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Finding economic feasibility in electrified LTL transportation systems

Identifying opportunities in electric LTL transportation flows

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Sammanfattning

Titel

Finding economic feasibility in electrified LTL transportation systems – Identifying opportunities in electric LTL transportation flows

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Bakgrund

När elektrifiering av fordon passerar sin linda och storskalig användning av tekniken blir verklighet, behöver tillämpningsområden inom olika branscher utforskas. Skiftet inom transportsektorn, särskilt för lastbilar, kan ha oidentifierade ekonomiska fördelar; som är fokus för denna avhandling.

Syfte

Syftet med denna avhandling är att utveckla en beslutsmodell med hänsyn till de ekonomiska konsekvenserna av LTL-rut strategier i ett kluster med hjälp av EFV:er.

Metod

Masteruppsatsen är en utforskande fallstudie som använder sig av ett abduktivt tillvägagångssätt. Extern forskning och intern kunskap på The Case Company utnyttjades för att skriva denna avhandling.

Avgränsningar

Fokus låg på elektriska LTL-transporter som för denna rapports syfte definierades som alla elektriska lastbilstransporter där transportörer accepterar ett pris per pall. Försändelser som lämnade ett visst nav till ett annat nav uteslöts från tillämpningsområdet. Endast utgående och inkommande försändelser inom ett visst nätverk, eller geografiska områden, där pallar skickas per pall beaktades i omfattningen. Det bör noteras att matematisk optimering inte var ett fokus i rapporten. Däremot användes intern kunskap om matematisk optimering, med avseende på scenarioskapandet.

Slutsats

Man skulle kunna dra slutsatsen att elektriska godsfordon har en framtid inom transportbranschen, men det är starkt beroende av flera faktorer; som batteri förbättringar, infrastrukturutveckling, statliga regleringar och samhällsanpassning. Dessutom är det uppenbart att ett elektrifierat LTL-transportsystem är starkt beroende av utnyttjandet av lastbilarna i ett visst system.

Nyckelord

Electric Trucks, Electrified LTL, Electrified Less-than-Truckload, Electrified LTL Transportation System, Electrified Less-than-Truckload Transportation System, Economics Electrified LTL.

Abstract

Title

Finding economic feasibility in electrified LTL transportation systems – Identifying opportunities in electric LTL transportation flows

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Background

As electrification of vehicles moves past its infancy and large-scale adoption of the technology becomes reality, application areas within different industries need to be scrutinized. The shift within the transportation sector, especially trucking, can have unidentified economic benefits; which is the focus of this thesis.

Purpose

The purpose of this thesis is to develop a decision model with regard to the financial consequences of LTL routing strategies in a cluster using EFVs.

Methodology

The master thesis is a exploratory case study which uses an abductive approach. External research and internal knowledge at The Case Company was leveraged to write this thesis.

Delimitations

The focus was on electric LTL transportation which for the purpose of this report was defined as any electric truck transportation where the carrier accepts a per pallet price. Shipments leaving a certain hub for another hub were excluded from the scope. Only outbound and inbound shipments within a certain network, or geographical areas, where pallets are shipped on a per pallet basis was considered in the scope. It should be noted that mathematical optimization was not a focus of the report. However, internal knowledge about mathematical optimization was used, with regards to the scenario creation.

Conclusion

It could be concluded that electric freight vehicles have a future in the transportation industry, but it is highly dependent on several factors; such as battery improvements, infrastructure development, governmental regulations, and societal adaptation. Moreover, it is evident that an electrified LTL transportation system is highly dependent on the utilization of the trucks in a certain system.

Keywords

Electric Trucks, Electrified LTL, Electrified Less-than-Truckload, Electrified LTL Transportation System, Electrified Less-than-Truckload Transportation System, Economics Electrified LTL.

