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An optimized cost-based Outbound Logistics Network Design (OLND) for a car manufacturer.

Master of Science thesis logistics and transport management, School of Business, Economics and Law at the University of Gothenburg

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Abstract

Title*:* An optimized cost-based Outbound Logistics Network Design (OLND) for a car manufacturer.

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Abstract purpose: The purpose of this research is to map existing frameworks, models and literature on Distribution Networks (DN), Supply Chain Network Design (SCND) and Outbound Logistics Network Design (OLND) relevant to the automotive industry. Based on a selection of applicable models, a suggested cost optimized OLND for the automotive industry, including two types of goods, will be presented.

Design/methodology/approach: Critical examination of literature on Distribution Networks (DN), Supply Chain Network Design (SCND) and Outbound Logistics Network Design (OLND) related to the automotive industry will be conducted in order to understand how optimization problems are currently addressed in their context. Several models and approaches will be investigated and analyzed. The findings of the academic literature and the empirical findings from the supporting company will be combined to construct a model, tested at Lynk&Co, relevant for the automotive industry.

Expected findings: A critical evaluation of current theories tackling Distribution Networks (DN), Supply Chain Network Design (SCND) and Outbound Logistics Network Design (OLND) will show that there is still limited research conducted on new mobility trends and their effects on practices in supply chains and logistics flows of car manufacturers. Current research and their results are not in a form that is actionable for practitioners embracing the shift in customer preferences in the automotive industry. The forward-looking research will provide understanding of the current research and propose a modified solution as well as identify gaps for further research and better practice for a more mature supply chain for car manufacturers in the future.

Research implications: The paper will provide an extensive literature review to identify key elements used in current DN, SCND & OLND and present a model usable to develop an optimized cost-based optimization for an outbound logistics network for an automotive Original Equipment Manufacturer (OEM)

Practical implications: The extensive research on current practice in Supply Chain Network design and Outbound Logistics Network design aims to support, assist and challenge current practice in the automotive industry and at the supporting company, Lynk&Co.

Keywords: *Supply Chain Network Design, Outbound Logistics Network Design, Distribution Network, Supply Chain Design, Automotive*

Type of paper: Degree project in Msc. Logistics and Transport Management

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1. Introduction

In the following section, the readers will be introduced to the thesis. A summary of current trends in the automotive industry and the supporting company, Lynk&Co, will be presented in order to clarify the background and to narrow down the scope of the thesis. The identified research problem will be addressed, a clear purpose as well as the delimitations will be stated.

1.1 Background

Despite several technologies that have been revolutionizing a broad range of industries, the distribution and sales model in the automotive industry has barely undergone any significant changes since the 1980s. This old view has put the industry in a disconnected flow with its customers and fails to satisfy the needs and wants of all its stakeholders (Deloitte, 2019).

Related to the increasing disconnection between stakeholders and car manufacturers, new entrants in the industry are starting to fill the gaps that are left by established players. Their main practices are to cut out large, out of town retail units and instead choosing to work from smaller sites. Another point of differentiation is the online sales model through which processes are operated (Deloitte, 2019). On top of that, it may be argued that Mobility as a Service (MaaS) will become the norm and allow for new opportunities in the industry (Roland Berger, 2018; McKinsey, 2017; Deloitte, 2019). Traditional car offerings are transforming, generating a shift from the historical asset-oriented view towards flexible and service-oriented mobility solutions (Roland Berger, 2018). The amount of mobility options offered is growing, but most people will remain using private cars as main transportation mode in the near future (Grazia Speranza, 2018).

One can say that this current disruption in the automotive industry has been generated by a combination of more digital technologies, platforms, electro-mobility and autonomous driving. Direct to consumer (D2C) models become a norm through a more extensive usage of digital platforms and creation of network effects across industries which car makers were relatively slow to respond to (McKinsey, 2017).

The above identified trends will have a significant impact on all the business processes used at car manufacturers. Supply chains and logistics movements will be affected and distribution networks will have a significant importance on the road to success (Roland Berger, 2018). Variation in offerings requires the need for improved flexibility, anticipation and response in the distribution. The goal is to achieve balanced flows and planning in the distribution network. In finished vehicle logistics and distribution, one must be even more careful of higher costs and imbalances in the transportation flow in times of disruption (Automotive Logistics, 2019b).

Operational steering of the network currently is considered as the most time-consuming part of the outbound logistics vehicle flows. Vision, competencies and understanding of the possibilities and challenges related to the distribution network, are needed, whereas the whole chain should be considered to create synergies across the full OLN (Automotive logistics, 2019a)

This thesis concerns the development and modification of cost optimization models for the design of an outbound logistics movements network for car manufacturers and is tested at Lynk&Co, a car manufacturer owned by the Chinese Geely Holding.

Identified by Roland Berger (2018), Europe is the leading market in both size and maturity in the new mobility shift and six core countries are at the forefront of this movement (France, Germany, Italy, The Netherlands, Spain, UK). A set of these markets will be serviced by Lynk&Co.

In further stages of this research process, some content and numbers will be anonymized as stipulated in a non-disclosure agreement signed by the author and Lynk&Co.

1.2 Problem description

The existing literature on SCND and OLND for OEMs in the automotive industry mainly considers one type of product in the outbound logistics flow. This ignores the new stream in the automotive industry where besides car sales and lease plans, subscription and mobility offers need to be included as well. This will impose some requirements on the downstream logistics chain and affect all the actors involved in this process. Starting from a build-to-stock supply, KPIs, identified by stakeholders involved and affected by the OLND at the company must be taken into account in order to gain an optimized cost-based logistics solution for outbound logistics flows at car manufacturers.

1.3 Research purpose

The purpose of this project is to conduct an extensive literature review on the current status in DN, SCND and OLND relevant for automotive OEMs and identify elements and research gaps to create a modified strategic cost optimization model for on-land OLND. Given the described purpose, the research objective can be formulated as follows:

Proposal for an optimized cost-based Outbound Logistics Network Design (OLND) for a car manufacturer.

This research objective can be broken down into two sub-objectives that will support the process to answer the general research question.

1. *Modifying previous models in OLND for car manufacturers.*
2. *Testing the presented model and its applicability for the automotive industry.*

1.4 Delimitations

To be able to perform the project in the limited timeframe, the scope is narrowed down. Firstly, within the outbound logistics flow, the focus will mainly be on the cost perspective of the industrial outbound logistics flow. By doing so, other parts of the supply chain such as last mile logistics and inbound logistics will not be considered. The ambition is to create a model which can be used by car manufacturers but tested and validated by one player in the market. Moreover, the presented research will mainly focus on cost optimization. Discussion on other KPI´s will be limited in this research.

1.5 Disposition

The research will have the following structure: chapter 1 describes the background to the thesis project, chapter 2 will contain a review of previous research, models and frameworks to obtain a solid understanding of the operational area. The research methodology will be presented in chapter 3. Chapter 4 will present the suggested model to answer the research question. Chapter 5 contains a description of the elements considered in the case-study. An analysis and discussion will be provided in chapter 6 of this degree project and will be followed by a summary with the most important conclusions and findings in chapter 7.

2. Literature review

This section, literature review, defines a right context to address the identified research problem. Distribution Networks (DN), Supply Chain Network Design (SCND) and Outbound Logistics Network Design (OLND) have been identified as the main domains and relevant streams of literature for this research project. Definitions, needed background and main characteristics for the cost-optimization of an OLND in the automotive industry will be considered. After establishing a connection between important concepts, amongst others, several models will be analyzed and assessed.

The first part of this chapter focuses on both general trends and logistics processes and network design in the automotive industry. This is an important element as it helps to understand the shift in practice and network designs that is happening at OEMs. The second section will discuss current DN, SCND and OLND practices in manufacturing industries, applicable to the automotive industry. Gaining a better understanding of trends and processes in the automotive industry, research on OLND and SCND will help answering the research question concerning an improved OLND-model for a car manufacturer.

2.1 Automotive industry.

The automotive industry has been a field without relatively much change over the past decades (Candelo, 2019). For many years, OEMs have been reluctant to accept the change from being just vehicle manufacturers to transportation solutions providers. Driven by digitization, new technologies and connectivity, multiple industries transformed from selling stand-alone products to providing consumer-oriented, full-service solutions with better reach, speed and convenience (Candelo, 2019). The effects of innovation in the industries serving durable goods such as automotive came later. Manufacturers heavily underestimated the possible consequences due to a lack of understanding. Automotive OEMs were afraid that making a fast shift was going to damage their existing products (Candelo, 2019).

Both Ford and General Motors (GM) launched their own value chain based on digital technology in November 1999. This can be argued as the first significant attempt in the history of the automotive industry to create a platform between customers and the OEMs. (Candelo, 2019). Over the past years, alongside with other industries, the actors in the automotive industry have faced fundamental changes in their value chain (Dörnhöfer et. al, 2016). These changes were mainly inspired by platform-based models focusing on developing relationships between participants in companies their networks (Roland Berger, 2018 ; Candelo, 2019; Dörnhöfer et. al, 2016). Customer demand, requirements and preferences have changed as fierce competition and fluctuating market demand has been on the rise (Zhang and Cheng, 2006).

In a traditional automotive value chain, value is created in separate stages. At parts and component suppliers, value is created with higher value products whereas at automotive manufacturers, assembly, design, marketing and branding generate the added value. Automotive dealers create value through sales, inventory management services and pre- and post purchasing before the product is received by the consumers. Current platform-based practices create more intense relationships between all these participants and shape a new perspective on the traditional value chains in use. This form of platform connection and digital interaction in the automotive industry has made a significant impact on the automotive industry and its stakeholders, yet, still behind compared to other major sectors (Candelo, 2019).

Traditional car demand is transforming, generating a shift from the historical asset-oriented view towards flexible and service-oriented mobility solutions (Roland Berger, 2018). The amount of mobility options offered is growing, but most people remain using private cars as main transportation mode (Grazia Speranza, 2018).

According to Ambe & Badenhorst-Weiss (2010), supply chain has been considered as a very important source of competitive advantage during times when an industry is transforming. A high degree of flexibility and customer responsiveness is required in order to keep operations streamlined and able to respond quickly. Buzzavo (2013) takes a similar stand and argues that perceived value by the customer is not only related to the finished product but also, amongst others, to the service and precision linked to the delivery of the car. Moreover, a significant portion of costs related to a value chain is generated by distribution flows. Industry observers estimate distribution costs to account for a percentage between 25% and 30% of the total vehicle list price (Buzzavo, 2013).

2.2 Supply Chain Network Design and Outbound Logistics Network Design in the manufacturing and automotive industry

2.2.1 General

The Council of supply chain management professionals defines supply chain management (SCM) as *“encompassing, planning and managing all activities involved in sourcing and procurement, conversion and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners which can be suppliers, intermediaries, third-party service providers and customers. (CSCMP, 2013)”*

Logistics Network Design (LND) is the planning processes within supply chain management (SCM) and the related Supply Chain Network Design (SCND), with the aim to optimize logistics flows and involves the location-allocation process regarding the amount and location of distribution centers and its capacity. This, in order to achieve cost minimization and a maximum level of customer satisfaction (Melo, 2014; Jaryaraman & Ross, 2003). It is an important component of a firm´s overall business strategy and has a direct impact on long term distribution investments and set-up (Robinson & Swink, 1994).

Outbound Logistics Network Design (OLND) and Distribution Networks (DN) are part of LND and SCND and are those services provided from the moment that the goods have left the production plants and go to the end location (Basic & Pavlic Skender, 2017). According to Eskigun et al. (2005), *“vehicle distribution network of an automotive company consists of all activities required to deliver finished vehicles from the assembly plants to the dealers”*.

