thus achieving the optimal configuration for the distribution network with determining the followings (but not limited to):

- Number and locations of DCs and CCs.
- Number of required trips between each pair of location during the optimization time span which is 1 year.
- Total transportation costs between each pair of location with respect to real existing route thanks to GIS feature.
- Total inventory costs during the optimization period including fixed costs and carrying costs.
- Penalty costs pertaining to each customer segment.

There are plenty of practical and useful information that could be extracted from the results of this stage according to the considered approach of this research, which is a compiled optimization and simulation package. The aforementioned items, however, are amongst the most useful and related information according to the scope and objective of this study. Needless to say, that this study benefits from more information than explained above.

Summarizing and Visualizing Essential Data

Although the information required were thoroughly explained in section 3.3, summarizing the input data for network optimization is beneficial and facilitate better understanding of the entire procedure. Therefore, a concise overview of the input data with more visualization is beneficial which includes customer demand, revenue generated by selling each item, penalty costs, expenses of facilities (fixed costs, carrying costs), location and capacity of facilities (for each CC and DC), location and maximum throughput of suppliers, transportation routes and distance calculations, capacity of the transporting vehicle, transportation cost drivers.

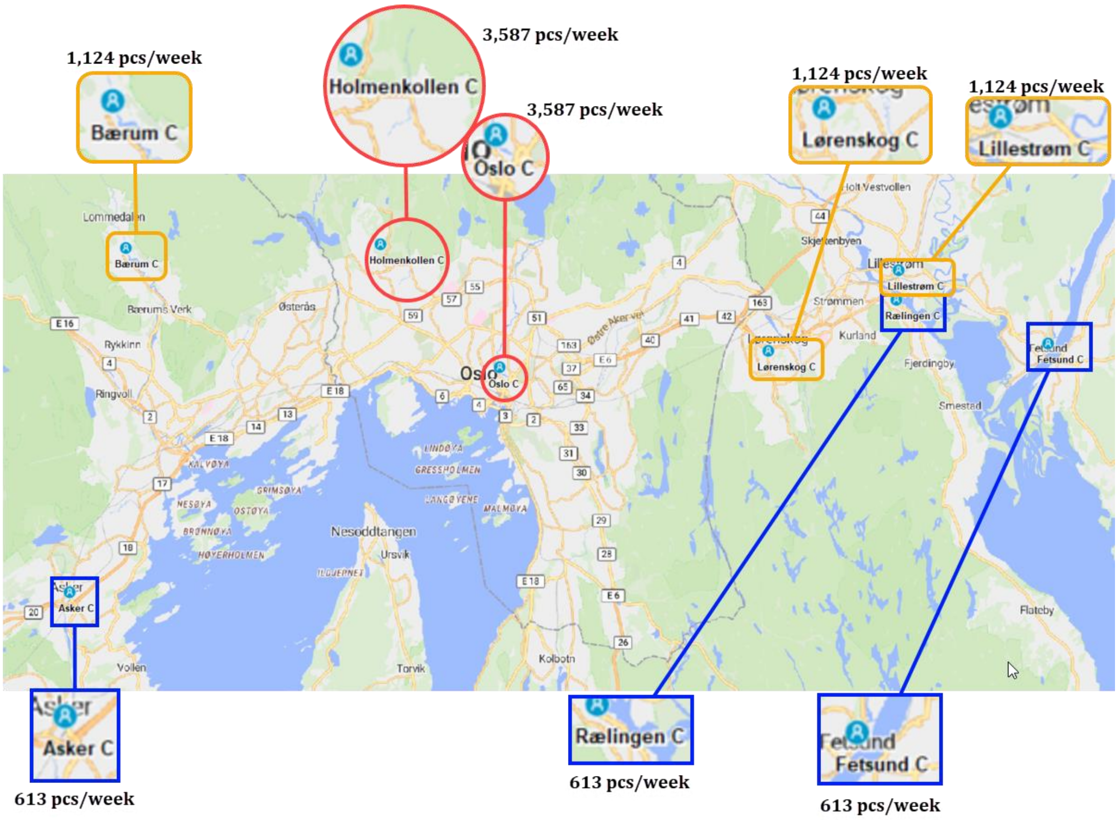


Figure 15. Demonstration of customers locations and their associated demand.

Figure 15, demonstrates the geographical locations of customer segments in which their associated demand is illustrated next to each. According to the colors used to highlight the customer on the map (red, orange, blue), three major categories exist based on the magnitude of their demands that are also depicted in Table 8. It is noteworthy to mention, that the average revenue generated by selling each item is 30 kr and the considered penalty cost for unsatisfied demands is 12 kr per item.

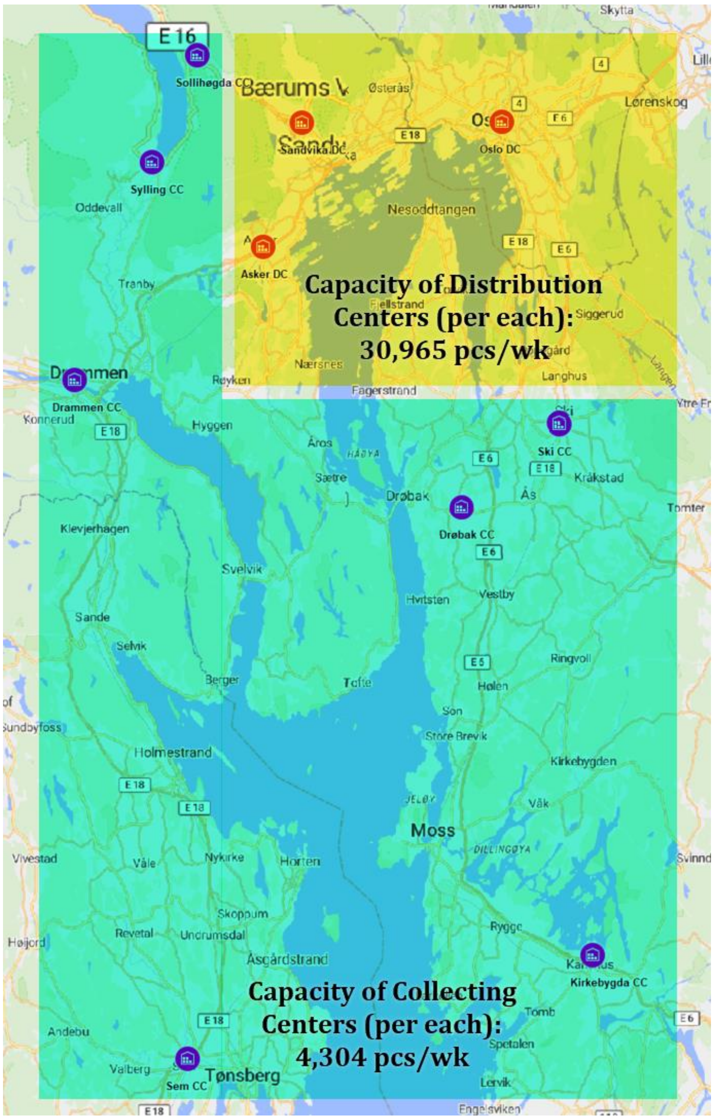


Figure 16. The visualization and categorization of DCs and CCs.

Figure 16 illustrates the locations of 3 DCs and 7 CCs and they are categorized according to the highlighted areas. As also depicted, the capacity of each DC is expected to handle 30,965 items per week, while this figure is 4,304 for each CC. Following the optimization purpose regarding the inventory expenses, the fixed costs of each DC and CC are 49,349 and 6,860 kr per week, respectively. In the same order, the carrying costs of both facilities has the same value and it is calculated as 1.6 kr per item per week.

Figure 17 depicts the location of 20 suppliers exist in the distribution network of Dyrket within the scope of this study. The supplying amount of each supplier is 538 products per week. The important factor in this regard is the maximum throughput of suppliers 1, 2, and 3 (located in Sandefjord and Tønsberg), which is twice the maximum throughput of other suppliers.

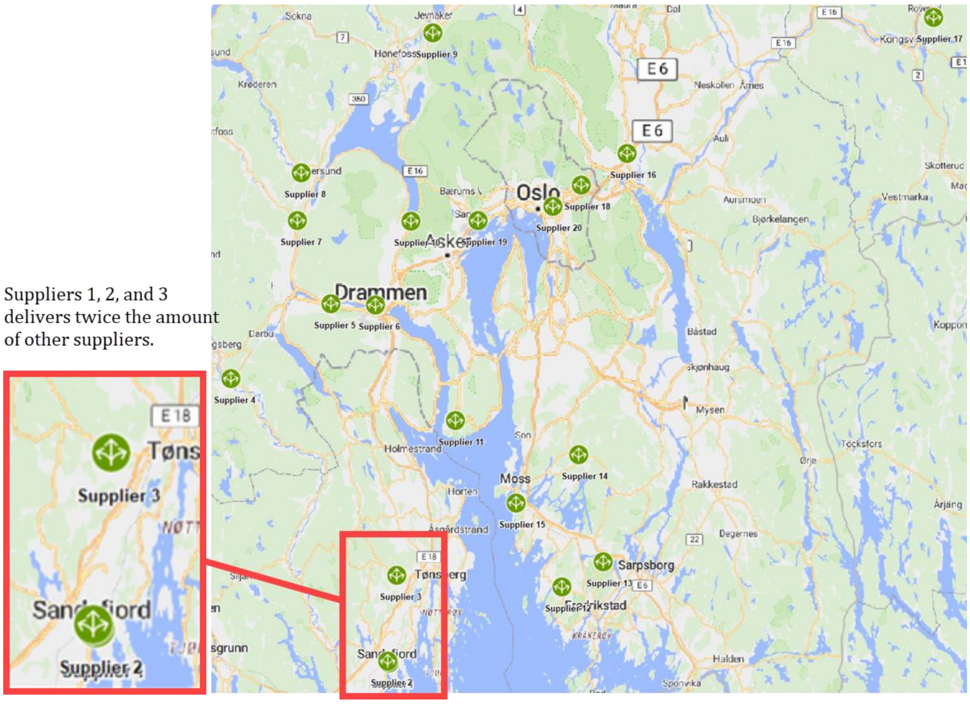


Figure 17. Demonstration of 20 suppliers.

As demonstrated in Figure 18, the optimization procedure benefits from GIS feature, and thus, the distance between each pair of facilities is calculated according to real existing routes.

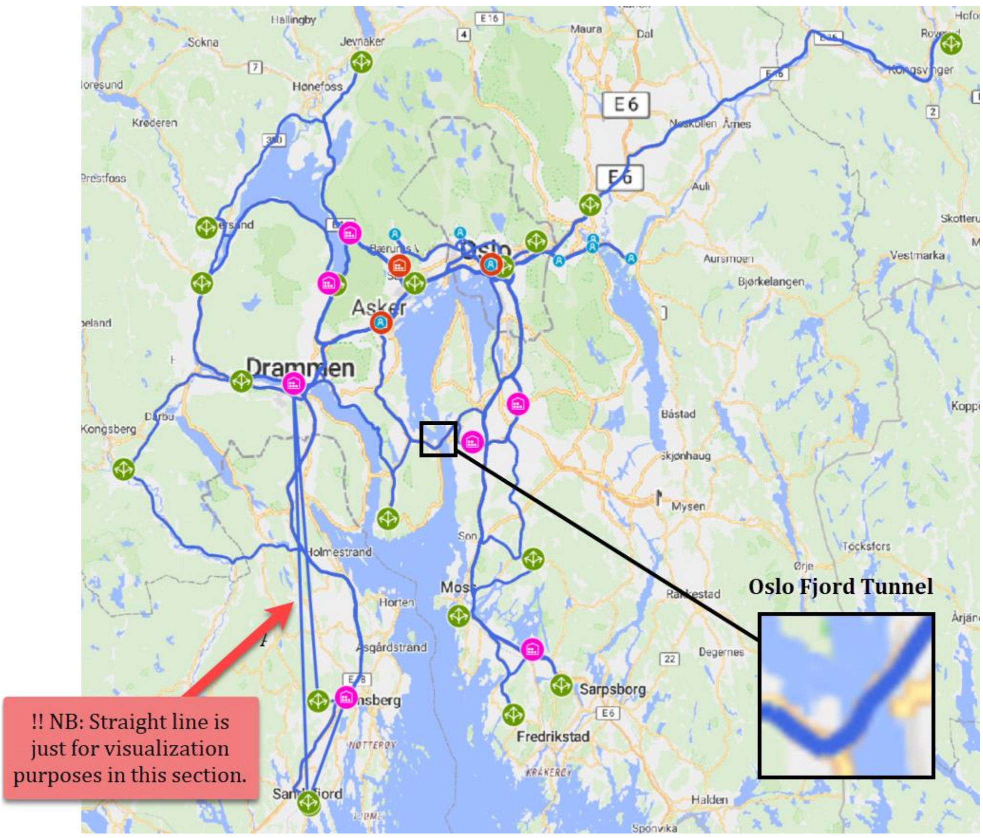


Figure 18. The real routes between supply chain players.

The precision of detecting the possible and available routes is substantial in the utilized tool for this research and as magnified in Figure 18, the "Oslo Fjord Tunnel" is also selected as an alternative to connect west to east which is a 7 km underwater tunnel. It is reminded that the straight lines connecting suppliers 1, 3, and 3 to the CC located in Drammen are not straight in practice, and they are illustrated as straight for *visualization* purposes. In fact, these routes align on other existing routes, and it is meant to separate them. As also explained in section 3.3.5, the transportation vehicle is a 'van' whose capacity is equivalent to an average of 3,200 products. For optimization purposes, the transportation costs appear in two forms as follows:

- 3.14 kr per km (distance dependent)
- 425 kr per hour (time dependent)

3.4.1.2 Optimization Scenarios

The potential CCs considered for Dyrket (see Figure 18) are scattered around the Oslo area in order to address the transportation between Dyrket and suppliers particularly within the Oslo city. This policy not only reduces the transportation through the heavy traffic jam but also, decreases the number of trips required for this purpose in total. The optimization procedure on one hand, seeks to connect a number of CCs to the suppliers by which the overall milage of transportation is minimized. On the other hand, the highest priority during the process is given to the demand satisfaction and there is a possibility that some CCs partially fulfil their inventory using suppliers that are not necessarily cheap in terms of transportation. This shapes the ground to perform the network optimization by categorizing the CCs in order to restrict them with regards to their connection with suppliers. To apply this policy and constraint two scenarios are constructed that are as follows.

Scenario A: Eastern-Western CCs

In this scenario the CCs are simply grouped into two major groups: east CCs and west CCs. In practice, suppliers that are located in the east of Oslo supply items to the east CCs and, in the similar manner, suppliers that are located in the west of Oslo supply items to the west CCs. In this regard, Table 10 and Figure 19 depict the two groups of CCs and their associated suppliers.

Table 10. The CCs and suppliers associated with scenario A.

West	Sup.	1	2	3	4	5	6	7	8	9	10	11	19
	CC	Sollihøgda; Sylling; Drammen; Sem											
East	Sup.	12	13	14	15	16	17	18	20	-	-	-	-
	CC	Ski; Drøbak; Kirkebygda											

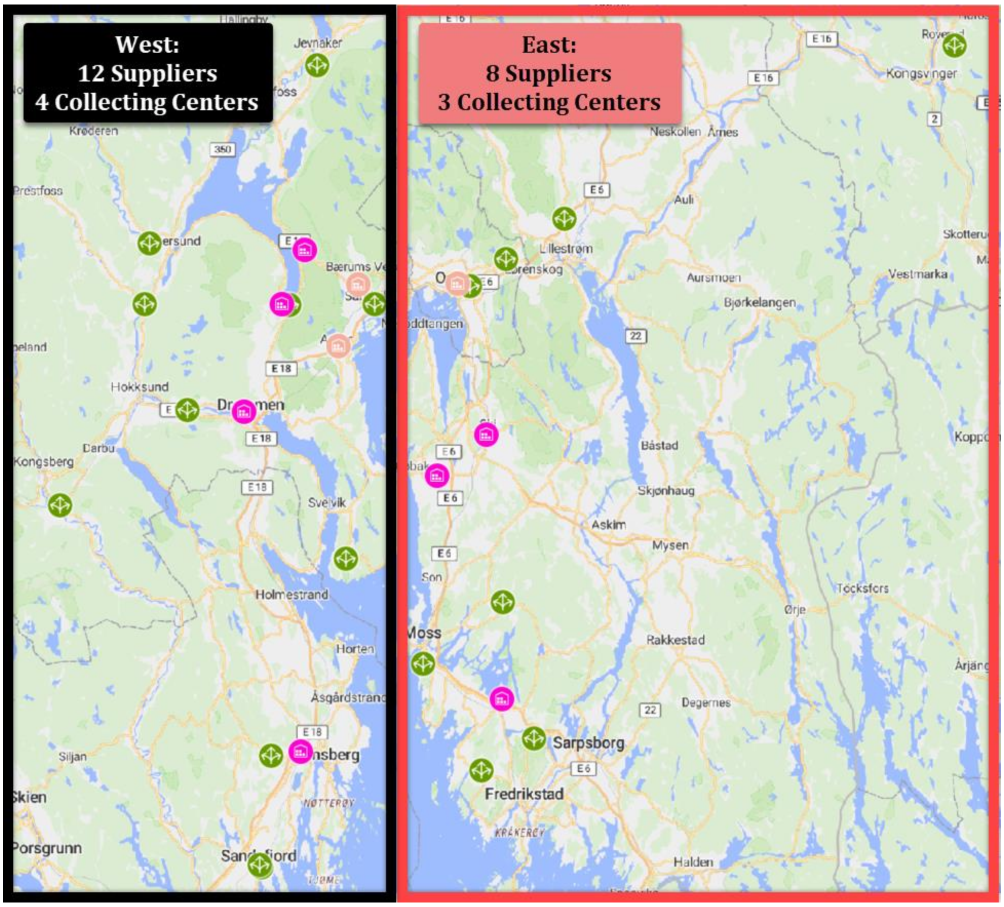


Figure 19. Demonstration of scenario A on map.

Scenario B: Geographical Grouping CCs

In this scenario, the categorization of CCs is conducted with a more focused approach. To that aim, four major groups are considered which are represented in Table 11.

Table 11. The CCs and suppliers associated with scenario B.

West		South-West		South-East		East-West	
Sup.	**CC.**	**Sup.**	**CC.**	**Sup.**	**CC.**	**Sup.**	**CC.**
5	Drammen Sollihøgda Sylling	1	Sem Drammen	12	Drøbak Kirkebygda Ski	16	Sollihøgda Sylling Drøbak Ski
6		2		13		17	
7		3		14		18	
8		4		15		19	
9		-		-		20	
10		-		-		-	
11		-		-		-	

The important factor that needs further attention is the allocation of CCs to the determined groups. In this regard, one particular CC could be allocated to more than one geographical group based on its potential to be served by suppliers of two different regions. For example, Drammen CC is allocated to 'South-West' and 'West' groups because it could potentially be a good alternative for both regions. To magnify this categorization, Figure 20 visualizes the CC groups and elaborates their associated suppliers. For instance, suppliers associated with 'south-west' group are specified with pin including a star sign inside and CCs pertaining to this group are within the red highlight box. The provided legend on Figure 20 explains the rest of groups.