Abbreviations & Concepts

LTL (In this thesis)	Less-than-Truckload: Any carrier accepting a per pallet price.
FTL (In this thesis)	Full-Truckload: Any carrier accepting a per truck price.
EV	Electric Vehicle
EFV	Electric Freight Vehicle
ICEV	Internal Combustion Engine Vehicle
VRP	Vehicle Routing Problem
e-VRP	Electric Vehicle Routing Problem
TCO	Total Cost of Ownership: The cost of acquiring and using a product or service.
DU	Distance Unit
CU	Cost Unit

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1. Introduction

1.1 Background

The shifting of technology can greatly affect industries and the business models prevalent within them. Though, the threat to existing business models arrives bearing promises of new value-creating processes. There are numerous examples throughout recent history of companies struggling to adapt technological shifts, especially in mature organizations in mature industries. (Tongur & Engwall, 2014)

Carleton (2019) argues that innovation, particularly the ability to keep competitors and disruptive actors in check, is crucial for organizational survival in a fluctuating business environment. Innovation comes in many forms, and not only from the R&D departments. Separating innovation into a number of categories can be beneficial, incremental innovation and radical innovation. Incremental innovations are those which improve an aspect of an existing product or service, such as the incremental improvements of handheld camera devices. On the contrary, radical innovation involves the introduction of a new product or service to replace an existing one, resulting in significant changes to the consumer landscape, such as when digital cameras were introduced in the late 1980s.

Disruptive innovation is separate from the former categories, often including elements of both incremental and radical innovations in different phases. A disruptive actor usually starts in simple, low-end applications, often by being more affordable and accessible. Later, moving upmarket and replacing existing competitors. Christiensen (1997) describes disruptive innovations as being modest at first but having the potential to transform an industry over time, such as Ubers disruption of the heavily entrenched taxi industry.

A category of disruptive innovations posed to disrupt several industries is autonomous technology. Autonomous technology is defined as hardware or software using programmed commands and automatic feedback mechanisms to operate without human intervention, leading to more efficient processes (Groover, 2020). In recent history, automation in manufacturing has revolutionized the sector with improvements in precision, productivity and cost of production (Chui, 2017). However, as argued by Nouzil et al. (2017), the increase in wealth generated as a result of automation is rarely distributed to those workers affected by job loss or wage suppression. They further argue that automation historically has eliminated repetitive, simple jobs, but may create more complex jobs that require higher levels of education which further hinders re-qualification efforts. As automation is increasingly adopted into processes consisting of non-repetitive tasks requiring decision making, such as autonomous transportation, the potential societal ramifications become increasingly apparent. A McKinsey study estimated that 70-80% of low-skilled jobs, 50-70% of medium-skilled jobs and 40-50% of high-skilled jobs have the potential of being automated in the near to medium future (Chui, 2017).

Currently, regulatory bodies in most countries strictly enforce measures which limit decision making automation in industries such as transportation. Examples of large-scale regulations that hinder driverless cars are the Geneva Convention on Road Traffic, Vienna Convention on Road Traffic, and UNECE’s WP.29, these three all point to a need for a human driver. Some recent regulation changes indicate a switch in attitude towards self-driving vehicles, such as the allowance of greater speeds when using an automated lane keeping system (UNECE, 2022). While political debates often highlight whether an autonomous vehicle performs better than a human counterpart, the core issue in the political sphere is the safety, liability implications (European Commission, 2020a), and further down the line its potential of significant impact on the labor force (NBER, 2020). Ethicists also raise concerns about autonomous beings' inability to make moral decisions, and who would be ultimately liable for the decisions of an autonomous navigation system. Nouzil et al. (2017) further argues that trust is a major issue, suggesting that the general public would trust a human over any autonomous system. For instance, in a situation where a self-driving car must make a quick decision to swerve into other vehicles to avoid hitting a pedestrian, it may be faced with a moral dilemma that could potentially discriminate against a particular class of vehicles – the cars action to swerve is a decision and not an action taken in the heat of the moment, as it would be under human operation. This might very well generate better outcomes than under human operation, but the vehicle has made a decision to prioritize the pedestrian over the vehicle bound passengers, contrary to a human who most likely only tries to avoid a pedestrian – not considering it a decision. Therefore, it is important to consider that programmed decisions made by autonomous technology may be treated differently under the law and ethical standards compared to those made by humans (Olson, 2017).

As autonomous technology such as autonomous vehicles have a high likelihood of permeating society to the point of becoming the societal standard, it is essential to steer its development to mitigate the environmental impact of this technology. Since autonomous vehicles are most commonly electric, they are often portrayed as environmental in a way not solely attributable to its autonomous characteristics and it is important to consider the increased need of electricity due to increased computing needs. Sudhakar et al. (2022) predicts that high adoption of autonomous vehicles will with a high probability result in emissions equivalent to the total emissions from data center computing in 2018, which is estimated to be 1-3% of global emissions, purely from the computing needed for the vehicles autonomous capabilities. This aligns with experts' growing concern that the increased computing demand of AI will result in a significant environmental burden, especially considering that conventional data centers already surpass the emissions of the airline industry (Knight, 2020).