One could see logistics as a key factor in the very competitive environment of the automotive industry. This is due to the increasing number of offers and variations from the OEM (Dörnhöfer, Schröder, Günthner, 2016). On top of that, the location of distribution centers is important in the logistics stream to balance long-term performance capabilities of a supply chain, customer needs and cost perspectives (Nozick & Turnquist, 2001). Facility locations represent long-term decisions. It is often either impossible or very costly to change locations frequently over the lifetime of the supply chain. Thus, locations that are not aligned with and do not support the strategic goals of the company may lead to long-term persistent inefficiencies and potential inability to achieve the firm´s strategic goals (Daskin & Mass, 2019).

Strategic decisions made on DN, SCND and OLND are important as they are the base for effective and efficient tactical and operational processes (Melo, 2014; Zheng & Yin Zhang, 2019; Zijm et al., 2019). The strategic level decision involved in SCND are the location of facilities and the allocation of customers to it. The tactical decision that SCND should deal with is how to control inventory and distribution in facilities (Zijm et al., 2019). The operation decision related to SCND is the routing problem (Zheng, 2019). As decisions related to distribution management have an impact on different levels of decision making in the company, it is important continuous evaluation and performance measurement takes place.

Businesses in the automotive industry operate in a very competitive market which requires controlling of product costs, improving product quality and shortening the development lead time (Roy, Souchoroukov & Shehab, 2011). Cost estimation requires quality data and information. Small margins are in place in outbound vehicle logistics processes and opportunities are needed to improve profitability. According to Roy et al. (2011), several overhead costs need to be considered when designing an OLN. These costs mainly cover labor costs that include a broad range of aspects from wages to premia. Roy et al. (2011) argues logistics costs to include packaging costs, transport costs including returns, inventory cost of finished parts and distribution cost. Costs related to logistics and distribution infrastructure have also been heavily discussed by Roy et al. (2011). These costs mainly include building costs, insurance and machine maintenance and repair. Apart from infrastructure and maintenance costs, the building costs also include depreciations or rent of land and building, if applicable.

Apart from cost aspects, customers are also interested in precision of delivery. This need puts a strong demand on the effectiveness of the overall supply chain and moreover the outbound vehicle distribution (Basic and Skender, 2017). The downstream movements in supply chain can be influenced by several aspects but are mostly vulnerable to change in customer demand (Zijm et al., 2019). Reiner (2005) states the effects of uncertainty in demand and supply on holding inventory and service level for the customers. Holding extra inventory will make customer service level rise but it will come at a higher cost. This identifies the need for a trade-off by exploring possibilities to decrease inventory while still matching the required level of customer service. An increase in orders on the demand side may have negative effects on the upstream flow of goods and can create high logistics costs due to the disproportionality in demanded volumes and transparency gaps. This identifies the need for safety inventory (Zijm et al., 2019).

A need for different types of inventory has also been identified in Reiner (2005). The aim is to create a buffer against volatility and supply chain uncertainties while still acknowledging that inventories sometimes reflect inefficient management of processes in the supply chain. The combination calls for an in-depth look in inventory management when designing logistics and supply chain flows. Finding a balance between the lowest possible inventory level and the highest possible customer satisfaction is needed (Reiner, 2005).

An effective designed outbound supply chain network can reduce the total cost and lead-time while maintaining profitability (Eskigun, 2005). As stated above and accurately summarized by Zijm et al. (2019), several objectives are included in an Outbound Logistics Network Design to achieve best possible practice. Amongst others, the most important are quality, customer satisfaction and cost-efficiency. An optimized transport system needs to be in place to move the goods to multiple geographical areas. Linked to both distribution and transport systems, evaluation and performance measurement systems to ensure that the right goods reach the right place at the right time in the right quantities need to be set up (Zijm et al., 2019).

Basic et al. (2017) identifies several criteria that reflect on performance of successful automotive outbound supply chain in his research. Among others, these are: on-time pickup, delivery reliability, lead time, dwell time and damage-free delivery. The reason to measure performance in the automotive sector is not different from any other industry. Companies must excel on various fronts, including cost, design, functionality, manufacturing and quality (Roy, Souchoroukov & Shehab, 2011). It is obvious that choice of performance indicators has an impact on operational decisions related to the logistics network. Basic et al. (2017), as earlier defined by Blanchard (2014), describes reliability as one of the main parameters when it comes to performance measurement of a logistics system. Previous literature has defined delivery reliability as the ability to stick to the defined schedule or planning. Translating this to the field of outbound logistics, this is referred to as the reliability to deliver the vehicles on-time, in-full and error-free (Basic et al., 2017).

Dörnhöfer et al. (2016) discussed the current, limited amount of performance management systems for logistics chain and identified a bigger need for better performance indicators. Basic et al. (2017) describes the difficulty to measure logistics operations and parameters to create better understanding in the processes, collaboration efforts and excellence in supply chain.

KPI´s should be analyzed in order to point out fluctuations. In case certain performances tend to have a negative curve, actions should be undertaken (Basic et al., 2017). At the same time, one should be careful with the use of systems for controlling logistics costs as those can cause disruptions in business processes due to an excessive focus on cost reduction (Škerlič & Muha, 2016)

The identified shift in car and mobility usage and more extensive use of sharing options in the automotive industry, will generate a more extensive reverse logistics flow to be considered. Jayaraman, Patterson & Rolland (2003) describe the reverse logistics flow as a flow covering the logistic activities from used products that are no longer required by the customer, to products again usable in the market. As in forward logistic flows, this contains the process of planning, implementing and controlling the efficient, cost-effective flow of goods and its information (Jayaraman, Patterson & Rolland 2003). The reverse stream includes both the physical transportation of the goods as well as transformation or refurbishing. This requires inventory management and production capacity constraints to be included (Fleischman, Bloemhof-Ruwaard, Dekker, Van Der Laan, Van Nunen & Van Wassenhove, 1997). Designing this channel for reverse flow operations requires businesses to consider the product, customer and demand characteristics together with the already occurring forward distribution system (Jayaraman et al., 2003). Although similarities occur between both flows, there will be elements such as capacity constraints over a multi-period planning horizon to be considered (Zikopoulos & Tagaras, 2015). Cardoso, Barbosa-Póvoa & Relvas (2013) discuss in their work the so called closed-loop supply chain in which forward and reverse supply chain activities are included together. The paper includes returned products and assumes that the collected products are brought back into the forward logistics stream after being refurbished. The overall objective of Cardoso et al. (2013) is to include optimal distribution planning with maximized value when setting up a supply chain structure.

2.2.2 Applicable models on OLND and SCND and related concepts in the automotive industry

The identified loading and routing problem of finished car logistics is hard, and the exact optimal solution cannot be obtained in a short time when the problem size is large. Several models and available research can assist to solve that problem.

The outbound supply chain network design model presented by Eskigun et al. (2005) is wildly accepted research in the automotive industry. The published paper provides a long-term perspective on OLND through scenario analysis and includes elements such as location and size of distribution centers, delivery transport mode and throughput volume. Eskigun et al. (2005) identifies a research gap compared to previous research, related to measuring customer satisfaction and operational aspects such as lead time. Referred to by Eskigun et al. (2005), Bookbinder (1988) has been used as a solid foundation for further research concerning distribution system design. His work discussed simple plant allocation problems, concerning cost minimization of transportations flows when deciding upon the location of a distribution center. Its outcome is rather practical in a strategic sense but less applicable for operational aspects.

Eskigun et al. (2005) includes waiting times in network nodes in his research. This is far from traditional and in previous research often considered as optional and not included as standard in a network design model. Eskigun et al. (2005) questions this abstraction of lead times in network optimization as it might result in a completely different network structure. Their approach distinguishes this work from previous research on network design models. Furthermore is assumed that the regional distribution centers (RDC) have no capacity restrictions on the number of vehicles that can be handled throughout the year. By doing so, the model assumes both routing and location decisions regardless of congestion and inefficiencies as a constant factor (Eskigun et al., 2005). The same transportation mode is considered throughout the delivery from one node to another. This considers economies of scale in processes such as loading, unloading etc. An increase in the percentage of truck usage results in a higher average transportation cost due to higher cost structure of truck compared to rail. In their findings, Eskigun et al. (2005). concluded that an increase in truck transport will decrease the effect of capacity limits on supply chain performance drastically.

Zheng et al. (2019) also presents a model aiming to optimize location, inventory and routing decisions in an outbound logistics network design, motivated by a Chinese passenger car company. This research focusses on capacity limitations of the truck deliveries and the limit on the number of locations that can be visited in one trip by one carrier vehicle. A three-tire supply chain system with one product type is considered, consisting of one supplier, multiple distribution centers and several end nodes. A restricted service radius is applied at each node. The mentioned location decisions involve choosing and locating a set of distribution centers and the allocation of customers to each distribution center. An integrated approach of this location decision together with inventory policies (including safety stock) and routing decisions is presented in a way that the total cost is minimized (Zheng et al., 2019). As in the research of Eskigun et al., 2005, the replenishment lead times of each DC are considered constant. Customer demands are independent and uncertain which follow the normal distribution with a known mean and standard deviation.

With the objective to minimize fixed and variable costs in the OLND, Geoffrion and Graves (1974) provides a model to find the optimal location for warehouses and each of its nodes in the network. This model, described in Zijm et al. (2019), considers multiple product types with known demand for each product type at the several customer areas. The goods are shipped from the origin destination to the customer areas via intermediate distribution centers and each customer area is only served by one warehouse with known upper and lower capacity bounds and a fixed cost of opening.

The objective of Manatkar et. al (2016) is to decrease inventory carrying and transportation cost. This includes the level of regular and safety stock, inventory holding cost and transportation cost in order to make an optimal assessment of the distribution network. Manatkar et. al (2016) considers a two-echelon environment with a single central distribution center (CDC), multiple regional distribution centers (RDCs) located geographically across a territory distributing multiple products to a set of local distribution centers (LDCs). This research contributes to making an integrated decision regarding the optimal assignment of a group of customers to multiple distribution centers (DCs), the level of safety stock to be stored at each facility by upholding given service level, the level of regular stock to be maintained at each facility and the maximum inventory at any echelon in the system.

Manatkar et al. (2016) has identified efficiency and responsiveness as two strategies that have emerged in supply chain practice in the recent year. According to their research, a supply chain consists of six drivers: location, transportation, information, sourcing, pricing and inventory. Managing inventory in a distribution network consists of three critical tasks. One must determine the location of the distribution centers (DCs) and allocate a group of customers to each DC while determining the amount of inventory at each location in the supply chain. The model supports generating management insights which will help to deal with real-world SCND problems. Manatkar et al. (2016) concluded that ordering management cost is not an indispensable part in the supply chain network design model if the company can control it efficiently. Besides that, reducing lead time has a limited influence on the structure of the supply chain network. Suggestions have been formulated to conduct further research on integration of other effective heuristic methods on real world design problems to include in the model. The authors also open the discussion for further research with multiple suppliers and multiple products, acknowledging its complexity.

Considering a manufacturing supply chain, Hiremath et al. (2013) proposes a domestic distribution network based on identified customer zones (CZs) with a known demand. The customer zones are served by an initial point of distribution and including several potential distribution centers, both regional and local. The objective of the paper is to design an OLND that delivers products at a desired speed and a configuration distribution network with multiple, changing, objectives such as to minimize cost, maximize the unit fill rate and maximize the resource utilization of the facilities in the network. Three demands have been classified by Hiremath et al. (2013): fast moving item, slower moving item and very slower moving item. A separate distribution strategy is used for each product type on a demand-based level. The proposed delivery channels are based on delivery lead time.