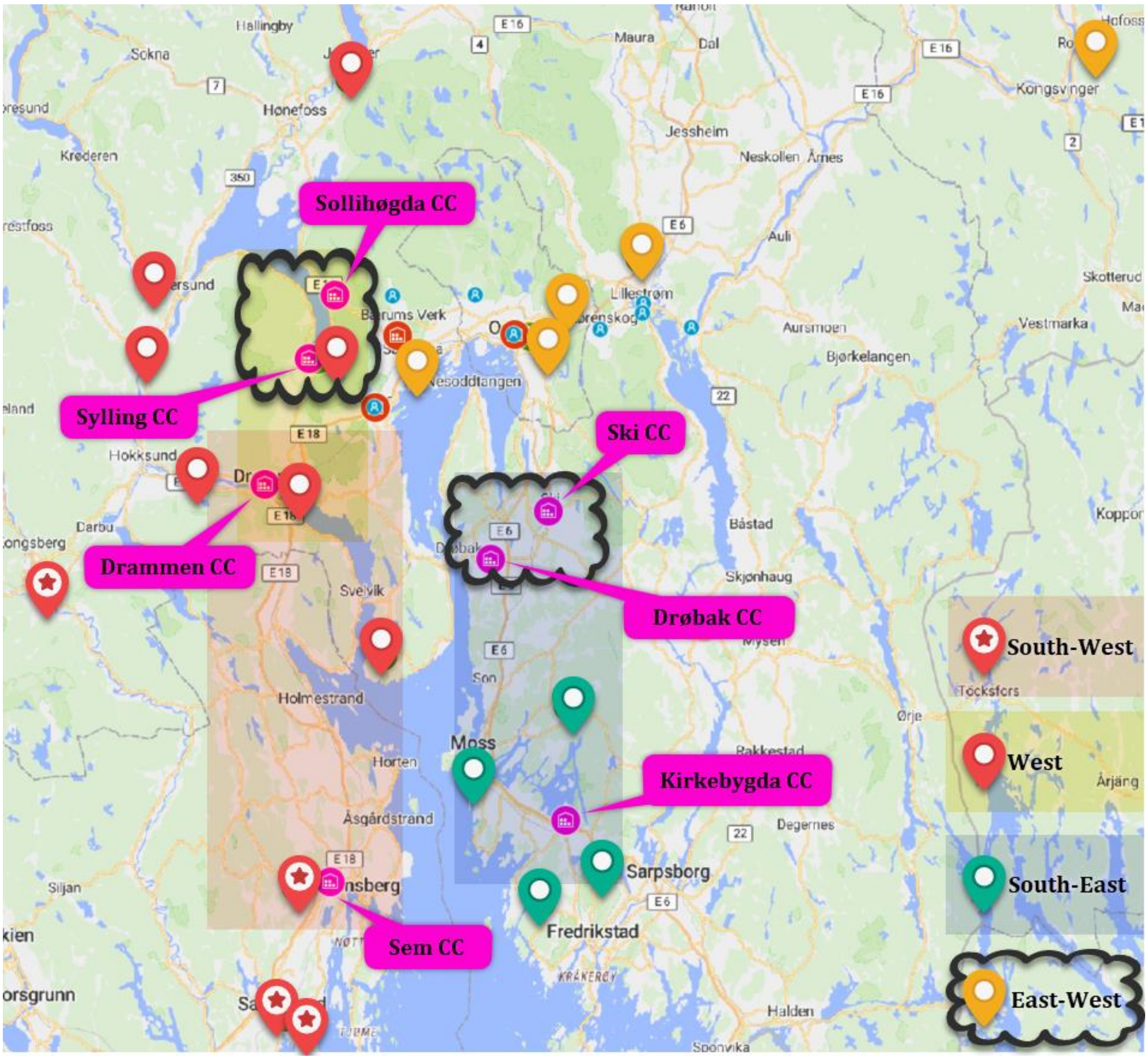


Figure 20. Demonstration of scenario B on map.

3.4.2 Simulation Experiment

The purpose of simulation in this study is to perform various experiments and what-if analyses according to the optimal achieved configuration which helps to make more rigorous inferences. This stage is integrated with network optimization in which the results of optimization are directly utilized for simulation experiments. This phase assists scholars to deal with more dynamic parameters in order to evaluate the performance of the supply chain from numerous indicators and under various conditions. Although there is plethora of indicators to facilitate decision-making process, this study focuses on **inventory** and **transportation** policy. In this regard, the simulation experiment favors to decide on the capacity level of facilities to keep a high service level. In addition, it contributes to identify the optimal transportation policy by which one can determine the vehicle load and strategy for items delivery.

Furthermore, simulation can potentially provide more inclusive results. For instance, the level of *inventory on hand* may potentially differ in network optimization and simulation, due to the fact that it is possible to test the impact of delivery lead time, as well as working and non-working days during the simulation period. For the purpose of this study, it is noteworthy to mention, that the delivery lead time at Dyrket company is 3 days. In addition, delivery to the customers is scheduled for two days per week which are Tuesday and Thursday, while the transportation between supplier and facilities takes place five days per week except for Saturday and Sunday. The company seeks to stay on 90% service level and simulation helps to meet this target by incorporating the aforementioned dynamics.

During the simulation procedure and in order to compare the results of various scenarios and experiments, some practical and beneficial key performance indicators (KPI) are considered. In this regard, total profit, service level, backlog demand, and so forth, are amongst the important KPIs that are utilized in this research.

Chapter 4. Experiments, Results, and Discussion

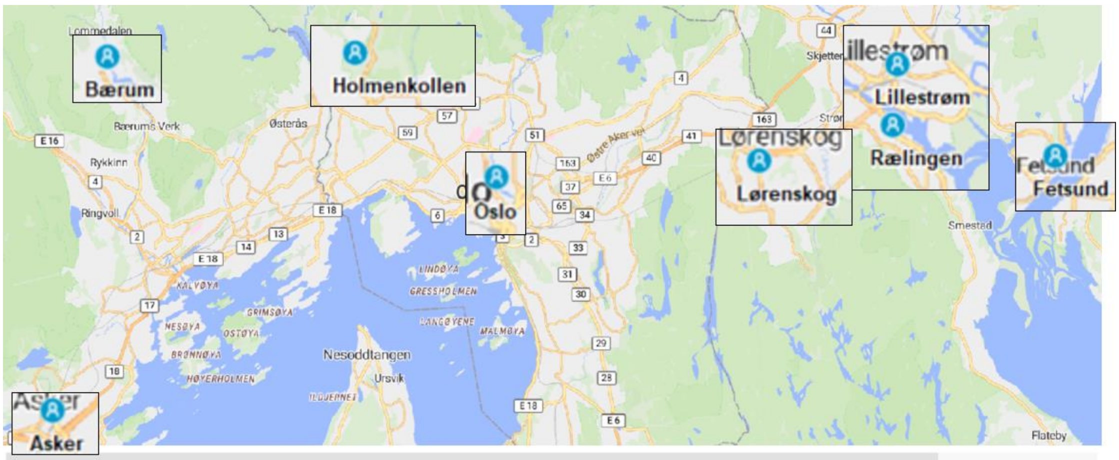
According to the main goal of this study and based on the idea and methodology explained in section 3.4, ***anyLogistix*** software serves as a powerful package to approach the problem. This platform assists in generating a digital twin of the supply chain and perform optimization experiments in a simpler manner compared to the mathematical approaches. In addition, it provides the possibility of performing simulation studies based on the optimization results so as to get more insights by taking the advantage of variety of KPIs. The graphical feature of anyLogistix is another beneficial function that not only illustrates the supply chain on the map in an interactive way but also, it leads to more accurate results given the fact that it considers the geographical coordinates of locations. In this regard, it is possible to accomplish experiments based on the real routes existing between each pair of points instead of straight distance corresponds to the same locations. Thus, the calculations associated with transportation time and expenses are more precise and accurate; however, the user has the possibility to count on straight distances instead of real routes as well.

This chapter initially sheds light on the software and opens up discussion regarding the initial steps of modelling through explaining the differences between considering straight lines or real routes between locations. Furthermore, the discussion continues with conducting the network optimization based on the explained proposal for Dyrket, which is followed by the simulation study in order to complete the entire experimental phase of this research. The chapter is concluded through final discussion and analysis.

4.1 Modeling Environment in anyLogistix

To realize the significance of differences between real route and straight line between any pair of locations in supply chain from a quantitative perspective, a short example based on the case study of this research is provided in this section. In addition, this example initiates the procedures (only the preliminary steps) required to complete the modeling and experimental phases of this research which will be further continued and thoroughly explained in section 4.2 and section 4.3.

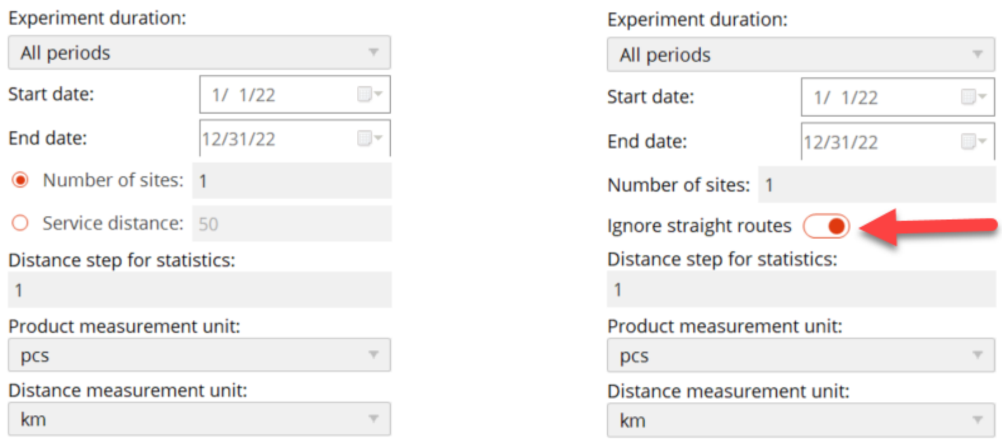
Assume that the objective of Dyrket is to find a potential location for a DC (or two) by which the company is able to minimize the logistics costs (majorly driven by transportation costs) according to the locations of customers. In this regard, anyLogistix facilitates this goal through *green field analysis (GFA)* experiment that functions according to the customers location and demand magnitude. The procedure commences with defining the locations of customer checkpoints which is accomplished utilizing the geographical coordinates of each customer. In this regard, as also explained in section 3.3.2, the latitude and longitude of each customer segment is imported into the software, which are corresponding to the downtown of each customer's region (see Table 27). Afterwards, the customer demand associated with each customer segment is imported into the software based on the collected data which are the weekly demand of each customer segment for one unit of product (see Table 8 or Figure 15 for customer demand). The customer locations and their associated demands which are inserted into the software are represented in Figure 21.



#	Customer	Product	Demand Type	Parameters	Time Period	Inclusion Type
1	Oslo	Grocery Item	Periodic demand	Order interval=7, Quantity=3,587...	(All periods)	Include
2	Holmenkollen	Grocery Item	Periodic demand	Order interval=7, Quantity=3,587...	(All periods)	Include
3	Bærum	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124...	(All periods)	Include
4	Lørenskog	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124...	(All periods)	Include
5	Lillestrøm	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124...	(All periods)	Include
6	Asker	Grocery Item	Periodic demand	Order interval=7, Quantity=613, ...	(All periods)	Include
7	Rælingen	Grocery Item	Periodic demand	Order interval=7, Quantity=613, ...	(All periods)	Include
8	Fetsund	Grocery Item	Periodic demand	Order interval=7, Quantity=613, ...	(All periods)	Include

Figure 21. Customer locations (magnified) and demand, screenshot of anyLogistix.

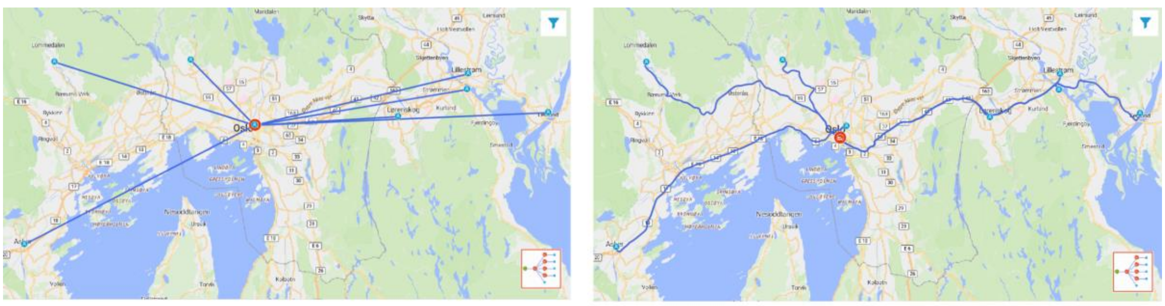
Afterwards it is possible to perform the GFA analysis which seeks to find the location that minimizes the transportation between DC and customers in order to fulfil the demand. It is worthwhile to mention, that the analysis is accomplished with the highest abstraction level and the number of trips is disregarded in this stage. To accomplish this experiment, Figure 22 demonstrates the settings required with respect to both approaches: (a) analysis by straight lines (b) analysis by real routes.



(a) **(b)**

Figure 22. GFA experiment for Dyrket. (a) GFA by straight distances between locations. (b) GFA by real routes between locations.

As observed in Figure 22 (b), the experiment with '<u>straight routes' is ignored</u> by which the software does the whole GFA analysis using real routes. Figure 23 illustrates the results of analysis in both cases demonstrating the connection lines between the customer locations and the potential DC chosen by software. The analysis is performed for a period of one year and attempts to consider one DC. The logical hypothesis is that experiment with real routes results in higher logistics costs due to longer distances between a pair of locations compared to a straight line between the same points.



(a) (b)

Figure 23. Demonstration of GFA analysis on map. (a) GFA using straight distances between locations. (b) GFA using real routes between locations.

The results in this regard verify this initial hypothesis and according to the analysis, the aggregation of distances between DC and individual customer checkpoints is larger in case of experiment with real routes (equivalent to 143 km in comparison with distance with straight lines which is 111 km). Moreover, such distance difference leads to 37% higher logistics cost (8,154,196 kr compared to 5,924,066 kr given 1 kr expense per product unit per km) and it proves that experiment with possibility of considering real routes would potentially results in significantly more precise analysis with respect to the real-word case.

4.2 Network Optimization

The goal of network optimization is finding the optimal configuration of facilities that could best serve the customer demand and minimize the logistics expenses throughout the distribution network. In fact, one may expect to find the answer regarding the best candidates among CCs and DCs throughout the considered network according to their considered capacity and required amount of material flow in the supply chain in order to meet the customer demand.

4.2.1 Creating the Distribution Network

The primary step in generating the model is defining the locations of facilities, including suppliers, CCs, DCs, and customer checkpoints. For this purpose, the experimented model in GFA analysis (section 4.1) will be utilized and the locations of suppliers and other facilities will be added to the model according to their respective latitude and longitude which are found out using Google Maps. In this regard, the locations of suppliers are specified according to their precise locations because they are the existing partners of Dyrket. Regarding DCs and CCs the situation is slightly different. For those facilities, the potential location is the downtown of the region corresponds to each facility. For example, collecting center in the Asker region (Asker CC) is selected based on the coordinates that Google Maps generates once one search “Asker”. The reason of such approach is that Dyrket has no potential particular site according to the proposed solution, and thus the facilities (CCs and DCs) are located according to the coordinates of the downtown associated with their respective region. It is reminded that the current distribution center of Dyrket (Sandvika DC) is specified with its exact coordinates, and it is considered within the experiment as a potential site. As a matter of fact, including this site in the experiment does not contradict with the initial problem which is the traffic jam and long transportation time within the congested area of Oslo. Because transportation between suppliers and Dyrket is considered to be only between the supplier and its corresponding CC, and in addition, another DC is considered within Oslo to serve the customers of that area. The similar strategy is applied for locating the customer checkpoints because there is no particular location for customers other than the downtown of their respective region. As also represented in section 3.3.2, Figure 13 illustrates the locations of suppliers, facilities, and customer checkpoints, for which the complete list of locations is provided in Table 27 (Appendix).

Another additional adjustment before the optimization stage is defining the Norwegian currency (NOK)[1] in the software to facilitate direct calculation of costs and profit in NOK and prevent from unnecessary conversion throughout the analysis. To apply this, the settings of the software menu is selected in which one can add NOK to the default list that contains Euro (EUR) and United Stated Dollar (USD). The important following step is unit conversion by which the exchange rate is required for the software to perform the calculations. In this regard, the exchange rate is derived on 31st March 2022 by which 1 NOK is equivalent to 0.102 EUR. The explained procedure is depicted in Figure 24.

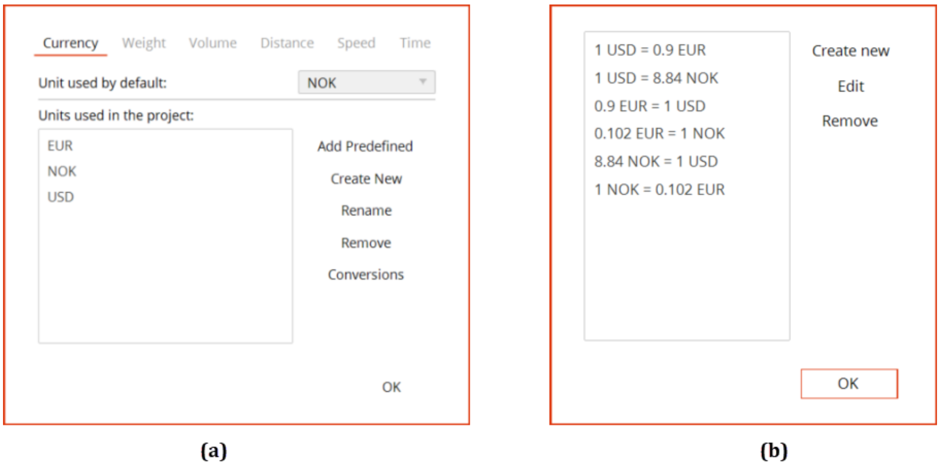


Figure 24. Defining the Norwegian currency (NOK) in anyLogistix. (a) adding NOK to the list. (b) defining the exchange rate compared to EUR/USD.

4.2.2 Defining the Customer Demand

Prior to defining the demand value corresponds to individual customers, it is essential to define the product types that are to be supplied and delivered throughout the supply chain. The software enables users to consider various product types pertaining to range of suppliers and customer; however, this research has simplified the product variety into one product type (mentioned earlier in section 3.3.6 Miscellaneous Data and Simplifications), named '*grocery item*'. The reason of this simplification is primarily the lack of information available from both

[1] NOK is used to represents the Norwegian currency, while 'kr' is used for accounting system.

company and their website, in addition to an extensive variation in food supplies that Dyrket provides, and it could potentially lead to significant level of complexity for modeling. Hence, the material flow throughout the distribution network includes only 'grocery item' which is measured by pieces of product, namely *pcs*. This product generates a revenue for 30 kr and the supply cost is unified into 6.4 kr. Figure 25 demonstrates the explained information that are defined in the software.

Products [1]

#	Name	Unit	Selling Price	Cost	Currency
1	Grocery Item	pcs	30	6.4	NOK

Figure 25. Defining the product type, selling price, and supply cost.

The distribution of customer demand between 8 customers are depicted in Table 8 and Figure 15, in which the numbers represent the weekly demand per unit of product.

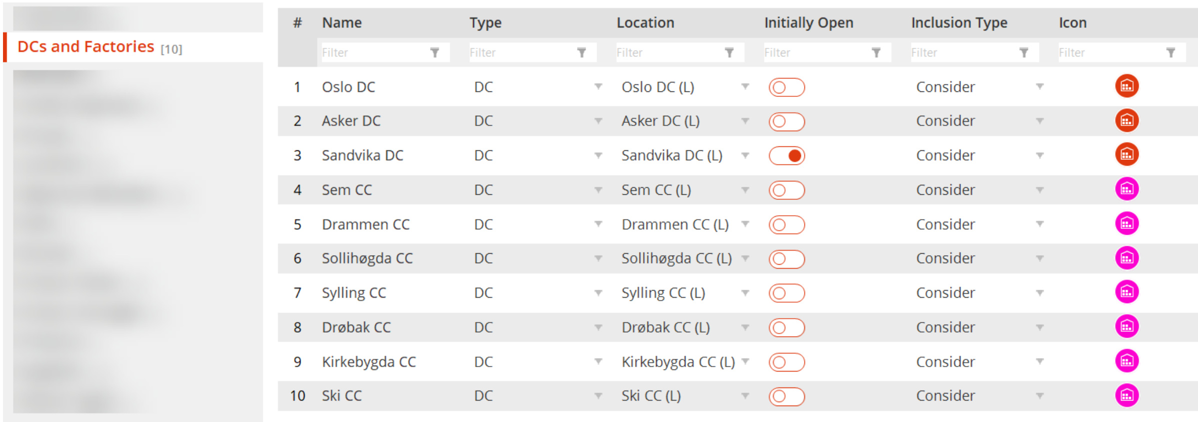
#	Customer	Product	Demand Type	Parameters	Time Period	Revenue	Down Penalty	Currency
1	Asker C	Grocery Item	Periodic demand	Order interval=7, Quantity=613, Fi...	(All periods)	30	12	NOK
2	Oslo C	Grocery Item	Periodic demand	Order interval=7, Quantity=3,587, ...	(All periods)	30	12	NOK
3	Bærum C	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124, ...	(All periods)	30	12	NOK
4	Holmenkollen C	Grocery Item	Periodic demand	Order interval=7, Quantity=3,587, ...	(All periods)	30	12	NOK
5	Fetsund C	Grocery Item	Periodic demand	Order interval=7, Quantity=613, Fi...	(All periods)	30	12	NOK
6	Lillestrøm C	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124, ...	(All periods)	30	12	NOK
7	Rælingen C	Grocery Item	Periodic demand	Order interval=7, Quantity=613, Fi...	(All periods)	30	12	NOK
8	Lørenskog C	Grocery Item	Periodic demand	Order interval=7, Quantity=1,124, ...	(All periods)	30	12	NOK

Figure 26. Defining the customer demand, and penalty cost in optimization model.