Electrified autonomous technology is increasingly being introduced to the transportation industry, with global development efforts (Uzialko 2019). While the applications vary from personal transportation to freight, companies competing in this space are still far away from producing profitable autonomous vehicle projects (Boutan, 2020). However, the spread of electric vehicles and their recent leaps in development pave the way for continuous improvement in the autonomous vehicle industry. An overview of available literature suggests that large-scale adoption of autonomous vehicles is significantly further away than the adoption of electric vehicles, and many consider electrification to be a prerequisite for the proliferation of autonomous vehicles. Electrification promises great environmental benefits while automation promises greater efficiency, which could potentially provide both increased profitability and decreased environmental impact.

Views on the disruptive innovations which lay the foundation for electrification and automation of the transportation industry are two-fold, electrification can be both a first step towards automation and a goal in itself. Industry consensus is to push toward electrification, for a myriad of reasons, and in the highly linked processes of the low-profit transportation industry, total electrification requires the electric alternative to be economically justifiable at every step of the way.

1.2 Transportation background

Today, freight transport by road accounts for 7% of global emissions, and 80% of consumer-packaged goods carbon footprint is caused by its transport, and contrary to passenger road transport little progress has been made (Bové and Swartz, 2016). There exist different forms of truck transportation, namely Full-Truckload (FTL) and Less-than-Truckload (LTL), these are common offerings from carriers. In simple terms LTL allows for carriers to serve several customers in one truck, and FTL allows only for one to be served. FTL routes are usually predictable and involve transport from point A to B, resulting in uncomplicated routing, whilst LTL routes are relatively complex. LTL is an offspring of FTL and has been popularized later. According to Schulz (2021) writing for Logistics Management, LTL carriers are bullish on the demand for LTL transportation since logistics networks have yet to fully adapt to the e-commerce boom. Corporate leaders at major LTL companies suggest that current changes in retail allow LTL carriers to participate to a larger extent in later stages of the supply chain than previously, an important development for an industry previously focused on the industrial sector. As of 2021 the sector's growth is accelerating and outperforming the transportation industry average.

Today, electric freight vehicles (EFVs) have been introduced to the transportation industry. At the time of writing, there is one actor providing a transportation solution using solely EFVs for full-truckload routes. The predictability of FTL routes is taken advantage of in this business offering. No LTL offering currently exists for EFVs, since it adds more complexity than an electrified FTL transportation system. For EFVs to truly be considered an alternative to diesel, it must be economically feasible in less-than-truckload transportation. The electrified LTL transportation system might prove to have a greater economic benefit than anticipated due to factors shaded by its complexity.

1.3 Purpose

The purpose of this thesis is to develop an understanding of the economic feasibility in electrified LTL routing strategies.

1.4 Delimitations

The focus will be on electric LTL transportation, in a business-to-business environment, which for the purpose of this report will be defined as any electric truck transportation where the carrier accepts a per pallet price. In most trucking LTL systems, hubs are found in high density areas where LTL shipments from within a certain area are consolidated to be forwarded. Either as FTL to another hub located in another high-density area or to be shipped as LTL in the same high-density area. The focus of this report will result in shipments leaving a certain hub for another hub to be excluded from the scope. Meaning that only outbound and inbound shipments within a certain network, or geographical area, where pallets are shipped on a per pallet basis were considered to be within scope. It should be noted that mathematical optimization with regards to electric LTL transportation will not be a focus in this report. However, the work done by The Case Company in this regard will be used, in a bottom-up approach, as guidance in creating a scenario for an electric LTL network. This study will examine the business-to-business context and will not consider any legal or political regulations that may currently exist. It will be assumed that these regulations will not pose any hindrances to the implementation of the proposed solution.