The single time, four echelon model, which does not allow shortage of inventory, identifies success of an outbound logistics network design dependent on its speed, flexibility and its efficiency in delivery towards customers. The research shows a short, moderate and longer lead time for respectively fast, slow and slower moving items. The outcomes of the study are argued to be beneficial for the managerial community. Identified extensions may include global network, multiple time periods, scalable capacities for facilities and elements of uncertainty in demand, unit cost and capacities to achieve a bigger scope (Hiremath et al., 2013).

Winkelkotte et al. (2005) aims to optimize complex logistics systems with approximate estimation of tactical and operational costs in order to generate a solid information base that can be used in the strategic problem solving. Their research argues that the most common approach in vehicle routing problems is to solve them with a set of exemplary customers and demands. The author argues that these approaches generate solutions that will not be performed.

The distribution area is investigated and choices for location and number of distribution facilities are identified. The result illustrates an optimal partition of the total area into smaller regions and districts to be served. Information considered is the customer demand and its distribution. In order to locate facilities and resources, Winkelkotte et al. (2010) draws border lines around each facility to define the regions for which each facility is responsible. The result is a partition of the total area into smaller regions and the located facilities must organize the distribution process within the region they are in charge for. The decision where to draw a border line depends on the demand density but not on potential customer locations. The constraint that the regions are connected is added.

Winkelkotte et al. (2005) reflects on their work as a tool to optimize strategic facility location problems approximately but acknowledges that the output requires further analysis in the form of logical thinking as well.

To conclude, Melachrinoudis & Hokey (2007) discuss a model analyzing customer reach from the nearest warehouse. The research assumes truck transportation as primary mode of transportation and considers both less-than-truckload (LTL) or truckload (TL). All products are considered to move from an initial point of distribution through a RDC to the end customer zone where a rational for warehouse location is established. The paper considers factors such as start-up cost, startup risk, labor availability, local regulations, tax, proximity to major customer bases, capacity expansion, overlap, learning curve and high cost. The research argues that a big share of volume might be concentrated in a certain area, so it is important that this is in line with corporate goals on inventory, warehouse cost and preferred service radius (Melachrinoudis et al., 2007)

3. Methodology

Arlbjørn & Halldórsson (2002) assign methodology an important role in generating logistics knowledge and facilitating a linkage between philosophy of science, theoretical perspectives and practice. Hence, this chapter will present the research method used to answer the research question and fulfill the purpose of this study. First, the research approach will be presented, followed by the research process, data collection & analysis and the quality of research.

3.1 Research purpose

Kerlinger (1986) states that the purpose of research is to increase the understanding of a phenomenon through a form of systematic process of collecting and analyzing data. The purpose of this research has been stated in section 1.3 of this degree project.

3.2 Research approach

Two main approaches have been identified by Patel & Davidson (2011): inductive or deductive approach. An inductive approach aims to develop a theory and is preferred when the amount of information is limited and there is limited previous research on the topic is available whereas deductive approach is used to provide add-ons on the existing theory.

The following research is based on a deductive approach as it will analyze previous research, combining relevant elements to be tested with a case study at Lynk&Co.

3.3 Research design

Sreejesh et al. (2013) defines research design as a framework for conducting a research project in an efficient manner where details on the process to collect, measure and analyze data are identified. Its goal is to maximize the likelihood of generating evidence that can provide convincing answers to research questions for a given level of resources and data (Woodside, 2010). Measurement is a very important aspect defined by Reiner (2005) related to the context of quantitative model-driven empirical research.

3.3.1 Modelling

Quantitative model-driven research can be divided into two different classes (Reiner, 2005). The first class, axiomatic approach, includes strict processes of theorems and logical proofs such as mathematical frameworks. The second identified class by Reiner (2005) is a model-driven research and is determined by empirical findings and measurement. The aim is to assure a good model fit between observation and action in reality.

The following research is model driven and will modify existing research and present a quantitative model to support decisions on OLND in the automotive industry. Quantitative and model driven empirical research takes advantage of the number of already published quantitative research projects (Reiner 2005). Based on Law & Kelton (2000) and described by Reiner (2005), a simulation process will be used in this research. First, a problem will be identified with specific objectives to be considered. Secondly, data will be collected based on the identified objectives. This data will include previous relevant research and empirically gathered data at Lynk&Co and will show what is known about the research question. Hereafter, basic assumptions concerning DN, OLND and SCND processes will be generated based on those underlying models. A conceptual model will be presented defining the relevant variables of the study, nature of relationship and their measurement. The outcome will be put into a computational framework of which a pilot run and verification and validation run will be conducted. In the last steps, improvement runs for further development of the model are presented.

3.3.2 Case study

"A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when boundaries between the phenomenon and context are not as clearly evident". (Yin, 2014 ; Dörnhöfer et al., 2016). The three main purposes of this kind of research are to analyze the identified problem, evaluate the possible alternatives and discover new ideas (Sreejesh et al., 2013).

An exploratory case study has been selected as testing method for the identified model, allowing for identification and description of critical variables (Dörnhöfer et al., 2016). This case study will be conducted at Lynk&Co as previously clarified in section 1.1 of this degree project and has the purpose to test and validate the model presented.

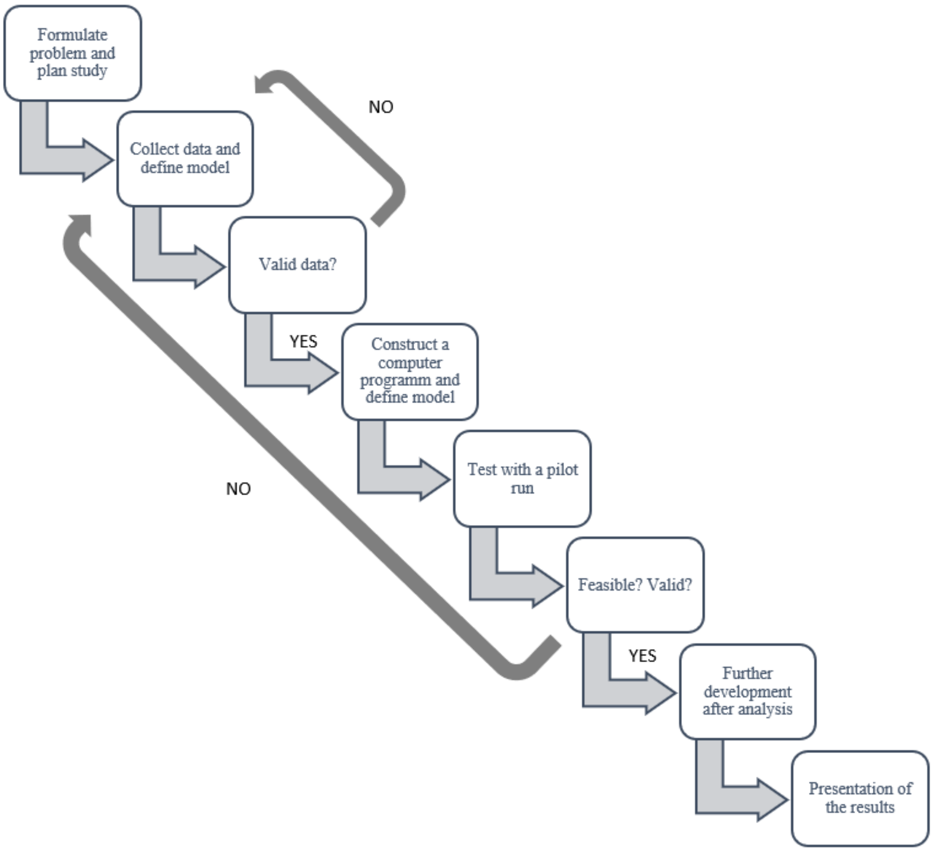

Figure 1. Research design

3.4 Research quality

Quality assurance is an important aspect to include in the research methodology. When gathering, analyzing and assessing data and its quality, several key principles must be considered (Rowly, 2012).

3.4.1 Data collection

In the following research, academic literature, industry reports and other secondary company-external data will be combined with information and data gathered at Lynk&Co: documents, interviews, archival records, direct observation, participant observation. Interviews and internal communication were further used to steer the direction of the literature search Due to a signed non-disclosure agreement with the company, The data included in this research will be available as evidence in a case study database but not presented in this academic project. As defined by Rowly (2012) it is important to have a good grasp of the questions and propositions needed to be examined in the case study using for testing as well as the ability to be unbiased and flexible when conducting the research. Different kind of insights and information will be gained from multiple sources and all of them have both their strengths and weaknesses. This multi-facetted perspective makes the study a very rich form of research (Rowly, 2012).

Primary data as defined by Sreejesh et al. (2013) will be used in the form of in-depth interviews both in unstructured, semi-structured and structured form. Unstructured interviews tend towards a natural form of conversation without clear guidance. Semi-structured interviews allow some amount of flexibility although the interviewer guards the situation so that the topic is strictly directed to the actual topic. Unstructured, semi-structured and structured forms of interviews will be used to identify parameters and data for the optimization model at Lynk&Co. A structured interview will be used to validate the presented model at the company.

Secondary data in the form of company documents and (academic) literature has been identified as another source of input for this exploratory research and will help to identify a better understanding of the research problem. Both qualitative data and quantitative data as defined by Sreejesh et al. (2013) will be used for the conducted research. To achieve the objective of the paper, articles on Supply Chain Management, Supply Chain Network Design and Outbound Logistics Operations Network Design, related to the automotive industry were searched via a mega search on the online databases GU library catalogue, Science direct and the European Journal of Operations Research and hereafter reviewed. The year 1999 was chosen as a starting point for selecting papers for review on OLND, DN and SCND since this year can be marked as a key year for practice in the automotive sector as both Ford and GM announced their plan to each launch their own value chain based on digital technology. This has been the starting point for many OEM to slowly start to rethink their processes (Candelo, 2019). Secondary empirical data on the company will be gathered from their databases and already existing documentation.

3.4.2 Data analysis

All propositions and identified problems should be addressed in an unbiased and objective manner (Rowly, 2012). Koullikoff-Souviron and Harrisson (2005) states three components of data analysis: data reduction, data display and conclusion drawing. Data reduction refers to the process of selecting, focusing, abstracting and transforming the data as a form of data preparation whereas data display will help to see patterns in the research.

Further data analysis based on the modeling procedure discussed by Law & Kelton (2000) is argued to be relevant as well. Analysis of the earlier gathered data will be done and its validity to use in our model needs to be tested, as presented in section 3.4.3 . Relevant variables on characteristics of the proposed model for OLND will be presented and relationships, measurements and their effect on the processes discussed will be revealed. To conclude, an analysis of the model and it´s pilot run testing will be conducted. Decisions and assumptions related to the supply chain in use will be made to assure feasibility of the presented logistics process in this research. As a part of the analysis, the data gathered at Lynk&Co will help testing the identified model and challenge it. The processes will either be confirmed, or an improvement of the model is suggested.

3.4.3 Data quality

Once the data is gathered, certain quality aspects need to be measured. Rowly (2012) and Seuring (2005) list validity and reliability as two important concepts to consider when assuring quality in research designs.

As described by Koullikoff-Souviron (2005), increased reliability can be achieved by documenting the research process to such an extent that the data can be duplicated at a later stage. The use of a research protocol will be able to ensure traceability of the data, hence increasing reliability.