Figure 26 represents the list of customers including their respective demand for grocery item. In order to define the demand magnitude with weekly occurrences in the optimization model, 'periodic demand' is selected for *demand type* through which, the order interval is set to 7 days to replicate the weekly occurrence of the demands. Due to the possibility of such approach, the demand values do not need any conversion and are directly use according to the previously outlined numbers. The revenue generated for each item, as also highlighted earlier in this section, is considered 30 kr which is also entered in the demand table as shown in Figure 26. It is noteworthy to mention, that the *revenue generated from satisfying demand* has higher priority compared to the *selling price* of the product (Figure 25), and thus, this value will override the selling price for the calculation purpose. However, in this case, same values are considered for both entries. The highly important factor in this step is the *penalty cost per unsatisfied demand*. For this purpose, the *down penalty* represents the penalty cost that the company is incurred for not satisfying each item for each customer segment. As mentioned earlier, this value is set to 12 kr.

4.2.3 Defining the Facilities and Associated Expenses

Locations of the facilities are already defined throughout previous stage, section 4.2.1 Creating the Distribution Network. However, it is critical to specify the status of each facility in terms of being initially open or closed at the beginning of the optimization period.



DCs and Factories [10]

#	Name	Type	Location	Initially Open	Inclusion Type	Icon
1	Oslo DC	DC	Oslo DC (L)		Consider	
2	Asker DC	DC	Asker DC (L)		Consider	
3	Sandvika DC	DC	Sandvika DC (L)		Consider	
4	Sem CC	DC	Sem CC (L)		Consider	
5	Drammen CC	DC	Drammen CC (L)		Consider	
6	Sollihøgda CC	DC	Sollihøgda CC (L)		Consider	
7	Sylling CC	DC	Sylling CC (L)		Consider	
8	Drøbak CC	DC	Drøbak CC (L)		Consider	
9	Kirkebygda CC	DC	Kirkebygda CC (L)		Consider	
10	Ski CC	DC	Ski CC (L)		Consider	

Figure 27. Specifying the facilities status for optimization.

According to 'initially open' column in Figure 27, the Sandvika DC is the only facility that is initially open for performing the optimization. Another crucial issue in this regard, is specifying the 'inclusion type' of each facility. In this regard, two options available for user: consider, and include. These options in general, are interpreted in the way that the facility with 'consider' status is an *alternative* for optimization and could be decided to be either opened or closed throughout the optimization. It is reminded that for 'include' option, the corresponding facility must be initially open.

Another debate in connection with facilities in the scope of this research is specifying the type of collecting centers (CCs) within the distribution network. On one hand, a supply chain in general includes suppliers, factories, distribution centers, and customers/retailers. On the other hand, Dyrket is majorly a logistic company, and its supply chain contains no factory. Thus, one may conclude that CCs could be defined as 'factory' for optimization model. However, such approach may lead to *misleading results* during the optimization process in terms of inventory and production costs. Hence, collecting centers are defined as DC (see column 'type' in Figure 27) and it is more consistent to their function for Dyrket because they are majorly an intermediary storage bridging suppliers to the DCs.

The expenses corresponding to CCs and DCs have a significant contribution to the network optimization, and particularly, *inventory costs*. Two cost drivers are considered in this study, including fixed costs, and carrying costs. The corresponding value of those two parameters defined for the optimization model are represented in Figure 28.

Facility Expenses [4]

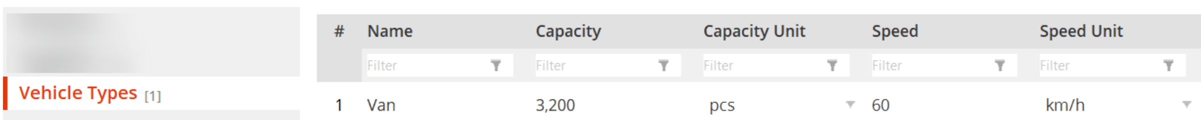
#	Facility	Expense Type	Value	Currency	Time Unit	Product Unit	Time Period
1	[DCs]	Other costs	49,349	NOK	week		(All periods)
2	[CCs]	Other costs	6,860	NOK	week		(All periods)
3	[DCs]	Carrying cost	1.6	NOK	week	pcs	(All periods)
4	[CCs]	Carrying cost	1.6	NOK	week	pcs	(All periods)

Figure 28. Facility expenses defined for optimization.

The initial issue that needs attention is grouping the facilities for ease of representation and prevent from redundancy of either entering and deriving the data throughout the optimization (and even simulation) procedure. As observed in Figure 28, the alternative distribution centers are grouped into DCs, and in the similar way, collecting centers are grouped into CCs. Based on earlier discussion, the value of fixed costs of individual DC is 49,349 kr/wk, and this figure is 6,860 kr/wk for every single CC. Carrying costs for both facilities maintain the same value, and it is 1.6 per item in each week.

4.2.4 Vehicle Properties and Transportation Costs

Transportation is another major driver of the network optimization. This element in practice, and within the scope of this study associated with the optimization model development, is initially influenced by the mean of transportation. Based on previous discussions, the vehicle for transportation is 'Van' with the capacity of loading 3,200 product items in each trip. In addition, the average speed of the vehicle is 60 km/h. These parameters are directly used to complete the 'vehicle types' for optimization model and represented in Figure 29.



Vehicle Types [1]

#	Name	Capacity	Capacity Unit	Speed	Speed Unit
1	Van	3,200	pcs	60	km/h

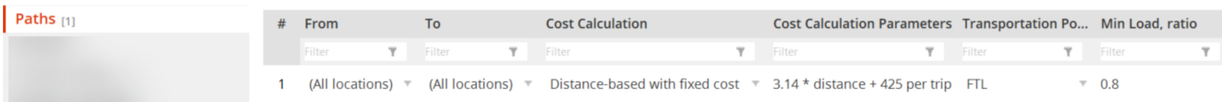
Figure 29. Defining the vehicle type and required properties.

Determining the vehicle properties ought to be followed by calculations regarding the transportation expenses. In this regard, the software provides variety of options, for instance fixed delivery by which each time the delivery is accomplished a fixed price is invoiced. Amongst the available options, there is no possibility to combine distance-dependent and time-dependent expenses which are in the scope of this study. To address this issue the 'distance-based with fixed cost' option is selected as the calculation method (see Figure 30), which equation is as follows:

$$Transportation\ Costs = \alpha\ \times distance + \beta \qquad \text{Eq. 4.1}$$

Note:
α: transportation costs per km (kr/km)
β: fixed costs per trip (kr)

As also represented in Eq. 4.1, this option calculates the transportation expenses based on the distance between each pair of location and an additional fixed cost for each trip. The first part of this equations is consistent with distance-dependent costs, and thus the coefficient of *distance* *(α)* is considered 3.14. Alternatively, to model the time-dependent transportation costs, a trial optimization is performed, and the results show that the average transportation time between each pair of locations is approximately 1 hour. Thus, it is equivalent to say that the cost of 1 hour transportation (425 kr/hr) could be used for the second part of the Eq. 4.1, which is β.


Paths [1]

#	From	To	Cost Calculation	Cost Calculation Parameters	Transportation Po...	Min Load, ratio
1	(All locations)	(All locations)	Distance-based with fixed cost	3.14 * distance + 425 per trip	FTL	0.8

Figure 30. Defining transportation expenses for optimization.

The final substantial issue within the context of transportation is the vehicle maximum or minimum load for accomplishing the transportation. The software provides a variety of options for this purpose. One alternative for such transportation policy is 'full truck load (FTL)' in which the vehicle does not complete the transportation until it is loaded at a specified level. In this case, the transportation policy, as shown in Figure 30, is set to FTL which is adjusted for 80% of the van capacity.

4.2.5 Product Flows

The network optimization is highly dependent on the flow of material in the context of feasible routes for a product to pass through, and thus, it is a substantial factor to define a precise and transparent connection between the supply chain players, i.e., suppliers, CCs, DCs, and customers. In a more precise word, the possible connections for transporting the product between every pair of players must be clearly defined throughout the whole supply chain. This implies **clarifying the path that a particular product needs to go through from supplier to customer with highlighting the feasible routes between suppliers to facilities, and facilities**

to customers. In the scope of this research, the connection between facilities to customers is demonstrated in Figure 31.

Product Flows [22]

#	Label	Source	Destination	Vehicle Types	Product	Product Unit
1	CC to DC	[CCs]	[DCs]	Van	Grocery Item	pcs
2	DC to Customer	[DCs]	[Customers]	Van	Grocery Item	pcs

Figure 31. Product flow between CCs to DCs and DCs to customers.

This setting, known as *product flow*, means that each product unit can be transported through any possible route or channel exists between CCs to DCs as well as between DCs and customers. In other words, the network optimization is not restricted for opting a route between these locations, and any CC can supply the product to any DC, and in the similar manner, any DC can deliver products to the customers. However, the routes between suppliers and CCs vary in the optimization scenarios which is in fact the underlying difference between scenario A and scenario B. According to the discussions given in section 3.4.1.2, in each scenario the CCs are categorized into distinct geographical groups and each group is connected to a particular number of unique suppliers.

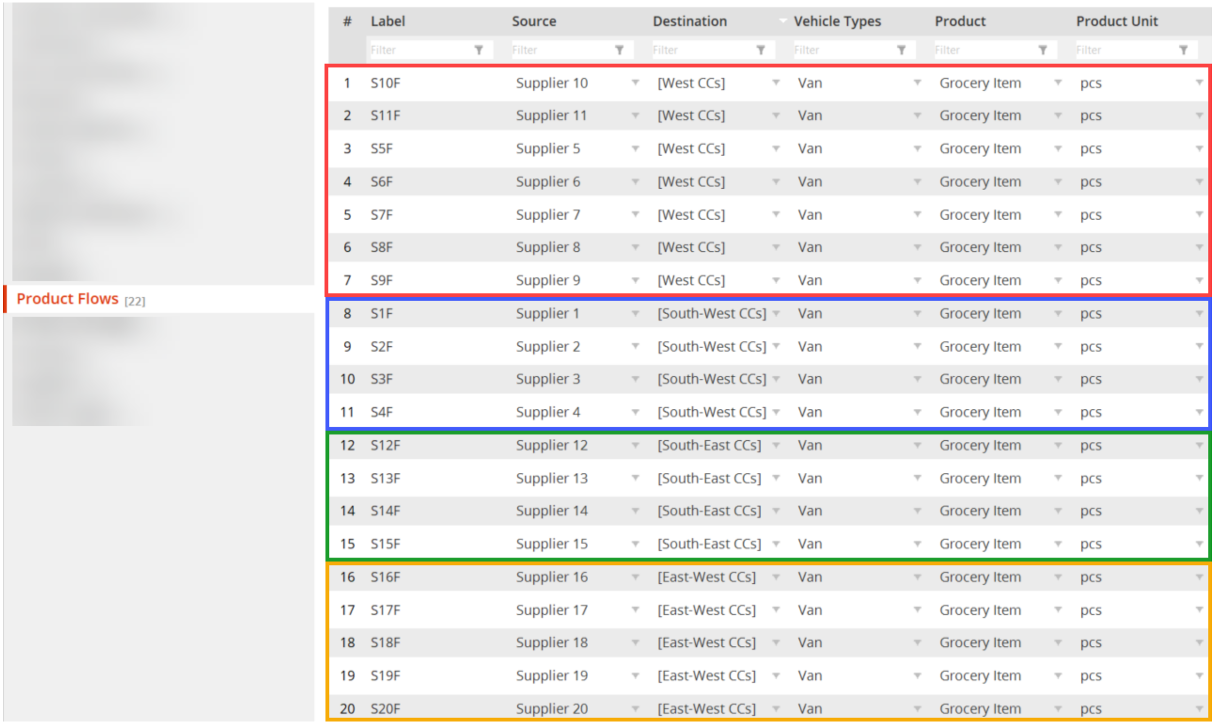
Product Flows [22]

#	Label	Source	Destination	Vehicle Types	Product	Product Unit
1	S1F	Supplier 1	[West CCs]	Van	Grocery Item	pcs
2	S10F	Supplier 10	[West CCs]	Van	Grocery Item	pcs
3	S11F	Supplier 11	[West CCs]	Van	Grocery Item	pcs
4	S19F	Supplier 19	[West CCs]	Van	Grocery Item	pcs
5	S2F	Supplier 2	[West CCs]	Van	Grocery Item	pcs
6	S3F	Supplier 3	[West CCs]	Van	Grocery Item	pcs
7	S4F	Supplier 4	[West CCs]	Van	Grocery Item	pcs
8	S5F	Supplier 5	[West CCs]	Van	Grocery Item	pcs
9	S6F	Supplier 6	[West CCs]	Van	Grocery Item	pcs
10	S7F	Supplier 7	[West CCs]	Van	Grocery Item	pcs
11	S8F	Supplier 8	[West CCs]	Van	Grocery Item	pcs
12	S9F	Supplier 9	[West CCs]	Van	Grocery Item	pcs
13	S12F	Supplier 12	[East CCs]	Van	Grocery Item	pcs
14	S13F	Supplier 13	[East CCs]	Van	Grocery Item	pcs
15	S14F	Supplier 14	[East CCs]	Van	Grocery Item	pcs
16	S15F	Supplier 15	[East CCs]	Van	Grocery Item	pcs
17	S16F	Supplier 16	[East CCs]	Van	Grocery Item	pcs
18	S17F	Supplier 17	[East CCs]	Van	Grocery Item	pcs
19	S18F	Supplier 18	[East CCs]	Van	Grocery Item	pcs
20	S20F	Supplier 20	[East CCs]	Van	Grocery Item	pcs

Figure 32. Product flows between suppliers and CCs in scenario A.

The product flows for *scenario A* (see Figure 32) are generated and developed according to the information represented in Table 10. As depicted, two groups of CCs exist, and each group is supplied by particular number of suppliers. This implies that every individual supplier pertaining to each category of CCs, can supply product to any of the CCs that exist in that particular group. The similar policy is applied for *scenario B*, and according to Table 11 four categories are considered for CCs, which is depicted in Figure 33.

In the context of this study, it is highly crucial to define the product flow between suppliers to the groups of CCs separately because these individual flows are to be further utilized in order to define custom constraints which will be explained in section 4.2.6.



#	Label	Source	Destination	Vehicle Types	Product	Product Unit
1	S10F	Supplier 10	[West CCs]	Van	Grocery Item	pcs
2	S11F	Supplier 11	[West CCs]	Van	Grocery Item	pcs
3	S5F	Supplier 5	[West CCs]	Van	Grocery Item	pcs
4	S6F	Supplier 6	[West CCs]	Van	Grocery Item	pcs
5	S7F	Supplier 7	[West CCs]	Van	Grocery Item	pcs
6	S8F	Supplier 8	[West CCs]	Van	Grocery Item	pcs
7	S9F	Supplier 9	[West CCs]	Van	Grocery Item	pcs
8	S1F	Supplier 1	[South-West CCs]	Van	Grocery Item	pcs
9	S2F	Supplier 2	[South-West CCs]	Van	Grocery Item	pcs
10	S3F	Supplier 3	[South-West CCs]	Van	Grocery Item	pcs
11	S4F	Supplier 4	[South-West CCs]	Van	Grocery Item	pcs
12	S12F	Supplier 12	[South-East CCs]	Van	Grocery Item	pcs
13	S13F	Supplier 13	[South-East CCs]	Van	Grocery Item	pcs
14	S14F	Supplier 14	[South-East CCs]	Van	Grocery Item	pcs
15	S15F	Supplier 15	[South-East CCs]	Van	Grocery Item	pcs
16	S16F	Supplier 16	[East-West CCs]	Van	Grocery Item	pcs
17	S17F	Supplier 17	[East-West CCs]	Van	Grocery Item	pcs
18	S18F	Supplier 18	[East-West CCs]	Van	Grocery Item	pcs
19	S19F	Supplier 19	[East-West CCs]	Van	Grocery Item	pcs
20	S20F	Supplier 20	[East-West CCs]	Van	Grocery Item	pcs

Figure 33. Product flows between suppliers and CCs in scenario B.

4.2.6 Capacity Constraints

The network optimization in this study is <u>*capacitated problem*</u>, and thus, the inventory level of each facility and the produced amount of each supplier are under constraints (associated data is provided in section 3.4.1.1). In this regard, the capacity of each facility and the maximum throughput of each supplier is converted from weekly basis to annual basis, which is the optimization time horizon. In this regard, the capacity of DCs and CCs are 1,614,603 pcs/yr and 224,475 pcs/yr, respectively. Moreover, the maximum throughput of each supplier is 28,105 pcs/yr. However, as outlined in section 3.3.2, supplier 1, supplier 2, and supplier 3 produce twice the amount that other suppliers produce, and thus, the maximum throughput of these suppliers are 56,210 pcs/yr.

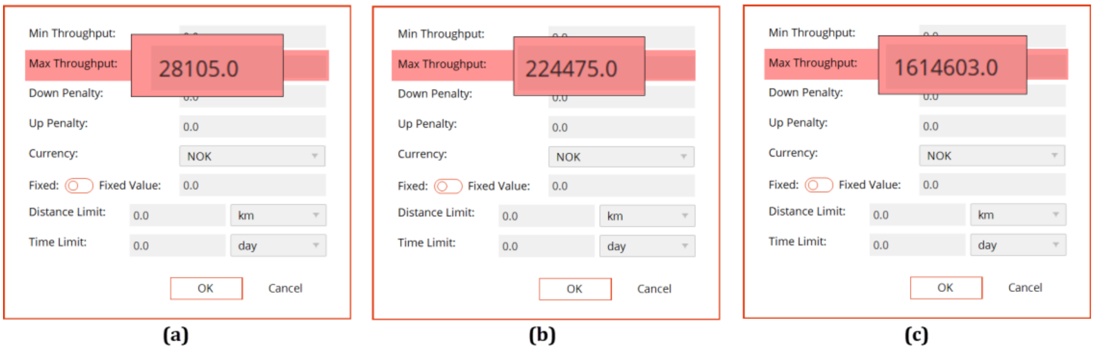


Figure 34. Capacity constraints: (a) maximum throughput of suppliers (supplier 4 to supplier 20) (b) maximum capacity of CCs (c) maximum capacity of DCs.

In order to apply the capacity constraints, the 'product flows' settings will be used, and as demonstrated in Figure 34, the capacity of constraints are specified individually. Note that penalty costs are entered for unsatisfied demand earlier in section 4.2.2.

4.2.7 Model Verification and Custom Constraints

The digital model of Dyrket's proposed distribution network is almost completed and prepared to perform the optimization experiment. For this purpose, the digital model is generated, and the required data and constraints are imported and considered which are explained so far in section 4.2. In this step, a trial optimization is run according to an arbitrary scenario (in this case scenario B is selected) in order to verify the distribution network policies and product flows. The result of optimization is illustrated in Figure 35.