2. Theory

This thesis' theory section discusses the societal technological shift pertinent to the context of transportation as well as the theory surrounding supply chain management and less-than-truckload (LTL) shipping, as shown in figure 2.1. This served as the thesis's literature review, providing a summary of the field's body of knowledge. The theory section examines how technological disruption affects societal structures and how these changes affect various industries, including transportation, in the context of the societal technology shift. This includes a discussion of how automation, digitization, and other technological advancements will affect supply chain management in the future. The supply chain management context, present theory on improvement investments, vulnerabilities and risks, sustainability aspects, and finally, operational aspects. The literature review further delves into the specifics of trucking and LTL theory. This involves a discussion of LTL shipping's characteristics, such as suitable cargo for LTL and the difficulties LTL carrier's encounter. The importance of technology in the trucking and LTL industries, especially the usage of digitalized tools for tracking and optimizing shipments, is also discussed in the literature review. Finally, the theory section concludes with key considerations for LTL networks based on the available literature.

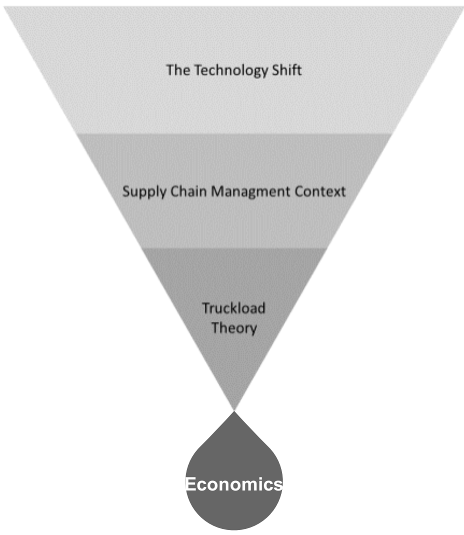

Figure 2.1 Illustration of the theory funnel

2.1 Technology shifts

2.1.1 Technology cycles

Technology cycles refer to the stages of development and adoption that new technologies go through, starting with the introduction of a technology and ending with its widespread adoption and acceptance. According to Rogers (2003), technology cycles follow a predictable pattern, with the early adopters being those who are more innovative and willing to take risks, followed by the early majority who are more skeptical and cautious, and finally the late majority who are even more skeptical and only adopt the technology when it becomes widely accepted and proven to be successful. However, not all technologies follow this cycle, and some may never reach the late majority stage due to social, cultural, or economic barriers (Gershenfeld, 2005).

The S-curve is a graphical representation of the technology cycle, with the horizontal axis representing time and the vertical axis representing the adoption or diffusion of the technology. The curve begins with a slow adoption rate at the beginning, followed by a rapid increase in adoption as the technology reaches the early majority stage. As the technology becomes more widely accepted and approaches the late majority stage, the adoption rate slows again, resulting in an S-shaped curve. During early stages when new technology is being developed, the rate of progress in terms of product performance compared to the expenditure in R&D is relatively low. Once the technology gains traction and becomes widely understood, the rate of progress increases and new improvements emerge. After a phase of continuous increase in product performance the development pace slowly decreases due to the approach of a natural and physical limitation. (Bass, 1969; Hall & Khan, 2003)

According to Christensen and Raynor (2003), technology cycles can be divided into two distinct periods: the era of ferment and the era of incremental change. The era of ferment is characterized by rapid and significant changes in technology, as new ideas and innovations are introduced and quickly adopted. Since the market is continually changing and it is difficult to predict which innovations will be successful, there is a significant level of uncertainty and risk throughout this time. During this time, businesses compete to develop the newest technology. On the other hand, technology advancements during the era of incremental change tend to be more gradual. The market has stabilized throughout this time, making it simpler to forecast the success of new technology. Instead of introducing brand-new technology, the emphasis is currently on refining and upgrading current ones. It is important to note that these two periods are not mutually exclusive, and technology cycles may go back and forth between the era of ferment and the era of incremental change. Additionally, different industries and technologies may be in different stages of the technology cycle at any given time.

In their work from 1990, Anderson and Tushman further investigate the stages in a technological cycle. It is concluded that the establishment of a new technology on the market starts when a technological discontinuity is being introduced. This is some sort of product or process innovation that shakes the foundations and questions the existence of the output firm (Anderson & Tushman, 1990). An example of this is the invention of the jet engine in the aircraft industry, threatening the previous standard of the rotary engine. Once a new technological discontinuity has been introduced the technological cycle faces an Era of Ferment. This period can best be described as a period of fierce design competition where companies fight to develop a new industry standard, or a dominant design. During this period, it is also common with customers substituting the old technology to leave room for the new one. When a broad majority have adopted a certain design of the new technology, the market reaches a phase when a dominant design is decided (Anderson & Tushman, 1990). An example of emergence of a dominant design is that a bicycle has two wheels that are the same size and air tubed, while there are alternative designs available.