Furthermore, two types of validity, internal and external, have also been identified by Koullikoff-Souviron (2005). Internal validity examines whether the right cause and effect relationships have been established and will be achieved through regular checkups with the company. External validity tackles the question of the applicability of all the findings beyond the population under study. As earlier discussed in earlier research by Yin (2003), Rowly (2012) also discusses construct validity, or the degree to which this research can state that it measures what it claims to measure, hence reducing and excluding subjectivity.

On top of reliability and validity, viability of the research will be investigated by stating feasibility of the model. Feasibility can give focus to a project and is able to identify if one should not proceed. Moreover, it can identify that the purpose of research has been investigated thoroughly (Hofstrand & Holz-Clause, 2009)

Multiple data collection methods are used which allows for better triangulation (Koullikoff-Souviron and Harrisson, 2005). Several sources will be listed and analyzed on OLND, DN and

SCND. All the data that has been gathered on the case-study will be centralized. Such data can include all notes, interviews, documents collected during research and available as evidence (Rowly, 2012).

Although the research is conducted at one specific OEM in the automotive industry, when using the above described data quality measures, the findings can be considered for other actors in the business network as well as other industries that identify their outbound logistics network design closesly related to this research.

4. Modelling

Shapiro (2001) describes optimization models in such a way that they provide a broad and rich framework with the ability to combine data, relationships and forecasts. Optimization models have the power to provide stakeholders with valuable insights in scenarios based on decisions, objectives and constraints identified by the company.

In this section, a strategic mathematical model for cost optimization of an Outbound Logistics Network Design will be shown. The formulation of the model integrates costs related to transportation, fixed investments, handling, lead-time and inventory for allocation choices of distribution in the network. Two types of products will be considered: fast moving goods (car subscription offerings) and slower moving goods (car sale and leasing offerings). The model has aimed application for (re)designing a new logistics network.

The industrial OLND-problem is situated in a two-echelon environment with a single central distribution center (CDC), multiple regional distribution centers (RDC), geographically spread over identified districts or customer zones (CZ), and a set of local distribution centers (LDC).

The aim is to find a near-optimal solution heuristically. This, meaning that its aim is not to find the exact optimal solution, but still wants to find the best possible solution (Winkelkotte et al.,2011). The choice for heuristic methodology and the gap in optimal solution generated by this approach can be justified as followed: Firstly, a trade-off must be made between the quality and the time limit of computing and research time. As the proposed model should be seen in a strategical context, where decisions need to be as precise as possible but within a reasonable time frame that allows for scenario analysis for managerial decisions, it is important that the solving times are not too long. Besides that, models should not be a full representation of the reality as it is not an exact solution of a real-world problem. Lastly, input data is in most cases not exact when looking into strategic problems (Winkelkotte et al., 2011).

The model will be tested in a Microsoft Excel – solver environment. The basic purpose of the Solver is to find a solution that satisfies the constraints and, in this case, minimizes the cost objective for our network design. The multi-objective model will select warehouses and distribution centres and will assume these selected sites fixed for re-optimization. The model can identify if potential facility locations and logistics structure are optimal for the company to minimize operational costs.

The outcome of the computational results of the model should be merged with the cognitive capabilities of management involved in the strategic decision-making process in a form of a scenario evaluation (SE) approach to network design systems and is suggested to be iterative (Robinson & Swink, 1994).

The following assumptions for the model have been made:

- Two types of products are considered: fast moving products (subscription cars) and slower moving products (cash & lease cars)
- The demand of each regional distribution center will be served by exactly one central distribution center.
- The demand of each local distribution center will be served by exactly one regional distribution center.
- Forecast of slower moving good and fast-moving good at the CZ is known
- Distribution centers (DC) have no capacity restrictions on the number of vehicles that can be handled throughout the year
- The dwell-time is constant over the full time of the investigated dwell time
- Only road transportation by truck is considered.
- Abstraction of taxation rates has been made.
- A single transportation cost per kilometer is considered

The suggested heuristic model will include the following parameters and decision variables:

Parameters

i: index of Central Distribution Center (CDC) (i = 1,2,…I) (1)

j: index of Regional Distribution Center (RDC) (j = 1,2,…J) (2)

k: index of Local Distribution Center (LDC) (k=1,2,…K) (3)

l: index of Customer Zone (CZ) (l=1,2,…L) (4)

d: index of district D(5)

I: number of CDCs (6)

J: number of RDCs (7)

K: number of LDCs (8)

L: number of customer zones (9)

D: set of districts (10)

CDC_i: CDCI (11)

RDC_j: RDC j (12)

LDC_k: LDC k (13)

CZ_l: CZ l (14)

q: index of “slower item” cash car and lease car (15)

p: index of “faster item” subscription car (16)

b_i^p: production capacity for fast moving item p in plant CDC_i (17)

b_i^q: production capacity for slower moving item q in plant CDC_i (18)

b_j^p: production capacity for fast moving item p in plant RDC_j (19)

b_j^q: production capacity for slower moving item q in plant RDC_j (20)

b_k^p: production capacity for fast moving item p in plant LDC k (21)

b_k^q: production capacity for slower moving item q in plant LDC k (22)

d_l^p: yearly demand for fast moving item p from CZ_l (23)

d_l^q: yearly demand for slower moving item q from CZ_l (24)

d_l^{pq}: yearly demand for all items from CZ_l (25)

μ_i^{pq}: mean demand for fast moving item p and slower moving item q at CDC_i (26)

μ_j^{pq}: mean demand for fast moving item p and slower moving item q at RDC_j (27)

μ_k^{pq}: mean demand for fast moving item p and slower moving item q at LDC k (28)

σ_i^{pq}: standard deviation for fast moving item p and slower moving item q at CDC_i (29)

σ_j^{pq}: standard deviation for fast moving item p and slower moving item q at RDC_j (30)

σ_k^{pq}: standard deviation for fast moving item p and slower moving item q at LDC k (31)

tpv_{ij}^p: transit time from CDC i to RDC j for fast moving good p (32)

tpv_{ij}^p: transit time from RDC j to demand LDC k for fast moving good p(33)

tpv_{ij}^q: transit time from CDC i to RDC j for slower moving good q (34)

tpv_{ij}^{q}: transit time from RDC j to demand LDC k for slower moving good q(35)

u_i^p: upper bound storage capacity of CDC_i for fast moving item p (36)

u_i^q: upper bound storage capacity of CDC_i for slower moving item q (37)

u_j^p: upper bound storage capacity of RDC_j for fast moving item p (38)

u_j^q: upper bound storage capacity of RDC_j for slower moving item q (39)

u_k^p: upper bound storage capacity of LDC_k for fast moving item p (40)

u_k^q: upper bound storage capacity of LDC_k for slower moving item q (41)

f_i: fixed cost of opening and operating CDC_i. This does not depend on the volume nor capacity of CDC_i, but is the fixed cost of establishing a new CDC_i(42)

f_j: fixed cost of opening and operating RDC_j. This does not depend on the volume nor capacity of RDC_j, but is the fixed cost of establishing a new RDC_j(43)

f_k : fixed cost of opening and operating LDC_k. This does not depend on the volume nor capacity of LDC_k, but is the fixed cost of establishing a new LDC_k (44)

V: maximum number of RDC_j to be opened (45)

U: maximum number of CDC_i to be opened (46)

W: maximum number of LDC_k to be opened (47)

v_i : variable cost of handling goods at CDC_i (48)

v_j : variable cost of handling goods at RDC_j (49)

v_k : variable cost of handling goods at LDC_k (50)

X_{ijk}: 1 if vehicles are delivered from CDCi to LDCk through RDCj, 0 otherwise(51)

π_{jd}: 1 if facility $j \epsilon J$ is located within district d ϵ D; 0 otherwise (52)

OC_i: administrative cost of placing an order at CDC_i (53)

OC_j: administrative cost of placing an order at RDC_j (54)

OC_k: administrative cost of placing an order at LDC_k (55)

h_i: inventory holding cost per unit of product, per unit of time at CDC_i, including total interest paid on average vehicle per day (56)

h_j: inventory holding cost per unit of product, per unit of time at RDC_j, including total interest paid on average vehicle per day (57)

h_k: inventory holding cost per unit of product, per unit of time at LDC_k, including total interest paid on average vehicle per day. (58)

h: monetary value of the lead-time (x euro / per day) assessed by the company (59)

c_{ij}^{q}: unit cost of shipping item q from CDC_i to RDC_j (60)

c_{ij}^{p}: unit cost of shipping item p from CDC_i to RDC_j (61)

c_{jk}^{q}: unit cost of shipping item q from $RDC_j$to LDC_k (62)

c_{jk}^{p}: unit cost of shipping item p from RDC_j to LDC_k (63)

x_{ij}^{q}: quantity of slower moving item q transported from CDC_i to RDC_j (64)

x_{ij}^{p}: quantity of fast-moving item p transported from CDC_i to RDC_j (65)

x_{jk}^{q}: quantity of slower moving item q transported from $RDC_j$to LDC_k (66)

x_{jk}^{p}: quantity of fast-moving item p transported from $RDC_j$to LDC_k (67)

x_{kl}^{q}: quantity of slower moving item p transported from $LDC_k$to CZ_l(68)

x_{kl}^{p}: quantity of fast-moving item p transported from $LDC_k$to CZ_l(69)

x_{ijkl}^{p}: number of fast-moving units p transported from CDC_i via RDC_j and LDC_k to CZ_l (70)

x_{ijkl}^{q}: number of slower moving units q transported from CDC_i via RDC_j to LDC_k to CZ_l(71)

T_i: order cycle of CDC_i= $\sum_{i=1}^{I} t_i z_i$ (72)

T_j: order cycle of RDC_j= $\sum_{j=1}^{J} t_j z_j$ (73)

T_k: order cycle of CDC_i= $\sum_{k=1}^{K} t_k z_k$ (74)

Decision variables

z_i: 1 if plant CDC_i is opened; 0 otherwise (75)

z_j: 1 if RDC_j is opened; 0 otherwise (76)

z_k: 1 if LDC_k is opened; 0 otherwise (77)

y_{ij}: 1 if CDC_i serves RDC_j, 0 otherwise (78)

y_{jk}: 1 if RDC_j serves LDC_k , 0 otherwise (79)

y_{kl}: 1 if LDC_k serves CZ_l, 0 otherwise (80)

4.1 Location

A set of locations (either CDC_i, RDC_j, LDC_k) to be chosen from, used as input for our model, needs to be determined. A tool to define this set of possible facilities is beyond the scope of this thesis and is assumed to differ from case to case depending on different needs identified by the actors using this framework.