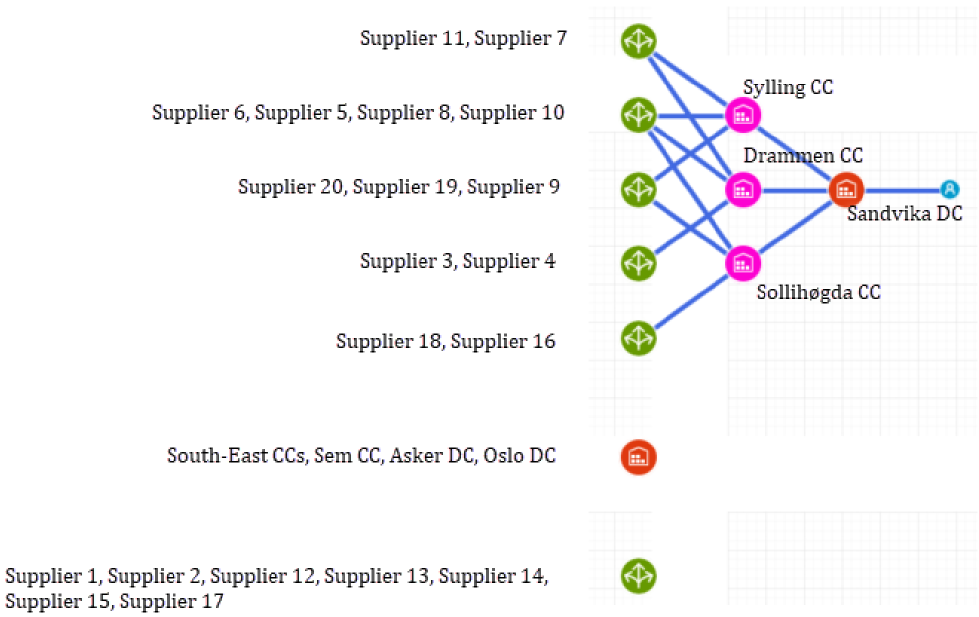
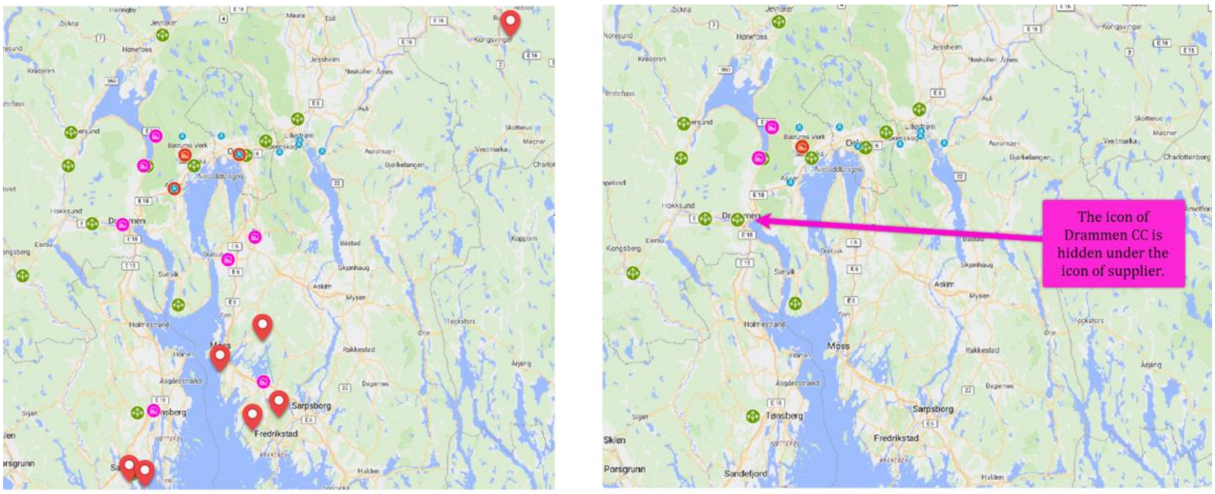


Figure 35. Trial optimization for model verification based on scenario B.

Regardless of the statistical results, the optimization shows that although the connection between suppliers and CCs are in accordance with the defined policies (in this scenario the connections are to comply with Table 11), 7 suppliers are not included in the optimal configuration which contradicts the expectations from this procedure. In fact, Dyrket has no intendency to ignore any suppliers within the distribution network.

4.2.7.1 Custom Constraint for Multi-Sourcing Supply Chain

It is essential to understand the logic of optimization in order to resolve this issue. On one hand, the optimization seeks to maximize the profit or minimize the logistics costs while satisfying the customer demand (including penalty costs in this study). Thus, it opts the suppliers and facilities that facilitate this objective. On the other hand, the supply chain in this study includes only one product type which is produced by all suppliers; in other words, suppliers are supplying the same product. As a result, receiving grocery item from suppliers that leads to higher expenses is disregarded by optimization because the same product can be produced by another supplier. A comparison between the initial distribution network and optimization results highlights this concept. In this regard, Figure 36 (a) shows the eliminated suppliers with red pinpoint icon, and it explicitly demonstrates that suppliers which are the furthest locations and lead to the higher transportation expenses are disregarded.



(a) (b)

Figure 36. Visualization of initial design and trial optimization: (a) the initial design of distribution network highlighting the eliminated suppliers (b) trial optimization of scenario B.

Therefore, it is crucial to tackle this problem and include every single supplier in the optimal configuration of the distribution network in both scenarios. For this purpose, a constraint is required that act as a hard constraint by which the optimization does not ignore any supplier throughout the process. In practice, this is equivalent to say that every single *product flow* from suppliers to CCs (explained in section 4.2.5 Product Flows) must be considered and satisfied throughout the optimization process. This means that optimization must include the flow of product from all suppliers, however, subject to the maximum throughout defined in section 4.2.6 Capacity Constraints. From a mathematical perspective, this requirement is satisfied by specifying the proportion that each supplier produces relative to the total supplied amount in the distribution network. Thus, the optimization process attempts to satisfy that constraint, and this leads to including all suppliers in the optimal configuration. In this regard, and according to the fact that the production amount of supplier 1, supplier 2, and supplier 3 is twice the other suppliers, Figure 37 illustrates the proportion of each supplier on the scale of 1.

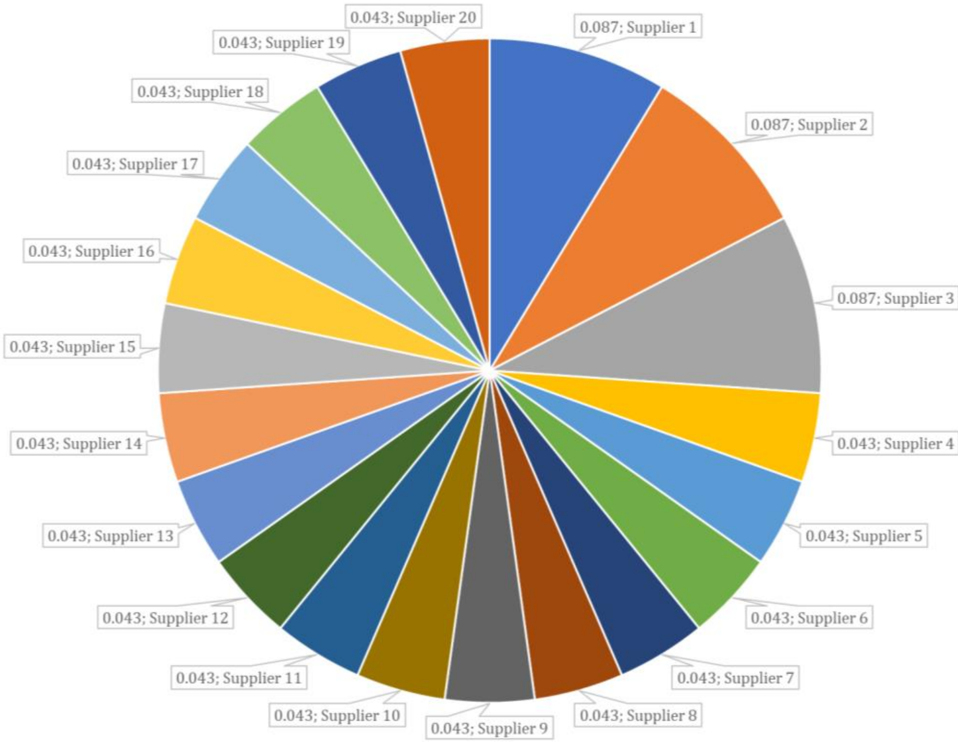


Figure 37. The proportion of supply amount of each supplier throughout the supply chain.

In this regard, the product flow pertaining to each supplier is subjected to the following equation:

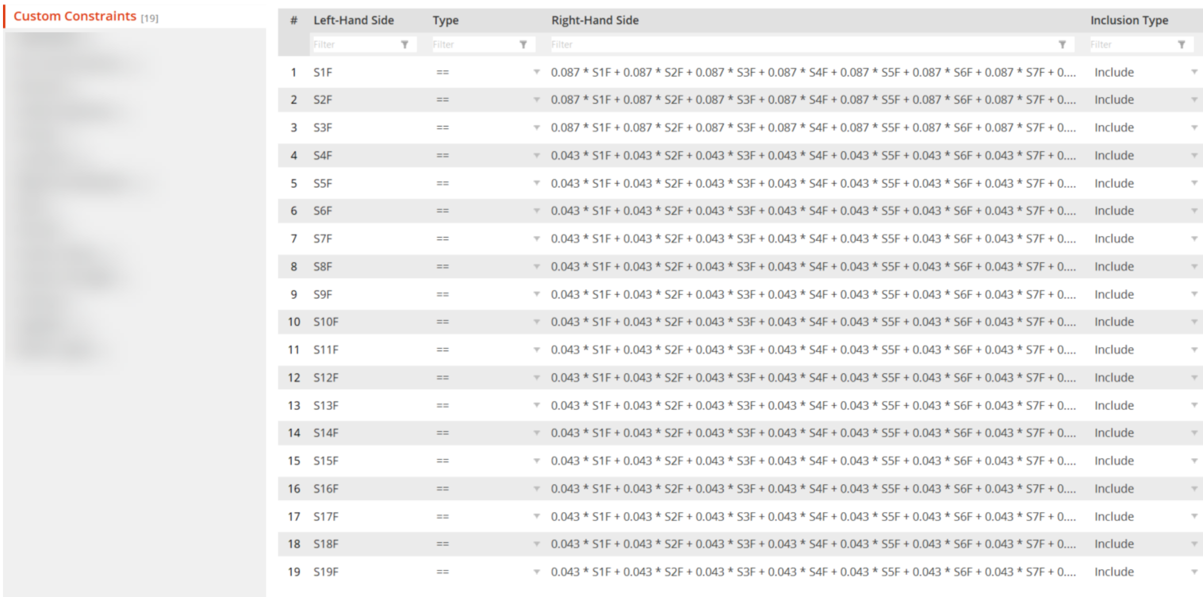
$$Supply\ Flow\ Proportion\ of\ Supplier\ x\text{:}\ SxF = \alpha \times \sum_{n=1}^{20} SnF \quad : \{x | x \epsilon \mathbb{N}, (1,19)\} \qquad \text{Eq. 4.2}$$

Note:
α: the coefficient/proportion of supply amount of supplier x
SnF: the supply amount from supplier n

For instance, according to Eq. 4.2 and based on the illustrated supply proportions of suppliers in Figure 37, the constraint for product flow from supplier 1 will be as follows:

$$S1F = 0.087 \times \sum_{n=1}^{20} SnF = (0.087 \times S1F) + (0.087 \times S2F) + \cdots + (0.087 \times S20F)$$

This constraint must be repeated for every single supplier except for supplier 20. The reason lies on the fact that the sum of all coefficients might not be exactly 1 (for example it could be 1.00001) and this could be troublesome for the software. To apply this constraint, 'custom constraints' menu is utilized by which the software enables user to incorporate any desired and parametric constraint. This constraint must be included in both scenarios, and the complete list of these constraints is depicted in Figure 38.



Custom Constraints [19]

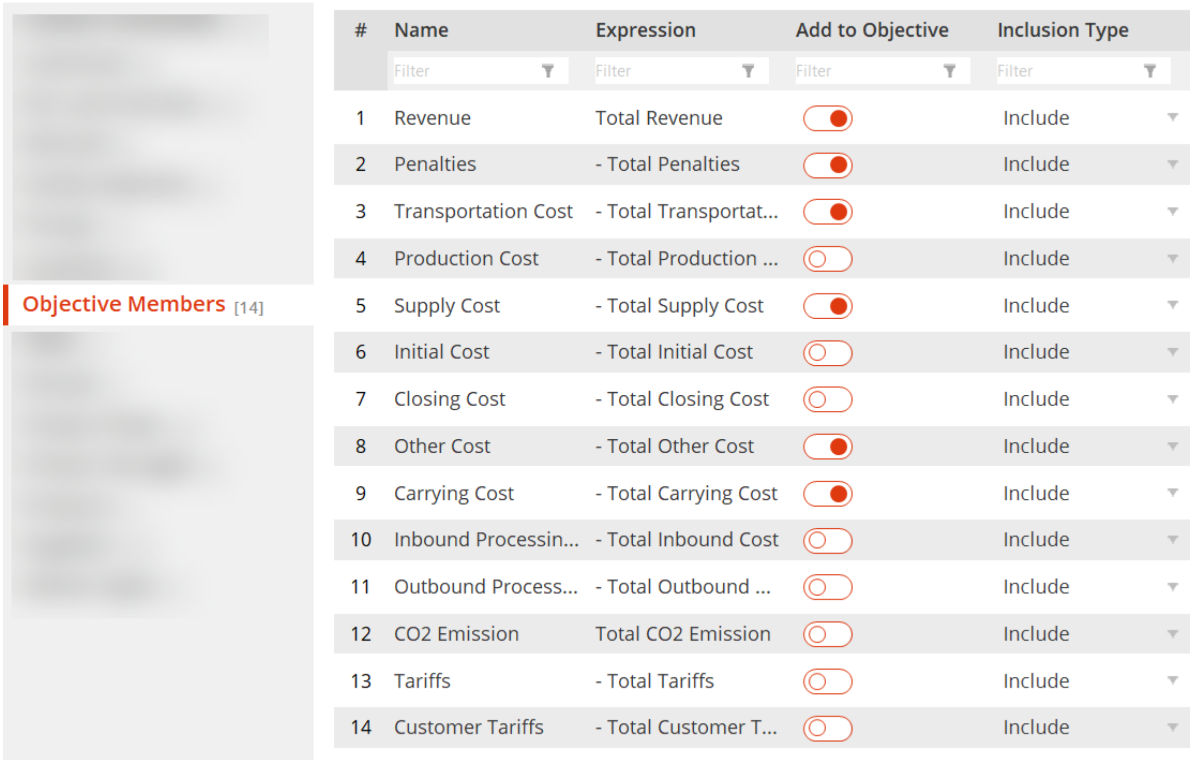
#	Left-Hand Side	Type	Right-Hand Side	Inclusion Type
1	S1F	==	0.087 * S1F + 0.087 * S2F + 0.087 * S3F + 0.087 * S4F + 0.087 * S5F + 0.087 * S6F + 0.087 * S7F + 0....	Include
2	S2F	==	0.087 * S1F + 0.087 * S2F + 0.087 * S3F + 0.087 * S4F + 0.087 * S5F + 0.087 * S6F + 0.087 * S7F + 0....	Include
3	S3F	==	0.087 * S1F + 0.087 * S2F + 0.087 * S3F + 0.087 * S4F + 0.087 * S5F + 0.087 * S6F + 0.087 * S7F + 0....	Include
4	S4F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
5	S5F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
6	S6F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
7	S7F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
8	S8F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
9	S9F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
10	S10F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
11	S11F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
12	S12F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
13	S13F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
14	S14F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
15	S15F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
16	S16F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
17	S17F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
18	S18F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include
19	S19F	==	0.043 * S1F + 0.043 * S2F + 0.043 * S3F + 0.043 * S4F + 0.043 * S5F + 0.043 * S6F + 0.043 * S7F + 0....	Include

Figure 38. Custom constraints regarding multi-sourcing supply chain.

4.2.8 Preparing the Optimization Experiment

The necessary steps required for network optimization associated with this research, i.e., generating the model, importing data, defining required constraints, model verifications, were discussed so far, throughout section 4.2.1 to section 4.2.7. This section focuses on running the optimization for both scenarios and comparing the results in order to find out the optimal configuration for Dyrket distribution network.

The one last necessary step prior to accomplishing the optimization, is determining the required parameters to be measured during the process. In other words, the results of the optimization are measured and represented in form of particular parameters that are to be specified prior to running the optimization, i.e., transportation costs, inventory costs, total profit, etc. For this special purpose, 14 parameters are available within the 'objective members' in the software, by which one can decide on desired parameters and metrics. It is noteworthy to mention that main *objective function* is **maximization of profit**. As represented in Figure 39, the objective function is driven by 6 metrics: revenue generated by selling the product to the customer, penalty costs for unsatisfied demands, transportation costs, supply cost, other costs which is equivalent to the facility fixed costs, and facility carrying costs.


Objective Members [14]

#	Name	Expression	Add to Objective	Inclusion Type
1	Revenue	Total Revenue	On	Include
2	Penalties	- Total Penalties	On	Include
3	Transportation Cost	- Total Transportat...	On	Include
4	Production Cost	- Total Production ...	Off	Include
5	Supply Cost	- Total Supply Cost	On	Include
6	Initial Cost	- Total Initial Cost	Off	Include
7	Closing Cost	- Total Closing Cost	Off	Include
8	Other Cost	- Total Other Cost	On	Include
9	Carrying Cost	- Total Carrying Cost	On	Include
10	Inbound Processin...	- Total Inbound Cost	Off	Include
11	Outbound Process...	- Total Outbound ...	Off	Include
12	CO2 Emission	Total CO2 Emission	Off	Include
13	Tariffs	- Total Tariffs	Off	Include
14	Customer Tariffs	- Total Customer T...	Off	Include

Figure 39. Desired metrics to be measured throughout the optimization: Objective Members.

After finalization of objective members, the optimization process could commence after minor adjustments. These settings are demonstrated in Figure 40, which encompass five general steps (but not limited to) before running the optimization process:

1. Checking the imported and modified data in terms of conflicts. In case of any problem, the software notifies user and does not start the optimization.
2. Show the experiment duration which is defined previously at the beginning of creating the NO scenario.
3. Ignoring straight routes is important to perform the optimization using real routes.

4. Determine whether the optimization impose any variations on the customer demand. The variation is either 100%-105% or 95-100%. For the sake of consistency in comparing both scenarios, this option is set to 'exact demand'.
5. User may decide whether the optimization provides best feasible answers or the optimal answer. In this study, the optimal answer is desired and for which 'the number of best solutions to find:' is set to 1.

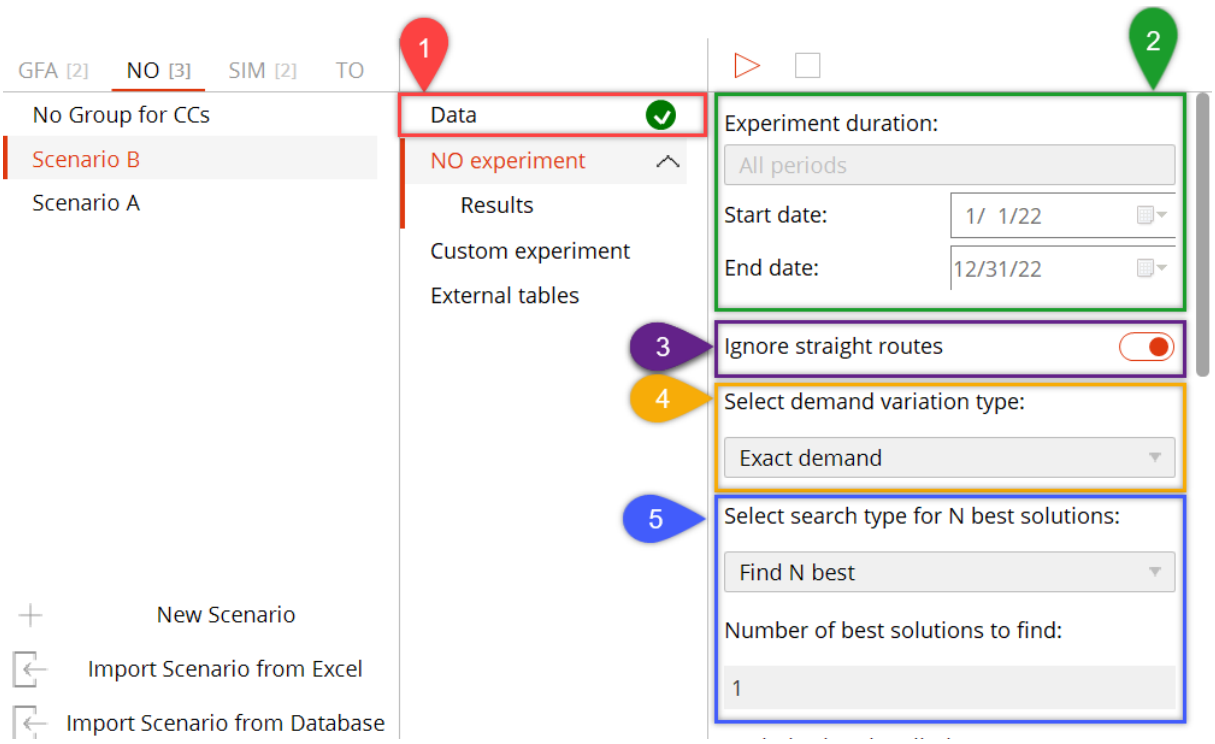


Figure 40. Adjustment of settings for network optimization.