2.1.2 Technology adoption (theory on the struggles of big change)

Technological adoption requires a set of prerequisites to commence. In the case of disruptive changes in society, the prerequisites are not guaranteed to be present in the necessary capacity. Beyond the significant infrastructural challenges with lacking precedent on which stakeholders should take initiative and ownership, there are several challenges that organizations and individuals may face when trying to adopt disruptive technologies, which is characterized by rapid technological change and innovation. Key organizational challenges are resistance to change, lack of understanding, financial cost, complexity and limited availability.

Resistance to change: People and organizations can be reluctant to adopt new technologies because they are accustomed to their existing procedures and may be unsure of how to use the new technology efficiently (Rogers, 2003). J. Kotter and L. Schlesinger (1989) shares the belief and adds that the issue occurs between management and its employees. Furthermore, they list five approaches for managers to manage resistance, these are; Education, participation, facilitation, negotiation, and lastly coercion.

Lack of understanding or knowledge: Some people or organizations could lack the understanding or expertise of new technology needed to embrace it successfully, which can be a barrier to adoption (Rogers, 2003).

Financial cost: Especially for small enterprises such as those common in the transportation industry, adopting new technology can frequently be expensive (von Hippel & von Krogh, 2003).

Complexity: Complex technologies are often more difficult for individuals and organizations to understand and adopt, particularly if they require significant changes to existing processes or systems (von Hippel & von Krogh, 2003). When tackling the issue, it is important to create a comprehensive and compelling vision that is easily understood by various stakeholders (Kotter, 1996).

Limited availability: Disruptive technologies may not always be immediately available or widely distributed, which can be a barrier to adoption (von Hippel & von Krogh, 2003).

2.1.3 Transport industry

Since the invention of the wheel man has been transporting goods or people with vehicles. From pushing carts, to driving carts with the help of horses, till today’s internal combustion engine vehicles (ICEVs). Petrol and diesel fueled vehicles dominate today's road transportation industry and play a critical part in the transportation industry, both for goods and persons (ACEA, 2021; Statista 2023a). The same holds true for most transportation methods, such as for airplanes and boats, besides trains. Current adaptation trends within the passenger car industry suggest a disruption where electric vehicles (EVs) are moving along the S-curve towards a broader audience; adoption barriers and incentives have been identified by several researchers (see e.g. Egbue and Long (2012), Kumar & Alok (2020), and Biresselioglu et al. (2018)). Many of these barriers and incentives are significantly less relevant in a business environment, though some studies suggest that driving range and financial incentives, and rebates on energy bills, parking fees and upfront rebates may be relevant in a business context (Kim & Heo, 2019; Gong et al., 2020). It's clear that some parts of the transportation industry are moving towards an electric future, while others sub sectors are at a crossroads.

The road freight market in Europe has an estimated value surpassing €300 billion (statista, 2023b) which is shared among 580,000 enterprises (European Commission, 2020b). New produced trucks in 2021 consisted of >95% diesel fuel, ~3% use an alternative fuel, and electric accounted for < .5% (ACEA, 2022). This is an upswing for alternative fuels and EVs compared to past years (Ibid.). A large influence in the adoption of EVs, besides passenger cars, are last-mile distributors in logistics. Electric delivery vehicles, electric cargo bicycles, and autonomous delivery vehicles have all been adopted by significant last-mile players (Behnke, 2019). These have several advantages especially in variable costs, such as lower maintenance, wear, and fuel costs, compared to diesel (Ibid.; Siragusa, et.al, 2022).

Noteworthy, is that these economic benefits are highly dependent on the expected life span of the electric freight vehicle (EFV). Moreover, the procurement cost of an EFV is relatively high, especially for vehicles over 3.5 tonnes, compared to an ICEV (Quak & Nesterova, 2018). This entails a significantly longer pay-back time than an ICEV. Furthermore, they argue that the price of an EFV is primarily influenced by its battery, but the battery's lifetime is uncertain and highly correlated with the price. The future holds promise of an improved battery life, but current knowledge of residual value of an EFV does not exist which creates an uneven playing field (Leung, & Peace, 2020). Therefore, companies currently opt to lease their EFVs to reduce this uncertainty (Ibid.). Other literature also propose that lack of charging infrastructure challenges the implementation of EFVs in logistics, since charging of EFV is far more complex than fueling of an ICEV (İmre & Çelebi, 2021).