As earlier stated by Winkelkotte et al. (2011), the presented model in this degree project, only states the need for a discrete structure where the whole area is portioned in smaller districts that serve the regions or customer zones. These districts are not allowed to overlap each other and need to serve the whole market. The identified size may depend on the context. This constraint can be formulated as follows:

$$y_{jk} \geq \pi_{jd} \sum_{j \epsilon J} z_j \;\; \forall l \; \in D, j \in J$$

4.2 Cost

The identified locations will be used as input for the actual cost optimization model for the outbound logistics network design. The identified cost elements included are transportation costs, lead time costs, fixed costs of opening a facility, variable handling costs and inventory costs. The total cost function that needs to be optimized, hence our objective function can be stated as follows:

$$\boldsymbol{TC} = \sum_{i,j,k}\left(c_{ij}^{q} + c_{jk}^{q}\right)d_l^q x_{ijk}^q + \sum_{i,j,k}\left(c_{ij}^{p} + c_{jk}^{p}\right)d_l^p x_{ijk}^p + \sum_{i,j,k} h\left(LTPVD_{ijk}^{q}\right)d_l^q X_{ijk} + \sum_{i,j,k} h\left(LTPVD_{ijk}^{p}\right)d_l^p X_{ijk} + \sum_{i=1}^{I} f_i z_i + \sum_{k=1}^{K} f_k z_k + \sum_{j=1}^{J} f_j z_j + \sum_{i=1}^{I} v_i (x_{ij}^q + x_{ij}^p) z_i + \sum_{j=1}^{J} v_j (x_{jk}^q + x_{jk}^p) z_j + \sum_{k=1}^{k} v_k (x_{kl}^q + x_{kl}^p) z_k + \sum_{I=1}^{I} \frac{OC_i}{T_i} + \sum_{j=1}^{j} \frac{OC_j}{T_j} + \sum_{k=1}^{K} \frac{OC_k}{T_k} + \sum_{i=1}^{I} h_i \frac{\mu_i^{pq}\, T_i}{2} y_{ij} + \sum_{j=1}^{j} h_j \frac{\mu_j^{pq}\, T_j}{2} y_{jk} + \sum_{k=1}^{K} h_k \frac{\mu_k^{pq}\, T_k}{2} y_{kl} + \sum_{i=1}^{I} h_i \sigma_i^{pq} \sqrt{T_i} y_{ij} + \sum_{j=1}^{J} h_j \sigma_j^{pq} \sqrt{T_j} y_{jk} + \sum_{k=1}^{K} h_k \sigma_k^{pq} \sqrt{T_k} y_{kl}$$

In what follows, a breakdown of this objective function in five cost components will be presented.

4.2.1 Transportation cost

The transportation cost consists of the sum of unit cost of shipping fast moving item p and slower moving item q from CDC_i to LDC_k via RDC_j multiplied by its demand in CZ_l

$$\textit{Transportation Cost} = \sum_{i,j,k}\left(c_{ij}^{q} + c_{jk}^{q}\right)d_l^q x_{ijk}^q + \sum_{i,j,k}\left(c_{ij}^{p} + c_{jk}^{p}\right)d_l^p x_{ijk}^p$$

4.2.2 Lead time cost

The lead time cost consists of the sum of costs at all facilities (CDC_i, LDC_k, RDC_j) of the lead-time of transporting vehicles from CDC_i to RDC_j and then to LDC_k multiplied by the demand at CZ_l of fast moving good p and slower moving item q and monetary value of the lead-time (x euro / per day).

$$\textit{Lead time cost} = \sum_{i,j,k} h\left(LTPVD_{ijk}^{q}\right)d_l^q X_{ijk} + \sum_{i,j,k} h\left(LTPVD_{ijk}^{p}\right)d_l^p X_{ijk}$$

$LTPVD_{ijk}^{q}$ equals the lead-time of transporting slower moving vehicles q from CDC_i to RDC_j and then to LDC_k and is defined defined by:

$$LTPVD_{ijk}^{q} = \mathrm{DTPV}_{ij}^{q} + \mathrm{DTVD}_{jk}^{q} + \mathrm{tpv}_{ij}^{q} + \mathrm{tvd}_{jk}^{q}$$

Where DTPV_{ij}^{q}, DTVD_{jk}^{q}, tpv_{ij}^{q} and tvd_{jk}^{q} are defined in the dwell time for slower moving good q functions respectively between CDC_i and RDC_j and $RDC_j \textit{ and } LDC_k$, as well as parameters sections for slower moving good q. Dwell time functions DTPV_{ij}^{q}, and DTVD_{jk}^{q} consists of the sum of the load make-up time, the time losses due to congestion and the other factors delaying the process (Eskigun et al., 2005)

DTPV_{ij}^{q} = Average dwell time of vehicles shipped from CDC_i to RDC_j.

$= c_{ij}^{1} + \frac{c_{ij}^{2}}{\sum_k d_l^q X_{ijk}}$ if $\sum_k d_l^q X_{ijk} > 0$, 0 otherwise

Where c_{ij}^{1} and c_{ij}^{2} are constant values.

DTVD_{jk}^{q}-= Dwell time for vehicles at RDC_j which are shipped to LDC_k

$= c_{jk}^{3} + \frac{c_{jk}^{4}}{\sum_i d_l^q X_{ijk}}$ if $\sum_i d_l^q X_{ijk} > 0$, 0 otherwise

Where c_{jk}^{3} and c_{jk}^{4} are constant values.

$LTPVD_{ijk}^{p}$ equals the lead-time of transporting fast moving good p from CDC_i to RDC_j and then to LDC_k and is defined defined by:

$$LTPVD_{ijk}^{p} = \text{DTPV}_{ij}^{p} + \text{DTVD}_{jk}^{p} + \text{tpv}_{ij}^{p} + \text{tvd}_{jk}^{p}$$

Where DTPV_{ij}^{p}, DTVD_{jk}^{p}, tpv_{ij}^{p} and tvd_{jk}^{p} are defined in the dwell time for fast moving good p functions respectively between CDC_i and RDC_j and RDC_j *and* LDC_k, as well as parameters sections for fast moving good p . Dwell time functions DTPV_{ij}^{p}, and DTVD_{jk}^{p} consists of the sum of the load make-up time, the time losses due to congestion and the other factors delaying the process (Eskigun et al., 2005)

DTPV_{ij}^{p} = Average dwell time of vehicles shipped from CDC_i to RDC_j.

$= c_{ij}^{1} + \frac{c_{ij}^{2}}{\sum_k d_l^p X_{ijk}}$ if $\sum_k d_l^p X_{ijk} > 0$, 0 otherwise

Where c_{ij}^{1} and c_{ij}^{2} are constant values.

DTVD_{jk}^{p}-= Dwell time for vehicles at RDC_j which are shipped to LDC_k

$= c_{jk}^{3} + \frac{c_{jk}^{4}}{\sum_i d_l^p X_{ijk}}$ if $\sum_i d_l^p X_{ijk} > 0$, 0 otherwise

Where c_{jk}^{3} and c_{jk}^{4} are constant values.

4.2.3 Fixed cost of opening a new facility

The fixed cost of opening a new facility consists of the sum of costs of opening facilities included in the network.

Fixed cost of opening up a new facility = $\sum_{i=1}^{I} f_i z_i + \sum_{k=1}^{K} f_k z_k + \sum_{j=1}^{J} f_j z_j$

4.2.4 Variable handling costs

Variable handling costs consists of the sum of the variable cost of handling goods at each facility for quantity of slower moving item q and the fast-moving item p.

$$\textit{Variable cost of handling the goods at each facility} = \sum_{i=1}^{I} v_i (x_{ij}^q + x_{ij}^p) z_i + \sum_{j=1}^{J} v_j (x_{jk}^q + x_{jk}^p) z_j + \sum_{k=1}^{k} v_k (x_{kl}^q + x_{kl}^p) z_k$$

4.2.5 Inventory cost

The inventory cost consists of the sum of administration costs and costs related to regular inventory stock and safety stock held at each facility. The administration cost consists of the sum at each facility of administrative cost of placing an order at that facility divided by the order cycle at the facility. The regular inventory can be defined as the sum at each facility of the average mean demand of slower moving item q and fast-moving item p at that facility multiplied by the order cycle time at the facility. To conclude, the safety stock is the sum at each facility of quantile α multiplied by the standard deviation of demand of slower moving item q and fast-moving item p at each facility multiplied by the square root of the cycle time at each facility.

$$\textit{Inventory cost} = \sum_{I=1}^{I} \frac{OC_i}{T_i} + \sum_{j=1}^{j} \frac{OC_j}{T_j} + \sum_{k=1}^{K} \frac{OC_k}{T_k} + \sum_{i=1}^{I} h_i \frac{\mu_i^{pq} T_i}{2} y_{ij} + \sum_{j=1}^{j} h_j \frac{\mu_j^{pq} T_j}{2} y_{jk} + \sum_{k=1}^{K} h_k \frac{\mu_k^{pq} T_k}{2} y_{kl} + \sum_{i=1}^{I} h_i \sigma_i^{pq} \sqrt{T_i} y_{ij} + \sum_{j=1}^{J} h_j \sigma_j^{pq} \sqrt{T_j} y_{jk} + \sum_{k=1}^{K} h_k \sigma_k^{pq} \sqrt{T_k} y_{kl}$$

4.2.6 Constraints

The presented total cost function for OLND will be subject to several constraints, listed hereafter:

- Constraints of flow of conservation between the facilities at different echelons **(A)**

$$\sum_{i=1}^{I} x_{ij}^{q} \geq \sum_{l=1}^{L} x_{jk}^{q}, \ \ \forall j$$

- Quantity of slower moving item q transported from CDC_i to RDC_j is smaller than or equal to the production capacity for slower moving item q in CDC_i. Quantity of slower fast-moving item p transported from CDC_i to RDC_j is smaller than or equal to the production capacity fast moving item p in CDC_i. **(B)**

$$\sum_{j=1}^{J} x_{ij}^{q} \leq b_i^{q}, \sum_{j=1}^{J} x_{ij}^{p} \leq b_i^{p} \ \ \forall i$$

- Quantity of fast-moving item p transported from $RDC_j$to $LDC_k$is smaller than or equal to the production capacity for fast moving item p in RDC_j. Quantity of slower moving item q transported from $RDC_j$to $LDC_k$is smaller than or equal to the production capacity for fast slower moving item q in RDC_j **(C)**

$$\sum_{k=1}^{K} x_{jk}^{p} \leq b_j^{p}, \sum_{k=1}^{K} x_{jk}^{q} \leq b_j^{q} \ \ \forall i$$

- The maximum number of facilities that can be opened to serve the demands of CZs in the proposed Outbound Logistics Network Design **(D)**

$$\sum_{i=1}^{I} z_i \leq U$$

- The maximum number of facilities that can be opened to serve the demands of CZs in the proposed Outbound Logistics Network Design **(E)**

$$\sum_{j=1}^{J} z_j \leq V$$

- The maximum number of facilities that can be opened to serve the demands of CZs in the proposed Outbound Logistics Network Design **(F)**

$$\sum_{k=1}^{K} z_k \leq W$$

- Constraints of non-negativity and binary values for the intended decision variables **(G)**

$$z_i, z_j, z_k, y_{ij}, y_{jk}, y_{kl,} \in \{0,1\} \ \ \forall i, j, k, l$$

$$\pi_{jd} = 1 \quad \forall j \in J, d \in D$$

- Demand of each product at each customer zone is met (number of units of slower moving product q transported from CDC_i via RDC_j and $LDC_k$to CZ_l is smaller than or equal to the demand for slower moving item q from CZ_l) **(H)**

$$\sum_{i=1}^{I} x_{ijkl}^{q} \geq d_l^q \qquad \forall j, k, l$$

- Demand of each product at each customer zone is met (number of units of fast moving item p transported from CDC_i via RDC_j and $LDC_k$to $CZ_l$to CZ_l is smaller than or equal to the demand for fast moving item p from CZ_l) **(I)**

$$\sum_{i=1}^{I} x_{ijkl}^{p} \geq d_l^p \qquad \forall j, k, l$$

- Each customer area is serviced by a single warehouse **(J)**

$$\sum_{k=1} y_{kl} = 1 \quad l = 1,2, \dots l$$

- Each RDC_j is serviced by one CDC_i **(K)**

$$\sum_{i=1} y_{ij} = 1 \quad j = 1,2, \dots j$$

- Each LDC_k is serviced by one RDC_j **(L)**

$$\sum_{j=1} y_{jk} = 1 \quad k = 1,2, \dots k$$

- Vehicles are delivered from CDC_i to LDC_k via RDC_j **(M)**

$$\sum_{j} X_{ijk} = 1 \quad \forall i, k$$

- Guarantees that demand area k is served through a single RDC **(N)**

$$\sum_{i,k} d_l^{pq} X_{ijk} \leq (u_k^q + u_k^p) z_j \qquad \forall j$$

- Vehicles delivered through VDC are not exceeding the capacity limit **(O)**

$$X_{ijk}, z_j \in \{0,1\} \quad \forall i, j, k$$

- We ensure that each customer is only allocated once and only once to each facility. **(P)**

$$\sum_{i \in I} y_{ij} = 1 \; \forall i \in I$$

$$\sum_{i \in I} y_{jk} = 1 \; \forall i \in I$$

$$\sum_{i \in I} y_{kl} = 1 \; \forall i \in I$$

- Sum of demands of the customers who are allocated to the same facility does not exceed its production and capacity **(Q)**

$$\sum_{j \in J} (d_l^p y_{ij} + d_l^p y_{ij}) \le \sum_{i \in I} (u_i^p z_i + u_i^q z_i + b_i^p z_i + b_i^q z_i) \; \forall i \in I$$

$$\sum_{k \in K} (d_l^p y_{jk} + d_l^p y_{jk}) \le \sum_{j \in J} (u_j^p z_j + u_j^q z_j + b_j^p z_j + b_j^q z_j) \; \forall j \in J$$

$$\sum_{l \in L} (d_l^p y_{kl} + d_l^p y_{kl}) \le \sum_{k \in K} (u_k^p z_k + u_k^q z_k + b_i^p z_i + b_j^q z_j) \; \forall k \in K$$