4.2.9 Analysis of Network Optimization Results

In this section the optimization results of both scenarios are compared to one another in order to select the better solution and utilize it further for simulation experiment. This analysis is performed according to various criteria including total profit, transportation costs, and so forth.

4.2.9.1 The Optimized Distribution Network

The initial impression from the results is the optimized distribution network pertaining to each scenario. This implies the answers to the following questions:

1. Which facilities are selected among the candidates for CCs and DCs?
2. Which suppliers deliver product to the selected CCs?
3. If there are more than one DCs, how is the customer demand distributed between them?

The optimal distribution network of both scenarios is depicted in Figure 41.

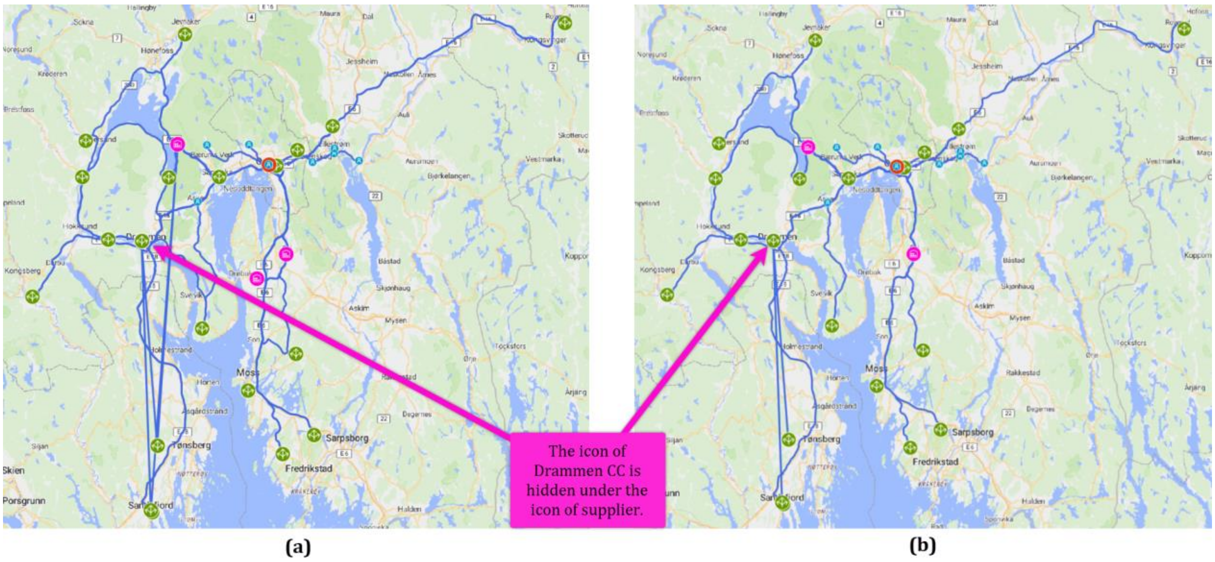


Figure 41. The optimal distribution network for Dyrket. (a) scenario A (b) scenario B.

The results show that Oslo DC is selected as the only distribution center in both scenarios. In scenario A this facility is fed by 4 CCs, including Drøbak CC and Ski CC in east, and Drammen CC along with Sollihøgda CC in west. On the other hand, scenario B has resulted in 3 CCs, i.e., Drammen CC, Sollihøgda CC, Ski CC. The distribution network of the better scenario will be further elaborated in section 4.2.10 (including the answer of question number 2 discussed above).

4.2.9.2 Demand Fulfillment

One of the primary objectives of any supply chain is demand satisfaction. In this regard, the performance of each scenario with respect this criterion is highlighted in Table 12.

Table 12. Comparison between scenario A and scenario B in optimization with respect to demand fulfillment.

Customer	Demand	Satisfied		Service Level %		Generated Revenue		Penalty	
		A	B	A	B	A	B	A	B
Asker C	32,489	32,489	32,000	100	98	974,670	960,000	0	5,868
Fetsund C	32,489	32,489	32,000	100	98	974,670	960,000	0	5,868
Rælingen C	32,489	32,489	32,000	100	98	974,670	960,000	0	5,868
Bærum C	59,572	59,572	57,600	100	97	1,787,160	1,728,000	0	23,664
Lørenskog C	59,572	59,572	57,600	100	97	1,787,160	1,728,000	0	23,664
Lillestrøm C	59,572	59,572	57,600	100	97	1,787,160	1,728,000	0	23,664
Oslo C	190,111	190,111	188,800	100	99	5,703,330	5,664,000	0	15,732
Holmenkollen C	190,111	190,111	188,800	100	99	5,703,330	5,664,000	0	15,732

The statistical results provided in Table 12, implies that scenario A has a better performance in fulfilling the customer demand. In this regard, the results show that all of the customer demands are satisfied in scenario A (100% service level) while this is not true for scenario B, in which a minor portion of customer demands are not fulfilled (98% service level). On the other hand, scenario A imposes no penalty costs on the company while unsatisfied demands in scenario B have caused penalty costs. In general, scenario A has a better performance in satisfying the customer demands, however, it is noteworthy to mention, that such responsiveness level is expensive for a company which requires significant efforts and investment for inventory activities.

4.2.9.3 Facilities Status and Expenses

The optimized configuration explained in section 4.2.9.1 showed that scenario A has resulted in 4 CCs while scenario B opted 3 CCs. While the results of scenario A leads to higher responsiveness (100% service level), it compromises supply chain efficiency and expenses. As depicted in Figure 42, the initiated facilities in scenario A incur higher expenses on Dyrket. Hence, from statistical perspective scenario B has a better performance with regards to facility expenses.

Site	Status	Other Cost, per period	Total Cost
...(5)	Open	Sum: 4,003,997.857	Sum: 4,003,997.857
Oslo DC	Open	2,573,197.857	2,573,197.857
Drammen CC	Open	357,700	357,700
Sollihøgda CC	Open	357,700	357,700
Drøbak CC	Open	357,700	357,700
Ski CC	Open	357,700	357,700

(a)

Site	Status	Other Cost, per period	Total Cost
...(4)	Open	Sum: 3,646,297.857	Sum: 3,646,297.857
Oslo DC	Open	2,573,197.857	2,573,197.857
Drammen CC	Open	357,700	357,700
Sollihøgda CC	Open	357,700	357,700
Ski CC	Open	357,700	357,700

(b)

Figure 42. Facility status and expenses after optimization. (a) scenario A. (b) scenario B.

It is crucial to notice that the facility costs in this optimization experiment, and particularly in this case study, is majorly driven by *fixed costs* (shown as *other cost* in Figure 42). The reason of this outcome is that suppliers and facilities have adequate capacity to satisfy the customer demands instantly which therefore results in low-to-zero expenses for inventory on hand particularly within the optimization. However, this is not true within the simulation study. In fact, with simulation study one can evaluate the results of various delivery schedules and lead times by which the inventory level at facilities increases. In fact, this is the privilege of simulation in this study that leads to more rigorous results as discussed earlier.

4.2.9.4 Transportation and Vehicle Flow

Transportation is one of the main drivers of the network optimization and inevitably the core element of this research objective. Referring to the proposal of redesigning the Dyrket ‘s distribution network, highlights that the aim is to reduce the transportation in Oslo area which is mainly satisfied in both scenarios. This is due to the fact that, instead of transportation between 20 suppliers and one distribution center which requires struggling in the congested traffics, only 3-4 transportation routes are considered in the optimized logistics networks. In this context, it is of significance to outline some particular metrics associated with both scenarios and evaluate their performances with regards to the transportation and its associated expenses.

Table 13. Transportation indices regarding the network optimization

Scenario \ Index	Transportation Cost	Distance Aggregation	Number of Trips	Number of Single Trips
Scenario A	-242,634	2450.76	624	18
Scenario B	-235,853	1406.35	612	3

Table 13 represents the important transportation indices associated with each scenario. The initial impression from this table is the total transportation costs, and according to this index scenario B has a better performance (3% lower expenses). In addition, the aggregation of distances between every single pair of location throughout the supply chain is significantly higher in scenario A. Reminded that this metric is calculated regardless of the traveled distance by the vehicle throughout the optimization period, and this is only based on the distance between locations according to real existing routes. This characteristic is potentially important for socio-economic issues and in this regard scenario A would have significantly lower performance. This could be realized in fuel consumption, CO_2 emission, etc. Moreover, this leads to higher *depreciation costs* regarding the vehicles which are the company’s assets.

Another concept that is substantially worth discussing is the *number of single trips*. This metric depicts the transportations that have taken place only once between particular pair of locations throughout the period. A comparison between scenarios in this regard, show that although the total number of trips throughout the whole distribution network (with a minimum load of 80% of the van capacity) is slightly higher in scenario A, this scenario has remarkably high number of single trips (accounted for 18 as opposed to 3 for scenario B). This issue is highly important, and it requires individual elaboration for each scenario which are provided below.

Evaluation of Single Trips in Scenario A

The number of single trips associated with scenario A as depicted in Table 13 is considerably high, accounted for 18. This figure requires more elaboration to evaluate the implications and consequences of such issue. For this purpose, the information provided in table 'vehicle flows' are initially filtered by '*vehicle trips*' and '*destination'* (see Figure 43 (a)). According to the statistics, transportation between some of the suppliers and three CCs, i.e., Drammen CC, Drøbak CC, Sollihøgda CC, constitutes of the single trips discussed.

Vehicle Flows

Vehicle Trips 〉 Destination 〉

	Iteration	Period	Source	Destination	Vehicle Type	Vehicle Trips
1	◢ Sum: 18	1 Year	...(18)	...(18)	Van	Sum: 18
2	◢ Sum: 6	1 Year	...(6)	Drammen CC	Van	Sum: 6
3	1	1 Year	Supplier 19	Drammen CC	Van	1
4	1	1 Year	Supplier 10	Drammen CC	Van	1
5	1	1 Year	Supplier 7	Drammen CC	Van	1
6	1	1 Year	Supplier 11	Drammen CC	Van	1
7	1	1 Year	Supplier 8	Drammen CC	Van	1
8	1	1 Year	Supplier 9	Drammen CC	Van	1
9	◢ Sum: 8	1 Year	...(8)	Drøbak CC	Van	Sum: 8
10	1	1 Year	Supplier 17	Drøbak CC	Van	1
11	1	1 Year	Supplier 16	Drøbak CC	Van	1
12	1	1 Year	Supplier 15	Drøbak CC	Van	1
13	1	1 Year	Supplier 18	Drøbak CC	Van	1
14	1	1 Year	Supplier 13	Drøbak CC	Van	1
15	1	1 Year	Supplier 12	Drøbak CC	Van	1
16	1	1 Year	Supplier 14	Drøbak CC	Van	1
17	1	1 Year	Supplier 20	Drøbak CC	Van	1
18	◢ Sum: 4	1 Year	...(4)	Sollihøgda CC	Van	Sum: 4
19	1	1 Year	Supplier 5	Sollihøgda CC	Van	1
20	1	1 Year	Supplier 4	Sollihøgda CC	Van	1
21	1	1 Year	Supplier 1	Sollihøgda CC	Van	1
22	1	1 Year	Supplier 6	Sollihøgda CC	Van	1

(a)

Vehicle Flows

Destination 〉

	Iteration	Period	Source	Destination	Vehicle Type	Vehicle Trips
5	◢ Sum: 12	1 Year	...(12)	Drammen CC	Van	Sum: 71
6	1	1 Year	Supplier 19	Drammen CC	Van	1
7	1	1 Year	Supplier 10	Drammen CC	Van	1
8	1	1 Year	Supplier 7	Drammen CC	Van	1
9	1	1 Year	Supplier 5	Drammen CC	Van	8
10	1	1 Year	Supplier 4	Drammen CC	Van	8
11	1	1 Year	Supplier 11	Drammen CC	Van	1
12	1	1 Year	Supplier 8	Drammen CC	Van	1
13	1	1 Year	Supplier 1	Drammen CC	Van	17
14	1	1 Year	Supplier 3	Drammen CC	Van	16
15	1	1 Year	Supplier 9	Drammen CC	Van	1
16	1	1 Year	Supplier 2	Drammen CC	Van	8
17	1	1 Year	Supplier 6	Drammen CC	Van	8
18	◢ Sum: 8	1 Year	...(8)	Drøbak CC	Van	Sum: 8
19	1	1 Year	Supplier 17	Drøbak CC	Van	1
20	1	1 Year	Supplier 16	Drøbak CC	Van	1
21	1	1 Year	Supplier 15	Drøbak CC	Van	1
22	1	1 Year	Supplier 18	Drøbak CC	Van	1
23	1	1 Year	Supplier 13	Drøbak CC	Van	1
24	1	1 Year	Supplier 12	Drøbak CC	Van	1
25	1	1 Year	Supplier 14	Drøbak CC	Van	1
26	1	1 Year	Supplier 20	Drøbak CC	Van	1
27	[illegible]	1 Year	[illegible]	[illegible]	Van	[illegible]
52	1	1 Year	Supplier 20	[illegible]	Van	9
53	◢ Sum: 12	1 Year	...(12)	Sollihøgda CC	Van	Sum: 64
54	1	1 Year	Supplier 19	Sollihøgda CC	Van	8
55	1	1 Year	Supplier 10	Sollihøgda CC	Van	8
56	1	1 Year	Supplier 7	Sollihøgda CC	Van	8
57	1	1 Year	Supplier 5	Sollihøgda CC	Van	1
58	1	1 Year	Supplier 4	Sollihøgda CC	Van	1
59	1	1 Year	Supplier 11	Sollihøgda CC	Van	8
60	1	1 Year	Supplier 8	Sollihøgda CC	Van	8
61	1	1 Year	Supplier 1	Sollihøgda CC	Van	1
62	1	1 Year	Supplier 3	Sollihøgda CC	Van	2
63	1	1 Year	Supplier 9	Sollihøgda CC	Van	8
64	1	1 Year	Supplier 2	Sollihøgda CC	Van	10
65	1	1 Year	Supplier 6	Sollihøgda CC	Van	1

(b)

Figure 43. Product flows and trips in scenario A, filtered by: (a) destination single trips (b) destination.

However, it is not sufficient to draw inferences based on the sole basis of single trips index, and thus, the vehicle flows are only filtered by 'destination'. As observed in Figure 43 (b), transportation between suppliers to Drammen CC and Sollihøgda CC have taken places numerous times, accounted for 71 and 64, respectively. On the other hand, the filtered information show that Drøbak CC has been only supplied 8 times during the optimization period which is exactly the same number as previous. This implies that Drøbak CC is completely supplied by single trips, and to some extent it is potentially an economic threat to the company because it has minor role in satisfying the customer demands while it imposes facility expenses to the supply chain. In addition, this is not a socio-economic approach because single trips to this facility are potentially unnecessary and leads to higher CO2 emissions.

Evaluation of Single Trips in Scenario B

Single trips in scenario B as represented in Table 13 is accounted for 3 which is basically not a high number. These single trips are elaborated as depicted Figure 44, and it shows that Drammen CC and Sollihøgda CC are the only facilities that have experience single-trip supply.

Vehicle Flows

Vehicle Trips > Destination >

	Iteration	Period	Source	Destination	Vehicle Type	Vehicle Trips
1	◢ Sum: 3	1 Year	...(3)	...(3)	Van	Sum: 3
2	◢ Sum: 2	1 Year	...(2)	Drammen CC	Van	Sum: 2
3	1	1 Year	Supplier 7	Drammen CC	Van	1
4	1	1 Year	Supplier 6	Drammen CC	Van	1
5	◢ Sum: 1	1 Year	Supplier 16	Sollihøgda CC	Van	Sum: 1
6	1	1 Year	Supplier 16	Sollihøgda CC	Van	1

Figure 44. Product flows and trips in scenario B filtered by single trips and destinations.

Further insights in this regard show that the total number of trips required to serve Drammen CC and Sollihøgda CC are 72 and 67, respectively, and this fact signifies single trips in scenario B are not socio-economic issues. As a result, and according to the concepts discussed with respect to transportation and vehicle flows, scenario B has a better performance from economic, environment, and societal perspectives.

4.2.10 The Overall Analysis and Ultimate Conclusion

According to the objective members described in section 4.2.8, the overall performance of the optimized distribution network of each scenario are provided in Table 14. As outlined in section 4.2.9.4, scenario B has lower transportation costs which is one of the primary goals in this study. Moreover, given the fact that scenario A comprises 4 CCs it incurs higher fixed costs on the company, and it was thoroughly explained in section 4.2.9.3. In addition, as also outlined in section 4.2.9.2, Table 14 shows that scenario B is subjected to penalty costs while this figure is zero in scenario A. Ultimately, the objective function, which is the total profit of the supply chain, shows that scenario B has slightly a better performance in comparison to scenario A, even though that scenario A has generated larger revenue.

Table 14. Overall stats of network optimization associated with both scenarios.

Index \ Scenario	Scenario A	Scenario B
Transportation Cost	- 242,634	- 235,853
Fixed Cost	- 4,003,997	- 3,646,297
Carrying Cost	0	0
Supply Cost	- 4,200,992	- 4,136,960
Penalty	0	- 120,060
Revenue	19,962,150	19,392,000
Objective/Profit	11,244,525	11,252,828

The performance of the optimized network pertaining to both scenarios were thoroughly discussed and analyzed in section 4.2.9 Analysis of Network Optimization Results. In this regard, major criteria were considered as the basis of comparison between scenarios A and scenario B, i.e., demand fulfillment, transportation, facility expenses, etc. The implications from those comparisons could be assessed from economic, environmental, and societal aspects. In this context, the financial performance of each scenario, provided in Table 14, depict that scenario B is a more profitable strategy, and as also discussed in section 4.2.9.4 it is a more sustainable approach. In this regard, it was also discussed that Drøbak CC could impose economic risks on the supply chain according to its minor role in satisfying the customer demand. In addition, supplying products to this facility in the scope of scenario A increases the environmental indices, e.g., CO_2 emissions. As a result, scenario B is selected as the better approach for Dyrket company in order to redesign the logistics network accordingly.

Hence, scenario B will be utilized further to conduct simulation studies in the next section. As previously stated, this approach has considered Oslo DC as the only distribution center, which is supplied by three collecting centers, namely Drammen CC, Sollihøgda CC, and Ski CC. In order to response question number 2 in section 4.2.9.1, Figure 45 illustrates the configuration of distribution network associated with scenario B, and it demonstrates "Which suppliers deliver product to the selected CCs?".