The transport industry is currently undergoing a shift in technology, towards EVs, and the degree of adoption is different in different sub sectors. There exist several different known and unknown barriers dependent on the context of adaptation.

2.2 Supply chain management context

2.2.1 Supply chain management & Industry 4.0

SCM as a practice can be traced back to the early textile industry (Lummus & Vokurka, 1999) and is viewed as an important competitive advantage (Li, et al., 2006; Barney, 2012). They further add that constant evolvement of the supply chain to ensure a competitive advantage is necessary. Mentzer et.al. (2001) defines Supply Chain as; a set of entities (e.g.organizations or individuals) directly involved in the supply and distribution flows of goods, services, finances, and information from a source to a destination (customer). Furthermore, they argue that there exists no commonly accepted definition of supply chain management. Improving the supply chain itself is an integral part of keeping the competitive advantage.

Isolated improvement investments on the supply chain are limiting the outcome of a general improvement effort; improvements, within a supply chain, call for an integration between actors, upstream and downstream (Stevens, 1989). Supply chain management has, after this realization, evolved rapidly since the 1980s, by the incorporation of several information systems, productivity practices (e.g. Total Quality Management), and improvement practices (e.g. Six-Sigma) (Stevens and Johnson, 2016). Some of the information systems allow for a greater visibility of the enterprise, inventory control, production planning, and shipment planning. These information systems and efforts have allowed for companies to reduce risks and uncertainties and in turn improve their business performance and efficiency

(Daneshvar Kakhki, & Gargeya, 2019). Although, supply chains still are inherently unstable and risk filled with inefficiencies and can be further improved upon. Industry 4.0 is one such example of improvement investment.

The move towards industry 4.0 puts an emphasis on digitalization (Tjahjono et.al., 2017; Hahn, 2020; Ivanov, Dolgui, & Sokolov, 2019). Hoffman and Rüsch (2017) concluded that there exists no commonly agreed upon definition of industry 4.0. They define it as; a shift in manufacturing logic towards an increasingly decentralized, self-regulating approach of value creation, enabled by concepts and technologies such as CPS, IoT, IoS, cloud computing or additive manufacturing. Noteworthy, Industry 4.0 is an 'announced' revolution, which is still being defined (Culot, 2020). A byproduct of this revolution is supply chain management 4.0 (SCM 4.0) which is a paradigm shift within SCM, where coordination of materials, information and financial flows between cooperation is largely automated (Hofmann, 2019). Some argue that the shift towards SCM 4.0 is highly driven by the customers (Alicke, Rachor, & Seyfert, 2020). On the other hand, Taghipour et.al. (2022) mentions digitalizations areas of impact such as forecasting, manufacturing, warehousing, and delivery, which originates from within an organization. Thus, the drivers towards change can be viewed as bilateral.

Differentiation or a cost advantage is essential to win business (Porter, 1985). Downstream, towards customers, there exists a demand for digitalization (Alicke, Rachor, & Seyfert, 2020) and sustainability (Laari et.al., 2016). Thus, there is a demand for differentiation in conjunction with a cost advantage. Since cost can be viewed as an adaptation barrier for customers (Trumpa, 2019). Internally, the order of improvements is ensuring quality, reliability, flexibility, agility, and finally, cost efficiency (Vokurka, Zank, & Lund, 2002). Thus, the focus is primarily placed in the differentiation strategy, and thereafter a cost and pricing strategy. These improvement efforts occur upstream and downstream throughout the supply chain, where transportation is the focus. The farther upstream, the farther from the end-customer thus a lower degree of digitalization.

2.2.2 Supply chain vulnerability

Supply chains are inherently unstable (Stevens and Johnson, 2016) which implies vulnerability. Vulnerability is an exogenous variable that determines the risk through the intensity of impact generated or caused damage (Elleuch, et al., 2016). The vulnerability has increased over time as supply chains have increased in complexity, through globalization, sustainability, customization, outsourcing, innovation, and flexibility (Serdarasan, 2013). Supply chains are on one hand affected by external disruptions, such as natural disasters, and on the other hand by internal factors, e.g. organizational dysfunction (Nowakowski, Werbińska-Wojciechowska, and Chlebus, 2015). Vulnerability can be counteracted through different forms of mitigation strategies, which calls for risk assessments to understand a supply chain's resilience.