4.3 Model references to existing research

The presented model has been based on research from Hiremath et al. (2013), Zijm et al. (2018), Zheng et al. (2019), Winkelkotte et al. (2011) and Eskigun et al. (2005). In the following section, their research will be linked with elements presented in the model in this research.

4.3.1 Parameters

The parameters used in the presented model refer to earlier research on which this framework is based upon.

- Parameters (presented in chapter 4) 1,2, 3, 4, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 75, 76, 77, 78, 79, 80 have been based upon parameter stated in Hiremath et al. (2013).

- Parameters (presented in chapter 4) 23, 24, 25, 42, 43, 44, 60, 61, 62, 63, 70, 71, 75, 76, 77, 78, 79, 80 have been based upon parameter stated in Zijm et al. (2018)
- Parameters (presented in chapter 4) 26, 27, 28, 29, 30, 31, 52, 56, 57, 58, 72, 73, 74 have been based upon parameter stated in Zheng et al. (2019)
- Parameters (presented in chapter 4) 5, 9, 10, 25, 36, 37, 38, 39, 40, 41, 52, 75, 76, 77, 78, 79, 80 have been based upon parameter stated in Winkelkotte et al. (2011)
- Parameters(presented in chapter 4) 25, 32, 33, 35, 35, 42, 43, 44, 51, 59, 60, 61, 62, 63 have been based upon parameter stated in Eskigun et al. (2005)

4.3.2 Location

From a location perspective, the model presented in this paper refers to literature Winkelkotte et al. (2011), presenting a discrete structure stating that each facility that it is responsible for the region, is also located within. For each facility, there must be a district which it belongs to. A facility lays in its region if the following constraint is satisfied,

$$z_{pi} \geq \pi_{pi} \sum_{k \epsilon K_p} y_{pk,} \ \forall i \ \in V, p \in P,$$

With clarification of the parameters in appendix 1.A

In this research, the constraint above has been modified to altered parameters and has been presented as,

$$y_{jk} \geq \pi_{jd} \sum_{j \epsilon J} z_j \ \ \forall l \ \in D, j \in J$$

With the parameters presented in section 4.

4.3.3 Cost

From a cost perspective, the model presented in this paper combines relevant literature previously presented in the literature review. Included models are Eskigun et al. (2005), Hiremath et al. (2013), Zheng et al. (2019) and Winkelkotte et al. (2011).

The author used Eskigun et al. (2005) as a base for the proposed model. In Eskigun et al. (2005), the objective function is defined as followed:

$$\sum_{i,j,k}(cpv_{ij} + \ cvd_{jk})\, d_{ik}X_{ijk} + \sum_{i,j,k} h(LTPVD_{ijk})d_{ik}X_{ijk} + \sum_j (fv_j)V_j$$

The first term in the objective function represents the total transportation cost form initial point of distribution through RDCs to the demand areas,

$$\sum_{i,j,k} (cpv_{ij} + \ cvd_{jk})\, d_{ik} X_{ijk},$$

With clarification of the parameters in appendix 1.B.

In the presented cost-optimization problem, this element has been altered by entering two product types into the term, as defined by Hiremath et al. (2013) (appendix 1.C). This has been motivated by the current trend in automotive to sell not only cash cars but also subscription cars, resulting in the following proposed term for transportation costs,

$$\sum_{i,j,k} \left(c_{ij}^{q} + c_{jk}^{q}\right) d_{l}^{q} x_{ijk}^{q} + \sum_{i,j,k} \left(c_{ij}^{p} + c_{jk}^{p}\right) d_{l}^{p} x_{ijk}^{p},$$

With the parameters presented in section 4.

The lead-time cost from shipment through RDCs was defined by Eskigun et al. (2005) as,

$$\sum_{i,j,k} h(LTPVD_{ijk}) d_{ik} X_{ijk},$$

With clarification of the parameters in appendix 1.B

In the presented model, abstraction between the fast moving and slower moving goods, as presented by Hiremath et al. (2013) (appendix 1.C) has been made. This has been motivated by the current trend in automotive to sell not only cash cars but also subscription cars and resulted in the following term for lead-time cost,

$$\sum_{i,j,k} h\left(LTPVD_{ijk}^{q}\right) d_{ik}^{q} x_{ijk}^{q} + \sum_{i,j,k} h\left(LTPVD_{ijk}^{p}\right) d_{ik}^{p} x_{ijk}^{p},$$

With the parameters presented in section 4.

As a last term identified, the fixed cost of opening RDC has been stated by Eskigun et al. (2005):

$$\sum_{j} (fv_j) V_j,$$

With clarification of the parameters in appendix 1.B

A cost of opening facilities has also been stated by Hiremath et al. (2013) as followed,

$$\sum_{i=1}^{I} f_i z_i + \sum_{j=1}^{J} f_j z_j + \sum_{k=1}^{K} f_k z_k,$$

With clarification of the parameters in appendix 1.C

And as well by Zheng et al. (2019),

$$FC = \sum_{i=1}^{I} f_i x_{i,}$$

With clarification of the parameters in appendix 1.D

Combining both Eskigun et al. (2005) and Hiremath et al. (2013) and Zheng et al. (2019), the following suggestion has been made in this degree project:

$$\boldsymbol{\sum_{i=1}^{I} f_i z_i + \sum_{k=1}^{K} f_k z_k + \sum_{j=1}^{J} f_j z_j}$$

With the parameters presented in section 4.

Motivated by the many processes included in outbound car logistics, apart from the fixed costs described by Hiremath et al. (2013)

$$\sum_{i=1}^{I} f_i z_i + \sum_{j=1}^{J} f_j z_j + \sum_{k=1}^{K} f_k z_k,$$

With clarification of the parameters in appendix 1.C

The current research based on the described procedure for fixed costs by Hiremath et at. (2013), includes variable costs, presented as:

$$\boldsymbol{\sum_{i=1}^{I} v_i (x_{ij}^{q} + x_{ij}^{p}) z_i + \sum_{j=1}^{J} v_j (x_{jk}^{q} + x_{jk}^{p}) z_j + \sum_{k=1}^{k} v_k (x_{kl}^{q} + x_{kl}^{p}) z_k,}$$

With the parameters presented in section 4.

To conclude, an inventory cost has been included in the model as well. Although not stated by Eskigun et al. (2005), the author found it, based on the structure of two types of goods, relevant to include inventory costs in the model. This is supported by the inclusion of these cost for optimization of location, inventory and routing in supply chain network design by Zheng et al. (2019).

Zheng et al. (2019) presents inventory costs as followed, including administration of inventory, regular inventory holding cost and safety stock holding cost,

$$IC = \sum_{i=1}^{I}\sum_{b=1}^{B}\frac{oc_i}{t_b}z_{ib} + \sum_{i=1}^{I}h_i\left[\sum_{j\in J}\sum_{b\in B}\frac{\mu_j t_b}{2}Z_{ib}y_{ij} + Z_\alpha\sqrt{\sum_{j\epsilon J}\sum_{b\epsilon B}\sigma_j{}^2 t_b Z_{ib}y_{ij} + \sum_{j\epsilon J}\sigma_j{}^2 l_i y_{ij}}\right],$$

With clarification of the parameters in appendix 1.E

The model presented in this paper also includes administration of inventory, regular inventory holding cost and safety stock holding cos, but includes these costs at all facilities: CDC, RDC and LDC.

$$\sum_{I=1}^{I}\frac{\boldsymbol{OC_i}}{\boldsymbol{T_i}} + \sum_{j=1}^{j}\frac{\boldsymbol{OC_j}}{\boldsymbol{T_j}} + \sum_{k=1}^{K}\frac{\boldsymbol{OC_k}}{\boldsymbol{T_k}} + \sum_{i=1}^{I}h_i\frac{\mu_i^{pq}\,T_i}{2}\boldsymbol{y_{ij}} +$$
$$\sum_{j=1}^{j}h_j\frac{\mu_j^{pq}\,T_j}{2}\boldsymbol{y_{jk}} + \sum_{k=1}^{K}h_k\frac{\mu_k^{pq}\,T_k}{2}\boldsymbol{y_{kl}} + \sum_{i=1}^{I}h_i\boldsymbol{z_\alpha}\sigma_i^{pq}\sqrt{\boldsymbol{T_i}}\boldsymbol{y_{ij}} + \sum_{j=1}^{J}h_j\boldsymbol{z_\alpha}\sigma_j^{pq}\sqrt{\boldsymbol{T_j}}\boldsymbol{y_{jk}} +$$
$$\sum_{k=1}^{K}h_k\boldsymbol{z_\alpha}\sigma_k^{pq}\sqrt{\boldsymbol{T_k}}\boldsymbol{y_{kl}}$$

With the parameters presented in section 4.

4.3.4 Constraints

The constraints used in the presented model refer to earlier research on which this framework is based upon.

- Constraints (presented in chapter 4) A, B, C, D, E, F, G, H, I, Q have been based upon parameter stated in Hiremath et al. (2013).
- Constraints (presented in chapter 4) G, J, K, L have been based upon parameter stated in Zijm et al. (2018)
- Constraint (presented in chapter 4) G has been based upon parameter stated in Zheng et al. (2019)
- Constraint (presented in chapter 4) G, P, Q have been based upon parameter stated in Winkelkotte et al. (2011)
- Constraint (presented in chapter 4) G, M, N, O have been based upon parameter stated in Eskigun et al. (2005)

5. Model testing

The model presented in the previous section has been tested in the form of a consultation project at Lynk&Co, aiming for interpretation of research results related to the theoretical model. This section investigates reliability, feasibility and validation confirmation of the theoretical model in relation to the decision problem and the process considered. As real data from the company will be used, content and numbers will be anonymized as stipulated in a non-disclosure agreement signed by the author and Lynk&Co. This implies that the output and results of the test cannot be presented in this paper and a validation interview will be conducted with relevant management to validate the strategic OLND cost optimization model.