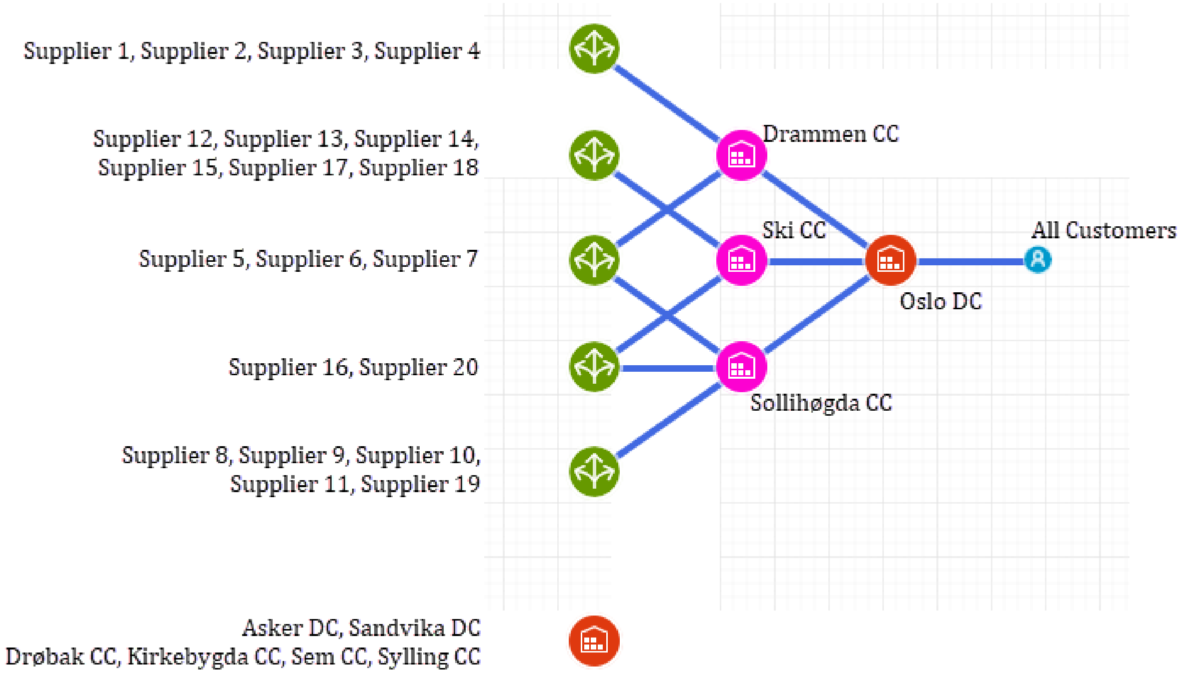


Figure 45. Distribution network configuration of scenario B after optimization.

4.3 Simulation Experiment

The thorough study conducted in Chapter 2, revealed that simulation and digital twin have a remarkable contribution into smart logistics in the industry 5.0 era. Needless to say, that other novel technologies are discussed as well, with significant impacts on smart logistics and Industry 5.0 development, e.g., artificial intelligence, virtual reality, etc. (see Figure 8; section 2.1.6). Further discussions showed that integration and intelligence are one of the key features in this regard. Thus, this research has opted the current methodology to create a digital model of the Dyrket's distribution network and paves the way to perform further analytical studies, including logistics network optimization and simulation. In section 4.2, network optimization procedure was comprehensively explained, and the best alternative were selected according to socio-economic aspects (scenario B). Simulation in this regard assists in giving more insights of the reconfigured supply chain with respect to the logistics performances. In simple words, simulation measures the logistics performances under various what-if scnearios and paves the way to make further tactical decisions for the reconfigured supply chain. Thus, a wide range of KPIs could be used in order to determine the inventory level of each facility, shipping policy between each pair of locations, and so forth.

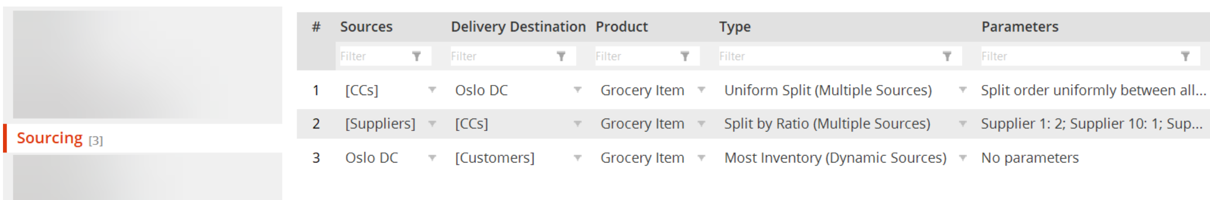
Hence, this section focuses on the entire process of simulation experiment and the goal in this regard is to determine the *inventory* and *shipping policies* throughout the Dyrket's redesigned distribution network.

4.3.1 Developing the Simulation Model

The benefit of anyLogistix software is the integration feature of this tool by which the optimized network associated with scenario B is directly utilized and incorporated into the simulation environment. The incorporated model, however, requires some adjustments to be prepared for the simulation experiment, as well as some additional data which will be described in the remainder of this section.

4.3.1.1 Supply Chain Adaptation and Sourcing

One of the essential adjustments required for developing the simulation model in anyLogistix is assuring the correct collocation of facilities and sourcing of products in each tier of the supply chain, i.e., from suppliers to facilities, from facilities to customer. In other words, and particularly in case of existing more than one facility and supplier (which is actually the major cases pertaining to supply chain studies), it is important to identify how the product is supplied and distributed to a range of destinations throughout the distribution network. It is worthwhile to mention, that this setting, however, is different from specifying the material flow throughout the supply chain according to the customized and desired channels. For instance, specifying the suppliers corresponding to the distinct identified CCs and routing between them is not in the scope of this step, instead the goal lies on a larger scale and it is, for example, specifying <u>how the grocery item is distributed to the CCs given the fact that 20 suppliers exist</u>.



#	Sources	Delivery Destination	Product	Type	Parameters
1	[CCs]	Oslo DC	Grocery Item	Uniform Split (Multiple Sources)	Split order uniformly between all...
2	[Suppliers]	[CCs]	Grocery Item	Split by Ratio (Multiple Sources)	Supplier 1: 2; Supplier 10: 1; Sup...
3	Oslo DC	[Customers]	Grocery Item	Most Inventory (Dynamic Sources)	No parameters

Figure 46. Sourcing settings in the simulation environment.

This is approached by a menu in the simulation environment, so-called 'sourcing'. As depicted in Figure 46, three tiers of the Dyrket's redesigned distribution network are specified in three distinct rows as follows:

1. Delivering grocery item from *collecting centers* to *Oslo DC*
2. Delivering grocery item from *suppliers* to *collecting centers*

3. Delivering grocery item from *Oslo DC* to *customers*

In this context, each tier of the product flow is characterized by five important elements: source, destination, product, distribution type, parameters. Source and destination determine the supplying and delivering point of each particular tier of the supply chain. The highly important feature in this stage is choosing the distribution type and specifying the required parameters according to the opted type. Thus, the remainder of this section elaborates these two parameters.

Distribution Between Suppliers and Collecting Centers

One of the major challenges of network optimization within the model generation phase was multi-sourcing attribute of the Dyrket's supply chain. As described in section 4.2.7, the created digital model of Dyrket's distribution network had an undesired behavior during the verification phase and according to which, some of the suppliers were not selected during the trial optimization. This issue was then resolved through custom constraints, by which delivering the grocery item from each supplier to CCs would take place according to a particular coefficient (Eq. 4.2) that defines the proportion of the supply amount of each individual supplier with respect to the aggregated supply amount of all suppliers that produce grocery item.

These constraints need to be replicated for the simulation experiment, however, in a different manner and more importantly according to the results of the network optimization. Hence the distribution type between suppliers and CCs, as shown in Figure 46, is selected as 'Split by Ratio (Multiple Sources)'. This option enables the possibility of defining the proportion of the supplied amount from each supplier with respect to the aggregated supplied amount, and the 'Parameters' column is to be utilized to specify the supply ratio of individual suppliers. Prior to this stage, it is beneficial to shed light again on the redesigned distribution network of Dyrket company which is the optimized distribution network of scenario B.

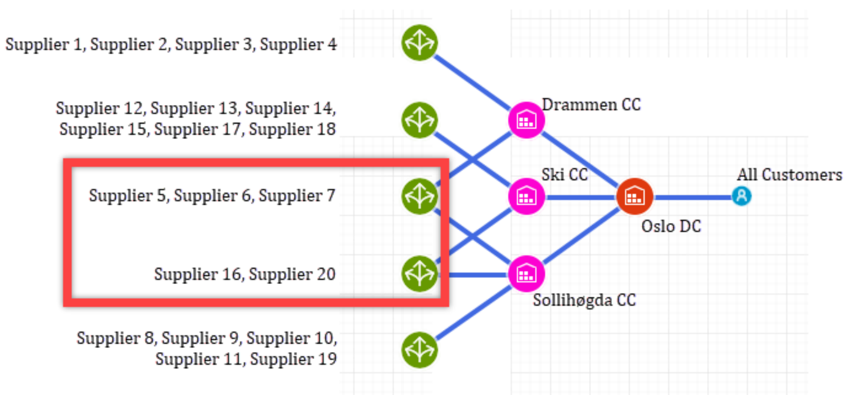


Figure 47. Redesigned distribution network of Dyrket.

According to Figure 47, two groups of suppliers are allocated to more than one CC. In this regard, Supplier 5, Supplier 6, and Supplier 7 deliver grocery items to Drammen CC and Sollohøgda CC, while on the other hand, Supplier 16 and Supplier 20 deliver grocery items to Ski CC and Sollohøgda CC. In more precise word, the maximum throughput of these suppliers is divided between the CCs that they are connected with. This correlation, from the viewpoint of defining a constraint, implies that the coefficient of the produced amount associated with these suppliers are divided by 2, in comparison to the coefficient of other suppliers. This is due to the fact that the event of supplying from the outlined suppliers to a collecting center occurs two times during the simulation period, given the fact that they are connected to two CCs. It is crucial to note that this does not define the proportion of the supplied amount to each collecting center, and it does not mean that those suppliers deliver the same amount to each of their connected CCs. As a matter of fact, this coefficient only acts as a constraint in order to make sure that suppliers do not exceed their maximum throughput.

#	Site	Ratio
	Filter	Filter
1	Supplier 1	2
2	Supplier 10	1
3	Supplier 11	1
4	Supplier 12	1
5	Supplier 13	1
6	Supplier 14	1
7	Supplier 15	1
8	Supplier 16	0.5
9	Supplier 17	1
10	Supplier 18	1
11	Supplier 19	1
12	Supplier 2	2
13	Supplier 20	0.5
14	Supplier 3	2
15	Supplier 4	1
16	Supplier 5	0.5
17	Supplier 6	0.5
18	Supplier 7	0.5
19	Supplier 8	1
20	Supplier 9	1

Figure 48. Parametrizing the distribution type once the suppliers are source in the simulation experiment.

The explained constraint is specified in the simulation model as represented in Figure 48. As observed, the supply ratio of normal suppliers is 1 while this number for the discussed suppliers is 0.5 (highlighted by *green* box). Additionally, it is previously described that Supplier 1, Supplier 2, and Supplier 3 deliver twice the amount that other suppliers deliver. Thus, the supply ratio of these suppliers is set to 2 (highlighted by *red* box).

Distribution Between Collecting Centers and Oslo DC

The optimized distribution network comprises 3 collecting centers as outlined earlier. The important issue in this regard is defining the policy of distributing products from CCs to Oslo DC which can impact the overall logistics performance. In this context, collecting centers serve as the suppliers for Oslo DC and this forms a multi-source relationship. Given the fact that existing CCs have the same share in satisfying the Oslo DC demands for grocery item under no particular constraint or policy, the 'Uniform Split (Multiple Source)' is selected as the distribution type. This approach, split the order between the collecting centers uniformly.

Distribution Between Oslo DC and Customers

The connection between Oslo DC and customers in the Dyrket's redesigned logistics network is simple. In fact, Oslo DC is the only facility that directly satisfies the customer demands and it is the touchpoint for the customers. Thus, there is no particular policy with regards to delivering grocery items from the distribution center to the customers, and the main aim at this facility is to satisfy the arrived orders regardless of the location of customers. Therefore, the distribution type in this part is set to 'Most Inventory (Dynamic Resources)' by which the customer demands are always satisfied by the available retailer, which in this case is Oslo DC.

4.3.1.2 Lead Time and Shipping Schedule

In real case scenario, different delivery schedules and lead times associated with various tiers of the supply chain, is one of the major reasons of inventory at facilities. Network optimization has barely the capability of incorporating these parameters and it is majorly driven by the inventory capacity at each facility, as well as other parameters, e.g., facility expenses, transportation expenses, etc. However, one of the advantages of this research is taking the delivery schedule and delivery lead time into account, enabled by simulation experiment.

The primary step in this context, is specifying the delivery lead time and associated schedule for this task. According to the information provided in section 3.3.4, delivery to the customers takes place two times per week which is scheduled for Tuesday and Thursday, and delivery lead time is expected to be at minimum 3 days which may deviates 1 to 2 days. In addition, delivery from suppliers to CCs, and from CCs to Oslo DC are scheduled for working days during the week, and thus, Saturday and Sunday are the off days throughout the supply chain.

Shipping [7]

#	Sources	Destinations	Product	Vehicle Type	Days of Week	Start Time	End Time
1	Oslo DC	[Customers]	Grocery Item	Van	Tue, Thu	8:00 AM	6:00 PM
2	[CCs]	Oslo DC	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM
3	[Sup. Drammen]	Drammen CC	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM
4	[Sup. Solli.]	Sollihøgda CC	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM
5	[Sup. Ski]	Ski CC	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM
6	[Sup. Drammen & Solli.]	[Drammen & Solli. CC]	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM
7	[Sup. Solli. & Ski]	[Solli. & Ski CC]	Grocery Item	Van	Wed, Tue, Mon, Fri, Thu	8:00 AM	6:00 PM

Figure 49. Shipping policy settings for developing the simulation model.

As observed in Figure 49, the first row determines the delivery from Oslo DC to customers that occurs only on Tuesdays and Thursdays between 8:00 to 18:00. The second row of shipping table highlights the delivery from CCs to Oslo DC, and as discussed it is scheduled for working days during the week.

On the other hand, shipping from suppliers to CCs requires extra attention in order to replicate the correct connection between these players of the supply chain and according to the results of the network optimization. In this regard, as previously shown in Figure 47, suppliers are categorized into five and each individual supplier is allocated to only one group. However, two groups of suppliers are connected to more than one collecting center and deliver grocery items to 2 CCs. According to this correlation, those five groups of suppliers that exist in the shipping table (see Figure 49) are denoted as follows:

1. Suppliers ship to Drammen CC → Sup. Drammen
2. Supplier ship to Sollihøgda CC → Sup. Solli.
3. Suppliers ship to Ski CC → Sup. Ski
4. Suppliers ship to Drammen CC and Sollihøgda CC → Sup. Drammen & Solli.
5. Suppliers ship to Sollihøgda CC and Ski CC → Sup. Solli. & Ski

The highly important step to finalize the practice of shipping policies, is adjusting the settings of 'Paths' menu according to the defined shipping routes mentioned above. This setting, in a similar way to the network optimization, bases the ground for transportation expenses calculation. Thus, in order for the shipping policies behaving accordingly and their associate expenses be calculated correctly, the completion of path settings is essential. As represented in

Figure 50, paths are generated according to the define shipping routes (see Figure 49) and their corresponding expenses is exactly the same as calculations performed in network optimization.

Paths [7]

#	From	To	Cost Calculation	Cost Calculation Parameters
1	Oslo DC	[Customers]	Distance-based with fixed cost	3.14 * distance + 425 per trip
2	[CCs]	Oslo DC	Distance-based with fixed cost	3.14 * distance + 425 per trip
3	[Sup. Drammen]	Drammen CC	Distance-based with fixed cost	3.14 * distance + 425 per trip
4	[Sup. Solli.]	Sollihøgda CC	Distance-based with fixed cost	3.14 * distance + 425 per trip
5	[Sup. Ski]	Ski CC	Distance-based with fixed cost	3.14 * distance + 425 per trip
6	[Sup. Drammen & Solli.]	[Drammen & Solli. CC]	Distance-based with fixed cost	3.14 * distance + 425 per trip
7	[Sup. Solli. & Ski]	[Solli. & Ski CC]	Distance-based with fixed cost	3.14 * distance + 425 per trip

Figure 50. Paths settings in the simulation environment.

4.3.2 Simulation and Logistics Performances

The simulation experiment basically examines the feasible tactical alternatives regarding the main activity streams throughout the supply chain, e.g., inventory, transportation, etc., and compliments the findings from network optimization with more rigorous insights. In fact, it enables the evaluation of logistics performances of the redesigned and optimized network by incorporating more parameters and dynamics. Thus, one may conclude more realistic and pragmatic solutions. **In the scope of this study, the simulation aids in deciding on two major logistics metrics:**

- *Transportation policies* throughout the entire distribution network, i.e., suppliers to collecting centers, collecting centers to Oslo DC, Oslo DC to customers.
- *Minimum required inventory at each facility* and the *maximum capacity that each facility* must have.

Therefore, the simulation experiment in this study is driven by various settings of two factors, which are inventory levels at facilities and transportation policies and different settings of these two drivers shape the what-if scenarios. To that aim, the simulation monitors and measures the logistics performances each scenario across three groups of KPIs. In this regard, the following KPIs are considered:

A. **Operational Performance:** This category of KPI seeks to measure the performance of the logistics network from operational perspective in response to the customer demands. Thus, some of the practical KPIs that are considered in this category are: *demand fulfillment, service level, delivery lead time.*

B. **Inventory and Capacity Dynamics:** In this category, the performances of the facilities, i.e., CCs, DCs, are measured in terms of *inventory on-hand,* and *peak capacity* that helps to determine the ultimate physical capacity of each particular facility.

C. **Financial Performance:** The main objective of a supply chain is maximization of profit or minimization of costs. In this regard, this category outlines the financial KPIs including *carrying costs*, *fixed costs*, *transportation costs*, *profit*, and so forth.

4.3.2.1 Initial Settings: Scenario A and Logistics Performances

The initial settings of scenario A are based on the results derived from network optimization. As also outlined in the introduction of section 4.3.1, the optimized distribution network associated with scenario B is incorporated into the simulation environment by which one may benefit from the produced data pertaining to the optimization phase. Thus, simulation of scenario A is executed according to the results of the optimization, and it bases the fundaments in order to perform examine further scenarios for improvement of the logistics performances of Dyrket's redesigned distribution network.

The simulation results reveal that the current settings do not lead to the expected or desired logistics performances, even though the data are derived from the network optimization. The reason of this issue lies on the fact that simulation environment is more dynamic compared to the network optimization. For instance, shipping schedule (this issue was explained in section 4.3.1.2) from Oslo DC to customers differ from the shipping schedule from suppliers to CCs and CCs to Oslo DC, which not only increases the inventory level at facilities but also, negatively impact the carrying costs. In this regard, the logistics performances of scenario A across some of the important KPIs are represented in Table 15.

Table 15. Simulation results based on scenario A.

KPI	Scenario A
Service Level	30.7 %
Lead Time (Mean)	14.4
Lead Time (Max)	38.4
Profit	8,019,955
Inventory Carrying Cost	2,722,605
Demand Received	656,405
Fulfilled Demand	634,169

According to the simulation results, service level and expected delivery lead time have significantly low performance. At the same time, the inventory carrying cost depicts a high number proportionally to the current service level. This signifies that delivery from Oslo DC to customers is not efficient. Thus, shipping from Oslo DC to customers requires improvement, for which the shipping policy is changed from FTL (at ratio of 0.8) to LTL (less than truck load) and leads to shaping scenario B. In this regard, Table 16 shows the fundamental data of scenario A and scenario B corresponds to inventory and shipping policies.

Table 16. Inventory and shipping data associated with scenario A and scenario B for simulation experiment.

Policy	Details			Scenario A	Scenario B
Inventory	Oslo DC		min	12,390	12,390
			Max	24,780	24,780
	Drammen CC		min	4,298	4,298
			Max	8,596	8,596
	Sollihøgda CC		min	3,990	3,990
			Max	8,043	8,043
	Ski CC		min	4,116	4,116
			Max	8,225	8,225
Shipping	Oslo DC	to	[Customers]	FTL, 0.8	**LTL**
	CCs	to	Oslo DC	FTL, 0.8	FTL, 0.8
	Sup. Drammen	to	[Drammen CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli.	to	[Sollihøgda CC]	FTL, 0.8	FTL, 0.8
	Sup. Ski	to	[Ski CC]	FTL, 0.8	FTL, 0.8
	Sup. Drammen & Solli.	to	[Drammen & Solli. CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli. & Ski	to	[Solli. & Ski CC]	FTL, 0.8	FTL, 0.8

4.3.2.2 Transition to Scenario B and Logistics Performances

Scenario B, as also explained in previous section, is generated based on the improvements applied to scenario A, and in this scenario, the shipping policy between Oslo DC and customers have been changed to LTL. According to the simulation results of this scenario (see Table 17), service level has not been improved; however, considerable improvement in carrying cost and profit is observed. In addition, higher proportion of customer demands is satisfied compared to scenario A. Needless to say that expected lead time is another parameter that has been improved through scenario B.