Manuj and Mentzer (2008) has compiled a list of general risks that a supply chain is exposed to, these are as follows; Supply, Operational, Demand, Security, Marco, Policy, Competitive, and Resource risks. These are more fleshed out in comparison to Christopher and Peck (2004) risks; Supply, Process, Demand, Control, and environmental risks. The typology differs but includes the same risks. Moreover, Samvedi, Jain, and Chan (2013) use four of the five proposed types of risk; Environmental, Process, Demand, and Supply risks. The last-mentioned typology of risks is therefore used in the thesis, since it is a broader definition which incorporates all mentioned risk types.

Environmental risks: these are risks external to the firm and can have impact upstream, downstream, on a tier of the supply chain, or the whole market itself. Political instability, natural disasters, macro economical stress, and terrorisms are examples of these risks. Some of these risks can be predicted. (Christopher & Peck, 2004; Samvedi, Jain, & Chan 2013)

Process risks: The firm within the supply chain can have value-adding sequences on certain products, which expose them to risks. The risks mainly occur for a product in between processes. These risks include machine failures, major technological changes, labor strikes and quality problems. (Christopher & Peck, 2004; Samvedi, Jain, & Chan 2013)

Demand risks: Volatility in demand of a product can lead to gaps in demand and supply. These risks can occur due to several factors, both external and internal. Upstream, market psychology can impact the demand for a product. Internally, forecasting errors can be at fault. (Christopher & Peck, 2004; Samvedi, Jain, & Chan 2013)

Supply risks: Is alike demand risks but occur internally or downstream. The upstream and internal flows can be smooth but an unexpected change in demand downstream can impede that harmony. (Christopher & Peck, 2004; Samvedi, Jain, & Chan 2013)

Christopher & Peck (2004) proposes several ways of managing these risks by creating a supply chain risk management culture, improving collaboration in the supply chain, and (re)engineering of the supply chain. These all add up to supply chain resilience. Tukamuhabwa, et al. (2015) define Supply chain resilience (SCRES) as; The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption. They have incorporated the term 'cost effectiveness' which is missing in several other definitions – and correlates well with Vokurka, Zank, and Lund (2002) supply chain improvement factors. Moreover, this is an interpretation of several frequently used definitions, and will be used throughout this thesis. Wieland and Durach (2021) on the other hand, adds that there exist two perspectives of supply chain resilience, a closed and engineerable system and an open social-ecological system. They continue to point out that there is missing research on the social-ecological approach. Our thesis will only focus on the technical aspects.

2.2.3 Green supply chain management

Green supply chain management was popularized in 1988 and coincides with the social and environmental sustainability of the 'Triple bottom line' framework (Rasool, 2016). There has been growing pressure from consumers and other stakeholders to have an environmentally and socially sustainable supply chain (Srivastava, 2007; Kim et.al, 2022). The drivers behind this pressure and transition towards a green supply chain is more nuanced (Diabat & Govindan, 2011). They list several different drivers; Certification (ISO-standards), Collaboration with suppliers, Governmental legislation and regulation, Green design, Environmental management integration, Reduction of energy consumption, Reusing and recycling of packaging, Collaboration with customers, and Reverse logistics. Other suggestions are more general and include; Top management, Government, Customers, Competitors, Society, Suppliers, Banks and insurance companies (Tachizawa, Gimenez, & Sierra, 2015). The connection between the two suggestions are evident and specific drivers can be of interest in specific situations, but the general types are more applicable to base assumptions on. Furthermore, they both conclude that coercive (governmental) pressures are less effective than non-coercive (societal) pressures, in some cases coercive pressures on collaboration might have negative effects.