5.1 Background

Lynk&Co is a car manufacturer owned by the Chinese Geely Holding. The company will launch its services in Europe at the end of 2020 and has chosen Amsterdam as the first city to implement their product before launching in several other cities in Europe. Its goal is to provide sustainable mobility experience by offering simple pricing, car sharing, connectivity, and subscription as a new way of ownership. Lynk & Co will make use of a D2C sales model, disregarding the use of dealerships as end node for delivery. The car company will offer three types of products: a normal car sale offer, leasing offer and a subscription-based service to customers. Users can operate the latter for a month at a time in addition to being able to share vehicles on a short-term basis to other consumers (internal communication).

The existing literature on SCND and OLND for OEMs only considers one type of product in the outbound logistics flow. This ignores the new stream in the automotive industry where besides the normal, slower moving car sales and lease plans, faster moving subscription and mobility offers need to be included as well. Lynk&Co currently tries to identify an optimized logistics process to distribute their cars in European markets. The business model is identified as a direct-to-consumer model without conventional dealerships. Moreover, the portfolio of the company is adapted to the new stream in the automotive industry and consists of cars that are either sold, leased (slower moving items) or included in a pool of subscription (fast moving items). This will impose some requirements on the downstream logistics chain and affect all the actors involved in this process. Starting from a build-to-stock supply, KPIs and elements, identified by stakeholders involved and affected by the OLND at the company must be considered in order to gain an optimized cost-based logistics solution for the car manufacturer.

Over the timespan of this degree project, several KPIs for the outbound logistics flow have been identified by the studied OEM. Although, three main objectives have been the main point of discussion: cost optimization, delivery precision and shortest possible lead time. The cost optimization perspective has been identified as the most important objective followed by delivery precision, which supports the customer satisfaction perspective to deliver the goods in the promised time frame. The shortest lead time is preferred but at a later stage when cost optimization and optimal delivery precision is achieved. The presented strategic OLND cost optimization will contribute to the most important KPI identified.

Lynk&Co identifies the need for a supply chain set-up with the following design: One regional car compound (RCC) will be in place to serve the European markets. This can be linked with a Central Distribution Center (CDC), to be found in the literature. Several local car compounds (LCCs) will be spread out over the European markets and are referred to as Regional Distribution Center (RDC) in literature. To conclude, the end link of the Industrial Outbound Logistics Network is a Micro Car Compound or Local Distribution Center (LDC) as referred to in literature. Various LDCs are linked with an RDC, whereas several RDCs are linked with the CDC.

5.1 Location

Location sets considered for input in the cost optimization model will be made through supplier offerings. A more supplier-independent set of locations will be identified through usage of a continues location model, as defined by Daskin (2013). This type of model seeks to minimize the weighted total distance or costs between facilities and demand nodes. Logistics stakeholders at the company site identified this as a useful and applicable way to make a first selection of potential sites that will be subject to the full cost analysis. All facilities will be in their respective districts that they must serve. The company mentions practical and legal constraints for this assumption. An internal tier section is applied to break down sales and forecasts of the goods for the different served markets, districts and regions.

5.2 Cost

In general, certain assumptions needed for cost calculations have been made. Firstly, the current sales forecast used, is given and made correctly. Capacity constraints have been identified less important by the company for the start-up phase in the upcoming year. Hence, the discussion and consideration of this aspect has been limited.

The model assumes a constant rate of demand per identified time period. Given the fact that car sales can be argued to have fluctuations during the year, this might generate a gap between the outcome of this model and actual practice. Mean demand and standard variation of demand are generated through date over a longer period as well and hence can generate a regular and safety stock that might not be applicable to each moment in time at Lynk&Co.

In general, Lynk&Co has put their focus on the transportation costs and inventory costs including a pre-defined lead time where a minimized cost should be achieved. This, by allocation the cars to a certain distribution node in the network based on the cost aspect. The company identified interest and storage as important factors in this inventory allocation decision.

5.2.1 Transportation cost

Given the division of the goods in two streams, the transportation costs between facilities will differ for the fast moving and slower moving goods at Lynk&Co. The fast-moving goods will be subject to a certain form of reverse flow.

In line with this, from a strategic point of view. the assumption has been made that transport costs related to the fast-moving goods need to be counted double in this case study due to these extra generated (reverse) movements.

5.2.2 Lead time cost

The considered cost included will be the process involved to move the cars after the goods arrive at each facility. Amongst others, processes identified are the registration process of cars, pre-delivery inspection (PDI) process, product disclosure statement (PDS) process.

The company identifies the same lead time cost for fast and slower moving goods on the movement from CDC to RDC but argues to separate the same type of costs for the movement between RDC and LDC as the fast-moving type of good is subject to a certain type of reverse flow.

In line with this, from a strategic point of view, the company argues to look into lead time costs related to the fast-moving goods for the movement between RDC and LDC from case to case as mentioned dwell times affecting the lead time cost depend on demand partitions, seasonality and might differ from area to area.

5.2.3 Fixed cost of opening a facility.

Fixed cost of opening a facility will depend on different areas. Partition of costs for fast moving and slower moving goods will not be needed as there is a given cost for all types of goods, regardless purpose or end destination.

5.2.4 Variable handling cost

The variable handling costs included will be the process involved to move the cars after the goods arrive at each facility. Amongst others, processes identified are the registration process of cars, pre-delivery inspection (PDI) process, product disclosure statement (PDS) process.

The company identifies the same variable handling cost for fast and slower moving goods on the movement from CDC to RDC but argues to separate the same type of costs for the movement between RDC and LDC as the fast-moving type of good is subject to a certain type of reverse flow.

In line with this, from a strategic point of view the assumption has been made that variable costs related to the fast-moving goods for the movement between RDC and LDC need to be counted double in this case study due to these extra generated (reverse) movements.

5.2.5 Inventory cost

At the initial stage, inventory will be decisions will be made based on the total amount of sales forecasted, both fast moving and slower moving goods included.

5.3 Relevance

The presented model in this paper focusses on a range of cost aspects that are included in an OLN. The cost elements included, have been identified through previous research and discussed with the studied company Lynk&Co. Combining both literature and this empirical data, the author argues that an extensive range of cost elements on logistics movement has been included.

Based on Basic et al. (2017), describing the most important criteria that reflect on performance of successful automotive outbound supply chain, and on discussions on the identified and needed KPI´s at Lynk&Co, important performance measurements have been discussed.

As in Basic et al. (2017), the company identified pick-up performance to be a more important KPI than reducing the transit time of goods (minimization of lead time and dwell time) when designing an OLND. Another important performance element identified by Basic et al. (2017), damage rate, was not able to be included for optimization in the cost-minimization model presented.

Analytic models are useful for insights into the structure of the problem (Daskin, 2013). The real-world constraints identified by literature and communication with Lynk&Co have been a big help to characterize a more precise problem structure to the structure, allowing to reduce the dimensions to be solved and get a more useful scope and application of the model.

5.4 Feasibility

Referred to section 3.4.3, feasibility of the study has been investigated. A run of the model has been made from the data provided at Lynk&Co.

The model has been tested in one of the future markets that will be serviced by the company. Three potential locations A,B,C for a regional distribution center had been identified. The model allowed for opening either all RDCs, two of them or a single one. The output suggested location B as the optimized location from a cost perspective.

After this initial successful run of the model and clear background and implementation description as presented in previous chapters, the author states that this research has passed feasibility constraints.

5.5 Validity

Referred to section 3.4.3, validity of the study has been investigated. A validation interview has been conducted with Mamun Abdullah, Product Owner Order to Delivery at Lynk&Co and supervisor for this thesis project at the company. “The output of the model generates a logic result for cost optimization options of our outbound logistics distribution. Based on the identified need to have a clear picture of the cost structure related to OLND, the model is able to give an insight into the costs related to inventory, including lead times, storage cost at each distribution node, and interest cost. On top of that, it gives a picture of the transportation costs both general and related to each facility.”

Based continuous communication and feedback with the company during the development and on this feedback at the company, the author states that this research has passed validity constraints. This, both internal, external as conducts, as explained in section 3.4.3 of this thesis

5.6 Reliability

Reliability, as defined in section 3.4.3 of this degree project has been achieved through the usage of a strict case study protocol and database where all the interviews and other data, both empirical as academical have been gathered. Due to a signed non-disclosure agreement with the company, the data included in this research will be available as evidence in a case study database but not presented in this academic project.

The model itself is based on earlier conducted academic models and research, approved by the academic community, improving the reliability of this study.

5.7 Limitations

The discussion and conclusions of this paper are not without any limitations. A very broad search of articles has been conducted without any restrictions to which academic journals to be included. Adding no restrictions to the journals included might have altered the results presented. The second limitation of this dissertation is the risk of subjective review of several articles investigated by the author. Moreover, this research project had a limited timeframe of four months.

6. Conclusion

Digital technologies, platforms, (electro)-mobility, autonomous driving and related subscription offerings have a significant impact on the business processes used at car manufacturers. Supply chains and logistics movements are affected and the need to rethink current practice has been identified. As limited research has been conducted on new mobility trends and their effects on practices in supply chains and logistics flows of car manufacturers, this research, embracing these new trends, established a proposal for an optimized cost-based Outbound Logistics Network Design (OLND) for a car manufacturer. This research objective has been broken down into two sub-objectives:

1. *Modifying previous models in OLND for car manufacturers.*

Starting from critical examination of literature on Distribution Networks (DN), Supply Chain Network Design (SCND) and Outbound Logistics Network Design (OLND) related to the automotive industry, context to the identified research problem has been presented and used as a foundation for investigation and analysis of several models and approaches. The findings of the academic literature and the empirical findings at the studied automotive OEM were combined to construct a model, relevant for the automotive industry.

The industrial OLND-problem presented is situated in a two-echelon environment with a single central distribution center (CDC), multiple regional distribution centers (RDC) geographically spread over identified districts and a set of local distribution centers (LDC). The elements of the model integrates costs related to transportation, fixed investments, handling, lead-time and inventory for allocation choices of distribution in the network. Two types of products will be considered: fast moving goods (subscription flow) and slower moving goods (cash and leasing cars). The model has aimed application for (re)designing a new logistics network.

The presented model, aiming to achieve an heuristic, near optimal solution, has been based on research from Hiremath et al. (2013), Zijm et al. (2018), Zheng et al. (2019), Winkelkotte et al. (2011) and Eskigun et al. (2005).

2. *Testing the presented model and its applicability for the automotive industry.*

The presented model has been tested in the form of a consultation project at Lynk&Co for interpretation of research results related to the theoretical model. Reliability, feasibility and validation have been achieved.

6.1 Suggestions for further research

As the proposed research considers a full cost perspective, several elements based on current trends in the automotive industry have been less investigated for inclusion in the presented OLND. Transportation mode, reverse flow, capacity constraints, performance measurement and supply chain resilience have been identified by the author as potential elements subject to further research.

Transportation mode

Due to scope limitation, only road transport by truck has been considered in the model. Road is often chosen as the main mode of choice for transportation thanks to its flexibility (Zijm et al., 2019). Although, Eskigun et al. (2005) already stated the possibility to analyze and compare rail transport with truck transport for outbound logistics. Train transportation can generate cost advantages for OEMs and cut operational costs. Aspects such as sustainability, transparency, speed, density and cost (Zijm et al., 2019) might influence the choice of transportation mode and are worth mentioning for further research.

Potential benefits of train transportation have not only been confirmed in research, but Lynk&Co also mentioned to idea to look into rail transport from a future development perspective of the OLND. The CDC and RDCs need to have close connection to a railway facility in this case, LDCs are at this stage not argued to be included in a potential rail system.