Table 17. Simulation results based on scenario B.

KPI	Scenario B
Service Level	30.7 %
Lead Time (Mean)	6.3
Lead Time (Max)	24.4
Profit	8,981,122
Inventory Carrying Cost	1,961,035
Demand Received	656,405
Fulfilled Demand	644,020

It is beneficial to investigate the inventory on-hand situation at Oslo DC as a mean of troubleshooting the low service level. In this regard, Figure 51 reveals that at several intervals throughout the optimization period, there is remarkably low inventory on-hand at Oslo DC. For instance, at day 157 and day 225 the inventory level at Oslo DC was 10 products which is considerably low. This issue not only reduces the service level but also, shows that shipping to this facility from CCs must be more effective.

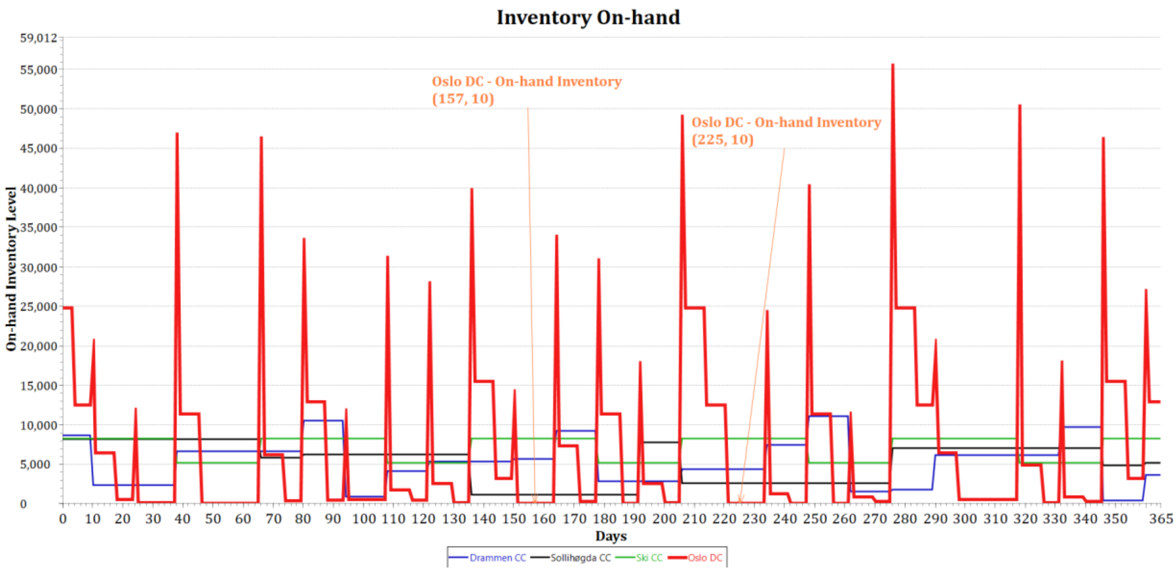


Figure 51. Inventory on-hand based on simulation results of scenario B.

Hence, the next improvement step corresponds to shipping from CCs to Oslo DC by which this activity stream is changed to LTL from FTL (at ratio of 0.8), and it leads to the development of scenario C. In this regard, Table 18 summarizes the information regarding scenario B and scenario C according to inventory and shipping policies.

Table 18. Inventory and shipping data associated with scenario B and scenario C for simulation experiment.

Policy	Details			Scenario B	Scenario C
Inventory	Oslo DC		min	12,390	12,390
			Max	24,780	24,780
	Drammen CC		min	4,298	4,298
			Max	8,596	8,596
	Sollihøgda CC		min	3,990	3,990
			Max	8,043	8,043
	Ski CC		min	4,116	4,116
			Max	8,225	8,225
Shipping	Oslo DC	to	[Customers]	LTL	LTL
	CCs	to	Oslo DC	FTL, 0.8	**LTL**
	Sup. Drammen	to	[Drammen CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli.	to	[Sollihøgda CC]	FTL, 0.8	FTL, 0.8
	Sup. Ski	to	[Ski CC]	FTL, 0.8	FTL, 0.8
	Sup. Drammen & Solli.	to	[Drammen & Solli. CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli. & Ski	to	[Solli. & Ski CC]	FTL, 0.8	FTL, 0.8

4.3.2.3 Transition to Scenario C and Logistics Performances

The results of simulation based on scenario C depict that service level has experience 7% improvements and the average lead time has been improved for 1 day. Due to higher frequency of shipping from CCs, lower inventory carrying cost has been achieved, which has also resulted in higher profit. The simulation results of this scenario are represented in Table 19.

Table 19. Simulation results of scenario C.

KPI	Scenario C
Service Level	37 %
Lead Time (Mean)	5.4
Lead Time (Max)	24.4
Profit	9,071,307
Inventory Carrying Cost	1,843,312
Demand Received	656,405
Fulfilled Demand	644,020

Although major focus on shipping policy throughout scenario B and scenario C has made some improvements, it is beneficial to examine inventory policies as well. As illustrated in Figure 52 (red line), the minimum level of available inventory at Oslo DC is considerably low and it is consistent for several intervals during the optimization period. This is also one of the reasons of low service level that has not been improved effectively so far.

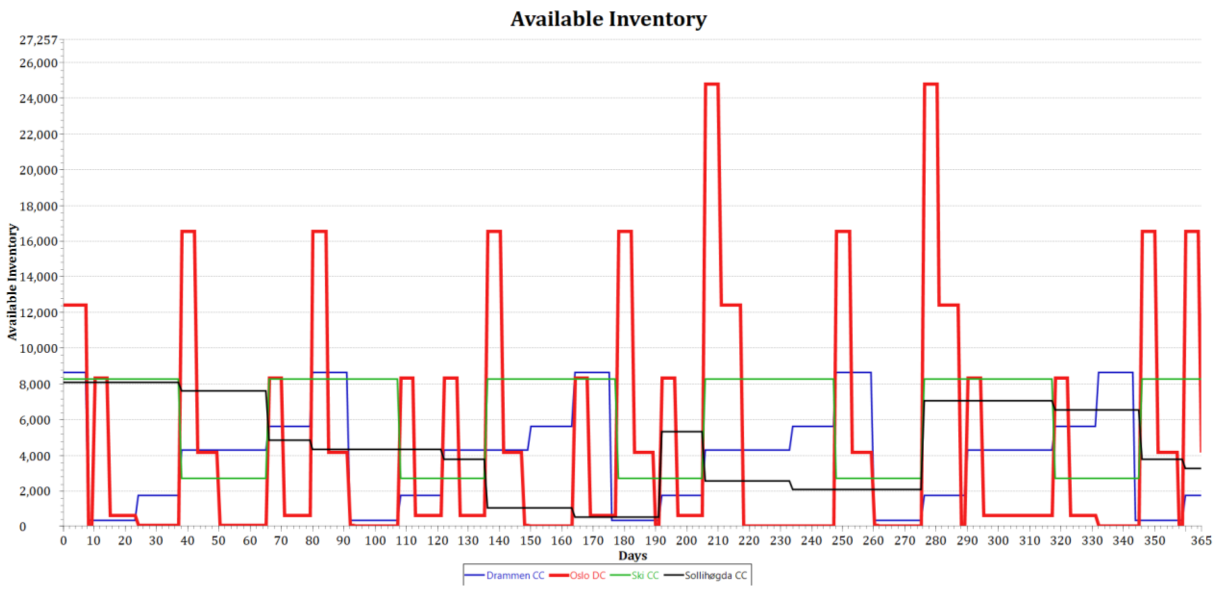


Figure 52. Available inventory of facilities in simulation scenario C.

As a result, next improvement seeks to increase the inventory capacity of Oslo DC and it leads to the generation of scenario D. The associated information according to scenario C and scenario D is represented in Table 20.

Table 20. Inventory and shipping data associated with scenario C and scenario D for simulation experiment.

Policy	Details				Scenario C	Scenario D
Inventory	Oslo DC			min	12,390	20,000
				Max	24,780	31,000
	Drammen CC			min	4,298	4,298
				Max	8,596	8,596
	Sollihøgda CC			min	3,990	3,990
				Max	8,043	8,043
	Ski CC			min	4,116	4,116
				Max	8,225	8,225
Shipping	Oslo DC	to	[Customers]		LTL	LTL
	CCs	to	Oslo DC		LTL	LTL
	Sup. Drammen	to	[Drammen CC]		FTL, 0.8	FTL, 0.8
	Sup. Solli.	to	[Sollihøgda CC]		FTL, 0.8	FTL, 0.8
	Sup. Ski	to	[Ski CC]		FTL, 0.8	FTL, 0.8
	Sup. Drammen & Solli.	to	[Drammen & Solli. CC]		FTL, 0.8	FTL, 0.8
	Sup. Solli. & Ski	to	[Solli. & Ski CC]		FTL, 0.8	FTL, 0.8

4.3.2.4 Transition to Scenario D and Logistics Performances

The simulation results according to the improvements made in scenario D show a significant leap in logistics performances. In this regard, service level has drastically increased to 85.7% and expected lead time has nailed the desired value of 3 days by a record of 3.4 days on average.

Table 21. Simulation results of scenario D.

KPI	Scenario D
Service Level	85.7 %
Lead Time (Mean)	3.4
Lead Time (Max)	10.4
Profit	8,572,330
Inventory Carrying Cost	2,303,378
Demand Received	656,405
Fulfilled Demand	644,020

According to the simulation results (see Table 21), inventory carrying costs has grown which is a logical due to the increase in the minimum inventory level of Oslo DC. In this context, Figure 53 elaborates this figure and it reveals that carrying costs at CCs has been reduced due to higher frequency of delivering to Oslo DC and the total increase in the inventory carrying cost of scenario D is driven by Oslo DC, which however has led to significant improvements in service level.

	Statistics name	Object	Value	Unit
1	Inventory Carrying Cost	Drammen CC	336,495.093	NOK
2	Inventory Carrying Cost	Oslo DC	626,555.904	NOK
3	Inventory Carrying Cost	Ski CC	507,938.916	NOK
4	Inventory Carrying Cost	Sollihøgda CC	372,322.831	NOK

(a)

	Statistics name	Object	Value	Unit
1	Inventory Carrying Cost	Drammen CC	284,997.967	NOK
2	Inventory Carrying Cost	Oslo DC	1,519,359.178	NOK
3	Inventory Carrying Cost	Ski CC	244,925.042	NOK
4	Inventory Carrying Cost	Sollihøgda CC	254,096.122	NOK

(b)

Figure 53. Inventory carrying costs of the simulation experiment: (a) scenario C (b) scenario D.

Further investigation regarding the logistics performances of scenario D depicts that despite notable improvements, the distribution network is unable to serve customers in the eastern part of Oslo at high service level. As shown in Figure 54, the service level associated with customers in the districts of Lillestrøm and Lørenskog is almost at 70% and lower than other customers.

	Statistics name	Object	Value	Unit
1	Service Level by Revenue	Asker C	0.962	Ratio
2	Service Level by Revenue	Bærum C	0.962	Ratio
3	Service Level by Revenue	Fetsund C	0.906	Ratio
4	Service Level by Revenue	Holmenkollen C	0.849	Ratio
5	Service Level by Revenue	Lillestrøm C	0.698	Ratio
6	Service Level by Revenue	Lørenskog C	0.698	Ratio
7	Service Level by Revenue	Oslo C	0.906	Ratio
8	Service Level by Revenue	Rælingen C	0.849	Ratio

Figure 54. Simulation results of scenario D according to "service level by revenue per customer".

In addition, while Figure 55 shows the improvements in Oslo DC inventory level, it shows that the inventory of Ski CC experiences major long periods at low inventory level, so as for Drammen CC. According to the above discussions regarding the possible drawbacks of scenario D, the minimum inventory level for Ski CC and Drammen CC will be increased.

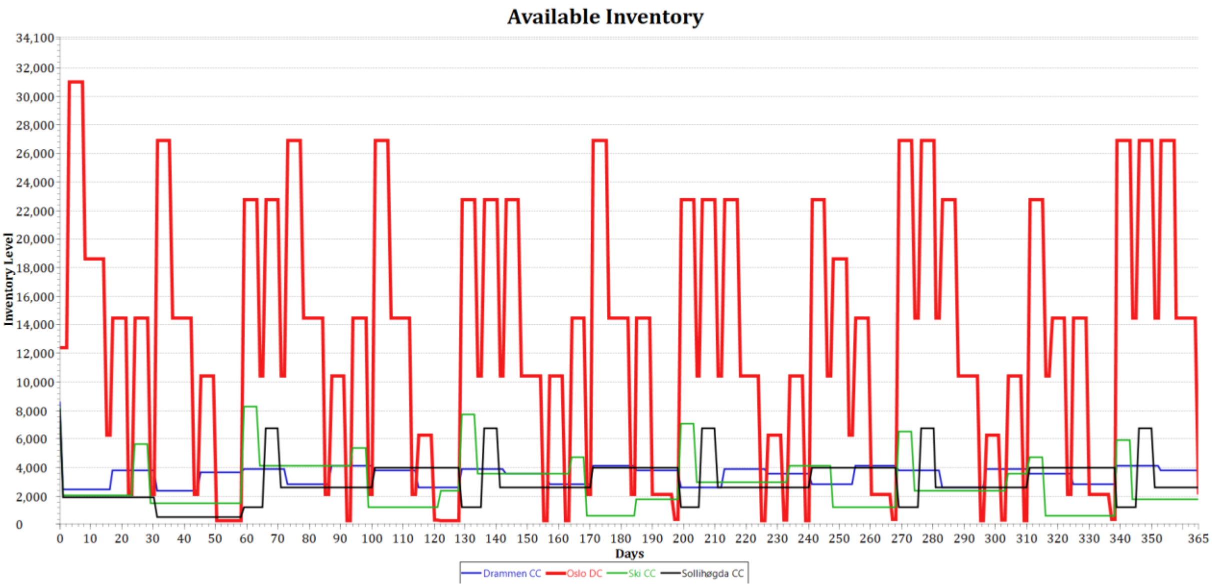


Figure 55. Available inventory of facilities in simulation scenario D.

Hence, transition from scenario D to scenario E is developed based on the minimum inventory level of Ski CC and Drammen CC, and associated data of each scenario is represented in Table 22.

Table 22. Inventory and shipping data associated with scenario D and scenario E for simulation experiment.

Policy	Details			Scenario D	Scenario E
Inventory	Oslo DC		min	20,000	20,000
			Max	31,000	31,000
	Drammen CC		min	4,298	5,400
			Max	8,596	8,596
	Sollihøgda CC		min	3,990	3,990
			Max	8,043	8,043
	Ski CC		min	4,116	5,400
			Max	8,225	8,225
Shipping	Oslo DC	to	[Customers]	LTL	LTL
	CCs	to	Oslo DC	LTL	LTL
	Sup. Drammen	to	[Drammen CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli.	to	[Sollihøgda CC]	FTL, 0.8	FTL, 0.8
	Sup. Ski	to	[Ski CC]	FTL, 0.8	FTL, 0.8
	Sup. Drammen & Solli.	to	[Drammen & Solli. CC]	FTL, 0.8	FTL, 0.8
	Sup. Solli. & Ski	to	[Solli. & Ski CC]	FTL, 0.8	FTL, 0.8

4.3.2.5 Transition to Scenario E and Logistics Performances

The simulation results of scenario E are highlighted in Table 23. In this regard, service level is leveled up by almost 4% while the maximum expected lead time still stands on the edge of 10.4 days. While the minimum level of inventory of Ski CC and Drammen CC has been risen, the inventory carrying cost is slightly increased.

Table 23. Simulation results of scenario E.

KPI	Scenario E
Service Level	89.2 %
Lead Time (Mean)	3.4
Lead Time (Max)	10.4
Profit	8,481,445
Inventory Carrying Cost	2,407,295
Demand Received	656,405
Fulfilled Demand	644,020

However, the issue with service level associated with customers in the east region of Oslo described in scenario D (see section 4.3.2.4), has not been resolved yet, and in this regard,

Figure 56 demonstrates that service level for Lillestrøm and Lørenskog customers have not experience significant improvements in service level.

	Statistics name	Object	Value	Unit
1	Service Level by Revenue	Asker C	0.981	Ratio
2	Service Level by Revenue	Bærum C	0.981	Ratio
3	Service Level by Revenue	Fetsund C	0.943	Ratio
4	Service Level by Revenue	Holmenkollen C	0.868	Ratio
5	Service Level by Revenue	Lillestrøm C	0.774	Ratio
6	Service Level by Revenue	Lørenskog C	0.774	Ratio
7	Service Level by Revenue	Oslo C	0.943	Ratio
8	Service Level by Revenue	Rælingen C	0.868	Ratio

Figure 56. Simulation results of scenario E according to "service level by revenue per customer".

Additionally, and also as it is also observable in scenario D, service level for Holmenkollen customers has still room for improvements. In this regard, further attention to the available inventory of Oslo DC (see Figure 57) reveals that this facility periodically experiences low inventory level while the average inventory level has significantly been improved throughout the simulation scenarios so far.

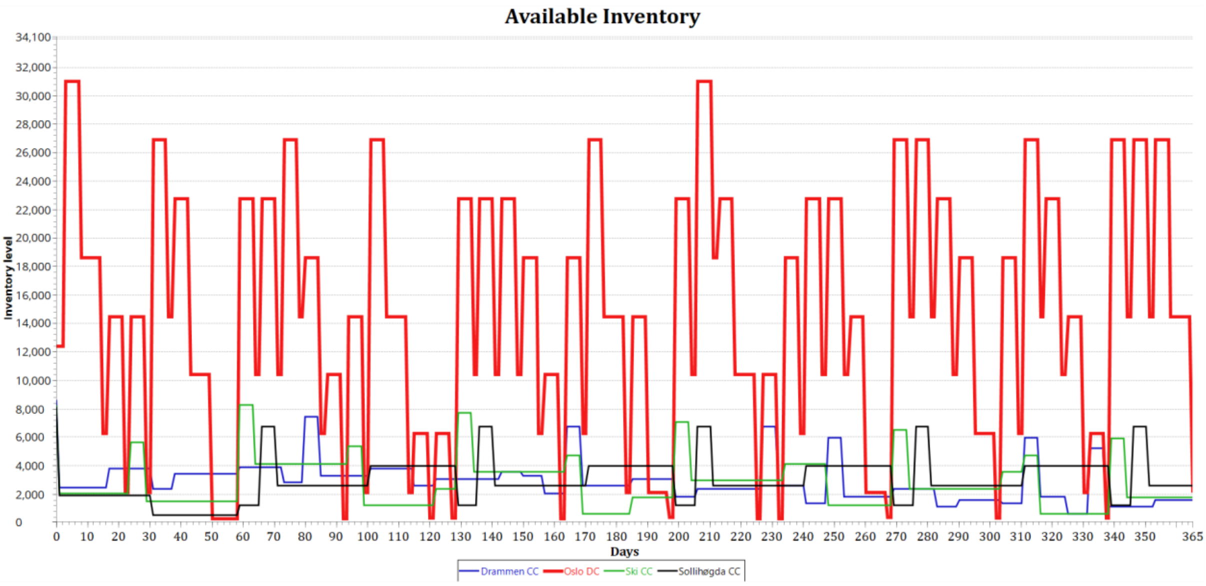


Figure 57. Simulation results of scenario E according to "Available Inventory".

Hence, the next improvement scenario, namely scenario F, is shaped based on the outlined shortages and in this regard, the aim is to increase the minimum and maximum inventory capacity at Oslo DC and Ski CC. These improvements are highlighted in Table 24.

Table 24. Inventory and shipping data associated with scenario E and scenario D for simulation experiment.