Extended reverse flow

As earlier discussed in the literature review, reverse flows within the car industry related to a growing share of subscription and short-term lease offers, will increase. Lynk&Co identified the need for reverse flows for their subscription cars. Although the model presented in this research already slightly opens for reverse thinking, more extensive research is recommended. Here, the author of this paper would also encourage to investigate other potential types of reverse streams such as end-of-life cycle, remanufacturing, reuse as well as the link to fleet utilization and flexible use of the car pool of the company.

To conclude, as practice is related to the automotive industry, the author acknowledges cost benefits can be generated by using already opened facilities their capacity for the reverse stream.

Capacity constraints

The proposed model is a cost focused model and makes significant abstraction of the capacity of distribution centers. This follows practice described by Eskigun et al. (2005), assuming that the regional distribution centers (RDC) have no capacity restrictions on the number of goods (cars) that can be handled throughout the year. By doing so, the model assumes both routing and location decisions regardless of congestion and inefficiencies and this factor is constant.

Further research on non-constant capacity constraints and related batch sizes can broaden the scope of the presented model in this degree project.

Performance measurement

To analyze different improvement alternatives, it is necessary to establish a system that allows for evaluation of supply chain (Reiner, 2005). As the automotive industry is currently struggling to cope with new practices and future trends, the proposed framework in the degree project has to be subject to continuous (re)-evaluation and performance measurement. Quantifying current state and improvement potential of the OLND is key to assess its effectiveness and efficiency (Dörnhöfer et al., 2016).

Stated by Dörnhöfer et al. (2016) the most typical objectives for logistics performance are cost advantage and being able to match service expectations from customers. Cost advantage can be achieved through realization of productivity which includes capital investment and cost reduction in operational expenses. Customer service level on the other hand, includes lead-time optimization and on time delivery and flexibility.

Further research on performance measurement of the proposed cost-reduction based distribution allocation model both in terms of productivity and service level is advised. The objectives of performance measurement might differ from company to company but given the scope of the global car manufacturing industry, additional elements such as cultural differences, information quality, green logistics and the capability of improving the current level of efficiency and effectiveness globally. Identified by Dörnhöfer et al. (2016), not all company-specific objectives can be included in the framework.

Supply Chain resilience

Another aspect that can be investigated further is the supply chain resilience. Considering situations such as facility failure, shift in demand, unforeseen circumstances, economic uncertainty, natural disaster.

An essential part of a Supply Chain Network design is to manage the risks that can affect our supply chain. Vulnerability and uncertainty are a serious risk that can be identified in a supply chain. The creation of more resilient supply chains is an effective way of reducing risks but comes hand in hand with the requirement to have higher levels of collaboration, responsiveness and agility amongst actors involved in the chain (Chopra et al., 2004).

Mersechmann et al. (2011) describes flexibility as the ability to adapt and transform a situation alongside managing the damage in terms of performance, cost and performance over time. Hence, supply chain flexibility can be defined as the ability to adapt volume and planning when changes at the supplier, manufacturer or customer side occur.

In general, information sharing, reductions in lead time and other factors would be able to reduce the amount of uncertainty but not able to exclude it completely (Reiner, 2005).

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Winkelkotte, Tobias, Jürgen W Böse, Hao Hu, Carlos Jahn, Xiaoning Shi, Robert Stahlbock, and Stefan Voß. "Optimizing Complex Logistics Systems with Approximative Consideration of Short-Term Costs." In Computational Logistics: Second International Conference, ICCL 2011, Hamburg, Germany, September 19-22, 2011. Proceedings, 194-208. Vol. 6971. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011.

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Appendix 1

1.A

Winkelkotte, Tobias, Jürgen W Böse, Hao Hu, Carlos Jahn, Xiaoning Shi, Robert Stahlbock, and Stefan Voß. "Optimizing Complex Logistics Systems with Approximative Consideration of Short-Term Costs." In Computational Logistics: Second International Conference, ICCL 2011, Hamburg, Germany, September 19-22, 2011. Proceedings, 194-208. Vol. 6971. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011.

I: set of customers

P: Potential facilities

K_p: Capacities of each facility

y_{pk}: 1, if facility p ϵ P is working with capacity K ϵ K_p, 0 otherwise

z_{pi}: 1, if customer i ϵ I is allocated to facility p ϵ P, 0 otherwise

π_{pi}: 1 if facility $p \epsilon P$ is located within district i ϵ V; 0 otherwise

Objective function

A discrete structure is needed where the whole covered area needs to be partitioned in small pieces, which we call districts. The districts must not overlap each other and the union of all districts has to cover the total area. The size of the districts depends on the context.

If the regions are connected, it seems to make sense that the facility, which is responsible for the region, is also located within. For each facility, there must be a district which it belongs to.

A facility lays in its region if the following constraint is satisfied:

$$z_{pi} \geq \pi_{pi} \sum_{k \epsilon K_p} y_{pk,} \;\; \forall i \; \in I, p \in P$$

1.B

Eskigun, E., Uzsoy, R., Preckel, P. V., Beaujon, G., Krishnan, S., & Tew, J. D. (2005). Outbound supply chain network design with mode selection, lead times and capacitated vehicle distribution centers, *European Journal of Operations Research,* 165, p. 182.

Parameters

d_{ik}: total yearly demand for vehicles of plant i at demand area k

cpv_{ij}: unit cost of transporting a vehicle by rail from plant i to vehicle distribution center (VDC) j (including the operartion cost of the VDCs per unit vehicle)

cvd_{jk}: unit cost of transporting a vehicle by truck from VDC j to demand area k,

cpd_{ik}: unit cost of transporting a vehicle from plant I to demand area k directly by truck

fv_j: fixed cost of opening VDC j (this cost does not depend the volume or the capacity of the VDC but it is the fixed cost of establishing a new VDC.

tpv_{ij}: transit time from plant i to VDC j

tvd_{jk}: transit time from VDC j to demand area k

h: monetary value of the lead-time (x euro / per day) assessed by the company

Decision variables

X_{ijk}: 1 if vehicles are delivered from plant i, to demand area k through VDC j, 0 otherwise

V_j: 1 if VDC j is opened, 0 otherwise

Objective function

The first term in the objective function represents the total transportation cost form plants through VDCs to demand areas + the lead-time cost from shipment through VDCs + fixed cost of opening VDCs

$$\sum_{i,j,k}(cpv_{ij} + cvd_{jk})\, d_{ik}X_{ijk} + \sum_{i,j,k} h(LTPVD_{ijk})d_{ik}X_{ijk} + \sum_{j}(fv_j)V_j$$

Where, $LTPVD_{ijk}$ is the lead-time of transporting vehicles from plant i to VDC j and then to demand area k and given by

$LTPVD_{ijk} = DTPV_{ij} + DTVD_{jk} + tpv_{ij} + tvd_{jk}$

($DTPV_{ij}$, $DTVD_{jk}$, tpv_{ij} and tvd_{jk} are defined in the dwell time functions and parameters sections, respectively)

$DTPV_{ij}$ = Average dwell time of vehicles shipped from plant i to VDC j.

$DTPV_{ij} = c_{ij}^1 + \frac{c_{ij}^2}{\sum_k d_{ik} X_{ijk}}$ if $\sum_k d_{ik} X_{ijk} > 0$, 0 otherwise

Where c_{ij}^1 and c_{ij}^2 are constant values.

$DTVD_{jk}$ = Dwell time for vehicles at VDC j which are shipped to demand area k

$DTPV_{jk} = c_{jk}^5 + \frac{c_{jk}^6}{\sum_i d_{ik} X_{ijk}}$ if $\sum_i d_{ik} X_{ijk} > 0$, 0 otherwise

Where c_{jk}^5 and c_{jk}^6 are constant values.

1.C

Hiremath, N., Sahu, C. & Tiwari, S., 2013. Multi objective outbound logistics network design for a manufacturing supply chain. Journal of Intelligent Manufacturing, 24(6), pp.1071–1084.

i: index of plant (i = 1,2,…,I)
j: index of Central Distribution Center (CDC) (j = 1,2,…,J)
k: index of Regional Distribution Center (RDC) (k=1,2,…,K)
l: index of Customer Zone (CZ) (l = 1,2,…,L)
p: index of fast moving item
q: index of slower moving item
r: index of very slow moving item.
I: number of plants
J: number of CDCs
K: number of RDCs
L: number of customer zones
P_i: plant I
CDC_j: CDC j
RDC_k: RDC k

CZ_l: CZ l

f_i : Fixed cost of opening and operating plant P_i

f_j : Fixed cost of opening and operating CDC_j

f_k : Fixed cost of opening and operating RDC_k

c_{ij}^{q}: unit cost of producing and shipping item q from p_i to CDC_j

c_{ik}^{p}: unit cost of producing and shipping item p from p_i to RDC_k

c_{il}^{r}: unit cost of producing and shipping item r from p_i to CZ_l

c_{jl}^{q}: unit cost of producing and shipping item q from $CDC_j$to CZ_l

c_{kl}^{p}: unit cost of producing and shipping item p from RDC_k to CZ_l

Decision variables

x_{ij}^{q}: quantity of slower moving item q transported from p_i to CDC_j

x_{ik}^{p}: quantity of fast-moving item p transported from p_i to RDC_k

x_{il}^{r}: quantity of very slow moving item r transported from p_i to CZ_l

x_{jl}^{q}: quantity of slower moving item item q transported from $CDC_j$to CZ_l

x_{kl}^{p}: quantity of slower moving item p transported from RDC_k to CZ_l

z_i : 1 if plant P_i is opened; 0 otherwise

z_j: 1 if CDC_j is opened; 0 otherwise

z_k: 1 if RDC_k is opened; 0 otherwise

Objective function

Defines the objective of minimizing the total cost of OLN, comprising of production costs, handling cost, transportation costs and fixed costs of opening and operating the potential facilities

$$= \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}^{q}\, c_{ij}^{q} + \sum_{i=1}^{I}\sum_{k=1}^{K} x_{ik}^{p} c_{ik}^{p} + \sum_{i=1}^{I}\sum_{l=1}^{L} x_{il}^{r} c_{il}^{r} + \sum_{j=1}^{J}\sum_{l=1}^{L} x_{jl}^{q}\, c_{jl}^{q} + \sum_{k=1}^{K}\sum_{l=1}^{L} x_{kl}^{p} c_{kl}^{p} + \sum_{i=1}^{I} f_i z_i + \sum_{j=1}^{J} f_j\, z_j + \sum_{k=1}^{K} f_k z_k$$

1.D

Zheng, X., Yin, M. & Zhang, Y., 2019. Integrated optimization of location, inventory and routing in supply chain network design. Transportation Research Part B, 121, pp.1–20.

f_i: fixed cost of locating DC i

x_i: Binary variable. If DC is is opened, it´s equal to 1; otherwise it is equal to 0

When locating a DC, a fixed cost is given by

$$FC = \sum_{i=1}^{I} f_i x_i$$

1.E

Zheng, X., Yin, M. & Zhang, Y., 2019. Integrated optimization of location, inventory and routing in supply chain network design. Transportation Research Part B, 121, pp.1–20.

B: set of alternative review intervals B = $\{t_{1,} t_{2,} \dots\ t_B\}$

I: candidate set of distribution centers

J: set of retailers

h_i: inventory holding cost per unit of product per unit of time at $DC\ i$

OC_i: administrative cost of placing an order at $DC\ i$

lt_i: lead time from supplier to DC i

μ_j: mean demand of retailer j per unit of time