Policy	Details				Scenario E	Scenario F
Inventory	Oslo DC			min	20,000	30,000
				Max	31,000	34,000
	Drammen CC			min	5,400	5,400
				Max	8,596	8,596
	Sollihøgda CC			min	3,990	3,990
				Max	8,043	8,043
	Ski CC			min	5,400	8,000
				Max	8,225	11,000
Shipping	Oslo DC	to	[Customers]		LTL	LTL
	CCs	to	Oslo DC		LTL	LTL
	Sup. Drammen	to	[Drammen CC]		FTL, 0.8	FTL, 0.8
	Sup. Solli.	to	[Sollihøgda CC]		FTL, 0.8	FTL, 0.8
	Sup. Ski	to	[Ski CC]		FTL, 0.8	FTL, 0.8
	Sup. Drammen & Solli.	to	[Drammen & Solli. CC]		FTL, 0.8	FTL, 0.8
	Sup. Solli. & Ski	to	[Solli. & Ski CC]		FTL, 0.8	FTL, 0.8

4.3.2.6 Transition to Scenario F and Logistics Performances

The simulation experiment of scenario F signifies remarkable improvements in service level and expected lead time. In this regard, service level stand at 97.9% and the expected lead time for customers is 3.4 days.

Table 25. Simulation results of scenario F.

KPI	Scenario F
Service Level	97.9 %
Lead Time (Mean)	3.4
Lead Time (Max)	3.4
Profit	8,050,060
Inventory Carrying Cost	2,868,685
Demand Received	656,405
Fulfilled Demand	644,020

It is essential to note that from scenario C, part of customer demand is not satisfied which is due to the fact that simulation ends at a time when the orders has been received while there is no time to satisfy those orders, and this has been a consistent issue up to scenario F. Further evaluation of scenario F depicts that, in comparison with scenario E, the profit has been reduced which is emanated from the increase in the service level which is driven by Oslo DC and Ski CC. In fact, this is a compromise between service level and profitability. In this regard, the profit is reduced by 5% while it has led to 8% increase in the service level.

In addition, Figure 58 demonstrates that service level stands at 100% for some customers and according to the aims of scenario F, the service level for Lillestrøm and Lørenskog customer has been considerable improved in comparison to scenario E (see Figure 56).

	Statistics name	Object	Value	Unit
1	Service Level by Revenue	Asker C	1	Ratio
2	Service Level by Revenue	Bærum C	1	Ratio
3	Service Level by Revenue	Fetsund C	0.925	Ratio
4	Service Level by Revenue	Holmenkollen C	1	Ratio
5	Service Level by Revenue	Lillestrøm C	0.925	Ratio
6	Service Level by Revenue	Lørenskog C	0.925	Ratio
7	Service Level by Revenue	Oslo C	1	Ratio
8	Service Level by Revenue	Rælingen C	0.925	Ratio

Figure 58. Simulation results of scenario F according to "service level by revenue per customer".

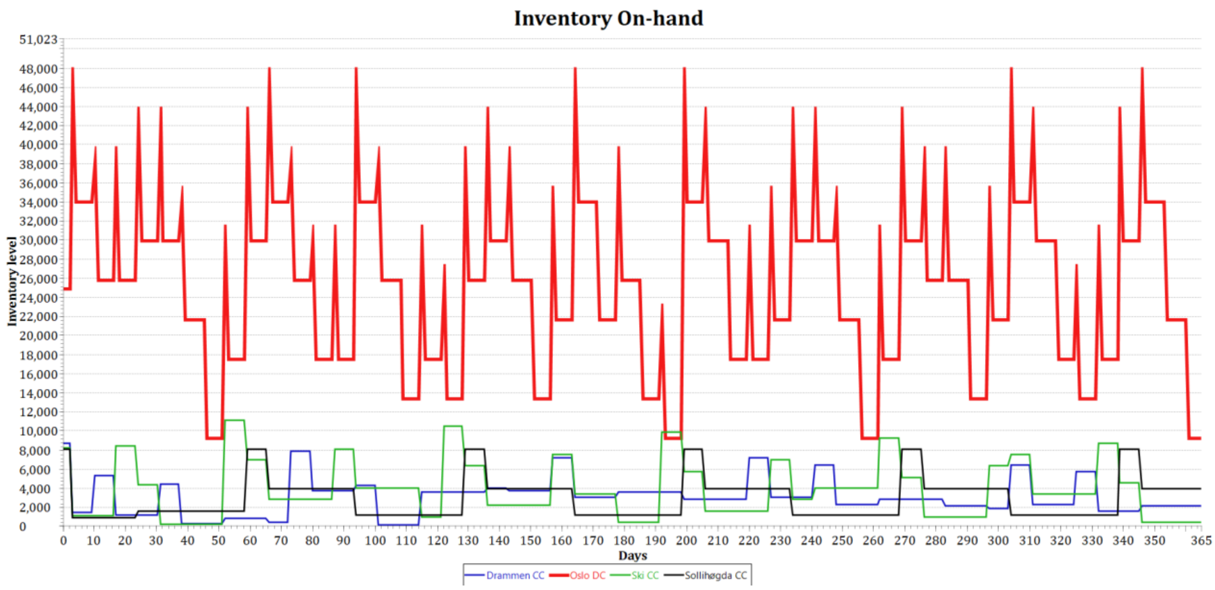


Figure 59. Simulation results of scenario F according to 'Inventory On-hand".

Further attention to Oslo DC reveals that the considered scenarios throughout the simulation experiment have successfully enriched the inventory activities at this facility. A comparison between scenario F (see Figure 59) and scenario B (see Figure 51) against inventory on-hand, reveals that this index has been substantially improved and higher service level is facilitated.

According to the achieved results, scenario F satisfies the expectations of logistics performances and bases the grounds to decide on the inventory and shipping policy which will be elaborated in section 4.4, and the improvement of scenarios is halted at scenario F.

4.4 Discussion and Final Assessment

The synthesis of network optimization and simulation explained in this chapter, favored to optimize the distribution network of Dyrket company (section 4.2), and perform simulation experiment in order to maximize the logistics performance of the optimized network according to inventory and shipping policies (section 4.3). Thus, this section finalizes the decisions that can be made according to the simulation results (scenario F) in combination with the inferences of the network optimization phase in order to present a coherent and concrete solution.

The initial inference that could be derived according to the simulation experiment is the decision on delivery lead time. According to the results of scenario F represented in Table 25, the maximum and the mean value of expected lean time is calculated as 3.4 days. This means that the company can consider the expected lead time for customer delivery as 4 days to benefit from not only the high customer satisfaction but also, on-time delivery. As demonstrated in Figure 60 (a), expecting 3 days for delivery lead time leads to a number of products being delivered late, while with 4 days as delivery lead time the entire satisfied demands are delivered on-time (see Figure 60 (b)). Hence, the company is recommended to take 4 days as delivery lead time into consideration.

	Statistics name	Value	Unit
1	Demand Placed (Products) by Customer	656,405	pcs
2	Fulfillment (Late Products)	2,248	pcs
3	Fulfillment Received (Products On-time)	641,772	pcs
4	Fulfillment Received (Products) by Customer	644,020	pcs

(a)

	Statistics name	Value	Unit
1	Demand Placed (Products) by Customer	656,405	pcs
2	Fulfillment Received (Products On-time)	644,020	pcs
3	Fulfillment Received (Products) by Customer	644,020	pcs

(b)

Figure 60. Simulation results regarding demand fulfillment in scenario F: (a) delivery lead time 3 days (b) delivery lead time 4 days.

The next decision is regarding the physical capacity of each facility which is determined by the maximum inventory level that each facility has experienced during the simulation period. For this purpose, the simulation results of scenario F (see Figure 61) show that the physical capacity of Oslo DC must be able to store 46,385 products at some points and this figure for Drammen CC, Ski CC, and Sollihøgda CC is, respectively, 8,596, 11,000, and 8,043.

	Statistics name	Object	Value	Unit
1	Peak Capacity	Drammen CC	8,596	pcs
2	Peak Capacity	Oslo DC	46,385	pcs
3	Peak Capacity	Ski CC	11,000	pcs
4	Peak Capacity	Sollihøgda CC	8,043	pcs

Figure 61. Peak capacity of facilities according to the simulation results of scenario F.

Last but not least, is the shipping policy throughout the distribution network, which according to the results of scenario F, takes place in varied forms. In this regard, shipping from suppliers to CCs is accomplished based on FTL (at ratio of 0.8), and it is performed according to LTL policy between CCs to Oslo DC, and Oslo DC to customer. The ultimate conclusion of this research is briefly demonstrated in Figure 62, which combines the results of network optimization and simulation experiments.

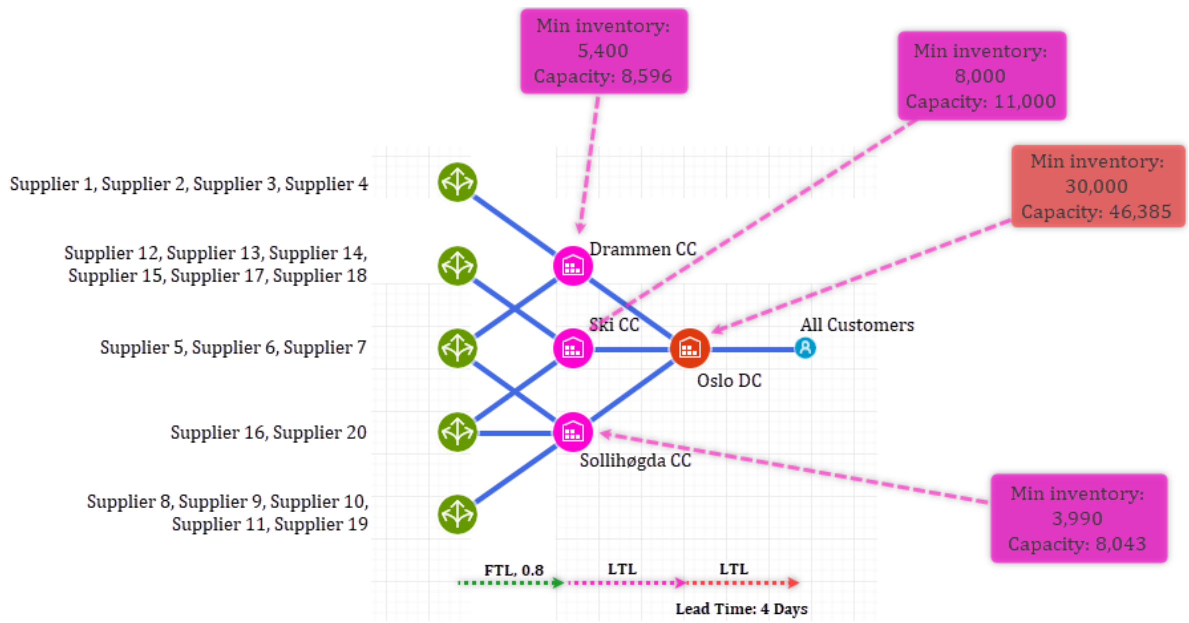


Figure 62. The final conclusion for Dyrket company regarding the network configuration, and logistics performances according to inventory and shipping policies.

Chapter 5.
Conclusion

The fifth industrial revolution emerged with an agenda to address the adverse impacts of automation and digitalization brought by Industry 4.0. Smart logistics is one of the major areas that has extensively benefited from the improvements in the recent years and this research aimed at investigating the impacts of Industry 5.0 in this context. Furthermore, a showcase study was accomplished to step forward in utilizing the enabling technologies of this new industrial paradigm.

The systematic literature review conducted in the first phase of the project highlighted that while Industry 4.0 is a technology driven paradigm, its successive revolution has appeared to be value driven and aiming to address socio-economic issues throughout the technological improvements. The core source of inspirations in Industry 5.0 revealed that sustainability, resilience, and human centricity shape the general framework of this industrial revolution and further developments in manufacturing and logistics systems must align with these objectives. The review study showed that attention from scholars to this concept are scattered with lack of focus on smart logistics, even though some concepts such as society 5.0, operator 5.0, sustainable smart logistics, and so forth, have been studies and introduced. Thus, Chapter 2 put forward to propose a framework for implications of Industry 5.0 for smart logistics by pointing out intelligence automation, intelligence devices, intelligent systems, and intelligent materials. Ultimately, a list of enabling technologies that are supported and promoted by studies associated with Industry 5.0 revealed that this paradigm has inherited many of the novel technologies attributed to Industry 4.0. However, the recent industrial revolution promotes the integration and intelligence features throughout further development of such technologies, artificial intelligence, collaborative robots, virtual reality, are amongst the emphasized technologies in this context, to name a few.

The second phase of the project was supported by one of the top-referred enabling technologies of Industry 5.0: simulation and digital twin. The application of a simulation package with high integration capabilities favored in generating a digital replica of the distribution network of a logistics company, enriched with high visualization features, and perform thorough analyses in two steps: network optimization and simulation. The former aided at solving a capacitated network optimization problem by which the goal was to redesign the logistics network utilizing some intermediary storage facilities that connect the suppliers to the distribution centers. The latter, aimed at incorporating more dynamics into the optimized network, e.g., shipping schedule, delivery lead time, etc., and determine the optimal inventory and capacity level of the facilities pertaining to the optimized distribution network. This approach benefited from high integration possibilities according to which the results of the optimization were directly used in the simulation environment.

This approach showed high capabilities in conducting more rigorous studies corresponding to supply chain network optimization problems. Integration and visualization features are helpful to not only combine network optimization and simulation but also, define the initial problem with higher precision. Replicating the supply chain in a digital environment with different abstraction levels paves the way for higher comprehension of the logistics network of a company. This digital model significantly contributes to decision-making processes given the fact that it is empowered by high analytical capabilities.

This research was, however, accomplished under the existence of some limitations which could be addressed in further research projects. One important aspect that was investigated during the optimization procedure was the number of single trips. This index helped to find that one of the selected facilities imposes extra and unnecessary transportation, particularly with only single trips. This issue was further assessed in terms of facility costs, and it was also mentioned that this potentially leads to increasing the negative environmental indices. In this regard, calculating the CO_2 emission and its impact on the supply chain profitability and transportation policies is of significant benefits that was skipped in this study. This is due to the fact that this research was limited by the available information and data with respect to this criterion, even though that the selected software and approach facilitates this sort of calculation. Hence, it is highly recommended that further effort put on translating the CO_2 emission into numbers and financial figures and incorporate it into the optimization and simulation experiments. Another issue that limited this research was fixed numbers pertaining to several parameters, particularly customer demand. As a matter of fact, this research performed a deterministic optimization while there is a possibility to incorporate stochastic parameters in the opted methodology of this study. In this regard, is a beneficial contribution to perform both network optimization, and particularly the simulation studies in various stochastic conditions associated with customer demand. For instance, different demand levels in different seasons, particularly in winter when the weather conditions become troublesome for farming in Oslo, and other parts of Norway.

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Appendix

Table 26. Industry 5.0 technologies in smart logistics.

Author [Ref. Nr.]	AI[a]	Cobot	Sim. & DT[b]	Sensor Tech	Cloud. Comp[c]	Big Data	ML /DL[d]	VR/ AR[e]	UAV /AGV[f]	Bio-Tech.	IoT	AM[g]	Block.[h]
Callaghan [29]	✓												
Nahavandi [24]	✓	✓	✓	✓			✓	✓					
Xu, Lu [1]	✓		✓			✓				✓			
Patera, Garbugli [47]	✓			✓	✓	✓							
Pathak, Pal [28]	✓	✓									✓		
Gaiardelli, Spellini [138]	✓	✓											
Duggal, Malik [139]	✓	✓					✓			✓		✓	
Kumar, Gupta [40]					✓			✓	✓		✓		✓
Javaid and Haleem [27]	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
Saptaningtyas and Rahayu [25]		✓	✓	✓				✓			✓		✓
Demir, Döven [30]	✓	✓			✓	✓					✓		
Doyle-Kent and Kopacek [59]		✓											
Gürdür Broo, Kaynak [140]	✓		✓										
Rega, Di Marino [60]		✓	✓					✓					
Brunzini, Peruzzini [75]			✓	✓				✓		✓			
Thakur and Kumar Sehgal [94]				✓									
Fraga-Lamas, Lopes [97]	✓				✓						✓		
Zhang, Hu [141]	✓		✓										
Golov, Palamarchuk [95]	✓		✓		✓								
Resende, Cerqueira [55]		✓											
Ávila-Gutiérrez, Aguayo-González [76]	✓			✓			✓				✓		

Author [Ref. Nr.]	AI[a]	Cobot	Sim. & DT[b]	Sensor Tech	Cloud. Comp[c]	Big Data	ML /DL[d]	VR/ AR[e]	UAV /AGV[f]	Bio-Tech.	IoT	AM[g]	Block.[h]
Doyle-Kent and Kopacek [64]		✓											
Bathla, Singh [103]	✓					✓					✓		
Romero and Stahre [54]	✓	✓				✓	✓	✓		✓			
Jabrane and Bousmah [65]	✓	✓				✓	✓						
Fraga-Lamas, Varela-Barbeito [84]			✓	✓							✓		
Fornasiero and Zangiacomi [62]				✓				✓			✓		
Carayannis, Dezi [43]						✓					✓		
Carayannis, Christodoulou [101]	✓										✓		✓
Hol [57]	✓	✓						✓	✓			✓	
Doyle Kent and Kopacek [63]		✓											
Longo, Padovano [77]		✓						✓					
Doyle-Kent and Kopacek [23]		✓				✓							
Martynov, Shiryaev [41]	✓												
Martynov, Shavaleeva [39]	✓					✓					✓		
Mihardjo, Sasmoko [42]											✓		
Welfare, Hallowell [56]		✓											
Rahman, Muda [102]	✓				✓	✓					✓		✓

a. Artificial Intelligence
b. Simulation and Digital Twin
c. Cloud Computing
d. Machine Learning / Deep Learning
e. Virtual Reality / Augmented Reality
f. Unmanned Aerial Vehicle / Automated Guided Vehicle
g. Additive Manufacturing
h. Blockchain Technology

Table 27. Latitude and longitude of suppliers, collection centers, distribution centers, and customer checkpoints.

Item Nr.	Location	Latitude	Longitude	Item Nr.	Location	Latitude	Longitude
S1	Sandefjord	59.12772	10.23193	C1	Oslo	59.9206349047173	10.7548990504474
S2	Sandefjord	59.1328	10.22446	C2	Holmenkollen	59.9664800449687	10.666617250514
S3	Valberg	59.28137	10.25456	C3	Bærum	59.9650158678428	10.477642323321
S4	Kongsberg	59.621891	9.6922998	C4	Lørenskog	59.9267304244125	10.9539788786662
S5	Drammen	59.7512784	10.0326281	C5	Lillestrøm	59.9568548138093	11.0509254289696
S6	Drammen	59.7474518	10.1839895	C6	Asker	59.8367605845738	10.4357296348848
S7	Amot	59.89353	9.9171	C7	Rælingen	59.9457573610631	11.0492240448314
S8	Vikersund	59.97389	9.93076	C8	Fetsund	59.9293898281984	11.1624316636498
S9	Hønefoss	60.21301	10.37797	DC1	Sandvika	59.9196163069129	10.4884216135486
S10	Sylling	59.89189	10.30487	DC2	Asker	59.8367605845738	10.4357296348848
S11	Holmsbu	59.55026	10.45545	DC3	Oslo	59.9206349047173	10.7548990504474
S12	Gressvik	59.26217	10.81974	CC1	Sem	59.2873306	10.3344803
S13	Rolvsøy	59.30468	10.95837	CC2	Drammen	59.7474518	10.1839895
S14	Våler i Østfold	59.49058	10.87547	CC3	Sollihøgda	59.96535	10.34713
S15	Moss	59.40718	10.66193	CC4	Sylling	59.8936501	10.28724
S16	Skedsmokorset	60.00734	11.04006	CC5	Drøbak	59.66164	10.70017
S17	Kongsvinger	60.23869	12.08385	CC6	Kirkebygda	59.3586082	10.8741703
S18	Oslo	59.95326	10.88479	CC7	Ski	59.7173233	10.8315973
S19	Sandvika	59.89291	10.53311				
S20	Oslo	59.91795	10.78732				

- S: Supplier
- CC: Collection Center
- DC: Distribution Center
- C: Customer