To achieve a successful green supply chain collaboration externally is focal to success, and in turn puts an emphasis on monitoring (Tachizawa, Gimenez, & Sierra, 2015). This implies that monitoring does not improve environmental performance, rather it is a success factor for collaboration which in turn improves environmental performance – if it is communicated as a goal. Moreover, according to Green, Zelbst, Meacham, and Bhadauria (2012), implementing green supply chain management (GSCM) practices results in improved performance in areas such as cost savings and has a positive impact on overall business performance. There are drawbacks with these conclusions, the focal firm driving change within the supply chain might be subject to others taking advantage and 'free rides' (Harms, Hansen, & Schaltegger, 2013). They add that this leads to unnecessary sunk costs.

2.2.4 Modes of transportation

Within a supply chain there exists several different options of transportation, some suited better than others under certain circumstances. These different modes can also be combined in a sequence with at least two types of transportation modes, called intermodal transportation. Using several modes has become standard practice under the emergence of globalization and its subsequent global customers. The different modes are; Air freight, Sea freight, Rail freight, and Road freight. One can encounter the term consolidation transportation system, which means one vehicle or convoy that serves to move freight for different customers with possibly different initial origins and final destinations. (Rondinelli & Berry, 2000)

2.2.4.1 Air

Air freight is often used for transporting high-value goods, perishable items, or goods that require next-day delivery (Rezaei, Hemmes, & Tavasszy, 2017). Although it is typically the most expensive mode of transportation, it is also the fastest. The western allies relied on air freight to deliver goods to West Berlin during the cold war due to road and rail blockades, playing a crucial role in supporting their society (Shlaim, 1983). This mode of transportation is still used today in areas with limited road, rail, and sea connections, such as the Himalayas, and in situations where speed is of the utmost importance. Air freight remains a key player in the transportation industry and continues to drive business for certain actors in the aviation sector. In 2023, air cargo tonne-kilometers (CTKs) rose by 18.7% year-on-year and volumes were 3.5% higher than pre-pandemic levels (iata.org, 2023).

2.2.4.2 Sea

Maritime shipping, specifically container ships, play a crucial role in China's trade with Europe, with 13% of all maritime trade being carried out by Chinese company COSCO (UNCTAD, 2022). This mode of transportation has a long history of being at the forefront of trade, driving the success of major empires such as the Dutch East India Company and the British Empire (Emmer & Gommans, 2020; Killingray, Lincoln, & Rigby, n.d.). Today, sea freight remains the most cost-effective option for longer routes, although it is also the slowest mode of transportation. Despite this, maritime shipping still accounts for over 80% of global trade volume (UNCTAD, 2022).

2.2.4.3 Rail

Shipping by rail is a widely used method for transporting raw materials and is closely associated with heavy industry. It has a rich history in the United States, where railroads in the late 1800s facilitated western expansion and economic growth (Library of Congress, 2023). Today, rail shipping continues to play a significant role in the transportation industry and is widely considered a more environmentally friendly option compared to other modes of transportation, as it results in lower carbon emissions. Trains remain a cost-effective option for transporting large volumes of goods, compared to other land and air transport methods. However, cross-border rail transport can present technological challenges due to geographical limitations.

2.2.4.4 Road

Trucking is the most widely used method of shipment in the United States, with 46% of the total tonnage being transported via trucks (BoTS, 2023). The same trend is observed in almost all European Union countries (Corselli-Nordblad et.al., 2019). One of the advantages of road freight is that it has fewer restrictions on cross-border transportation compared to other modes of transportation. The only hindrances are customs and toll fees. Another advantage of trucking is that the infrastructure needed is relatively simple. Unlike trains, which require specialized tracks, cargo ships which require ports and airports for airplanes, roads are necessary for transportation in some capacity and are readily available in most regions. This makes road freight a convenient option for many businesses, especially for those operating within a specific region or country.

2.2.5 Truckload theory

2.2.5.1 Full truckload

Full-truckload (FTL) transportation can be conducted in several ways with the defining characteristic being that the customer has paid on a per truck basis. The route can be either A to B or a milk-run and the transport can be scheduled or requested. The operational management is similar between all FTL cases, even though the pricing may differ. A truck is assigned to a mission and the customer pays for the fulfillment of this mission, any empty runs or low utilization is no issue as the pricing of the service should cover all adjacent costs. The literature on data-driven optimization of routing is extensive, the degree of adaptation is unknown but using algorithms like simplex is common practice. The need for FTL routing models, beyond finding the shortest route, increases with the route's complexity. Dynamic demand milk-runs are the most complex and here, computer modeling is especially useful.

2.2.5.2 Less-than-truckload (LTL)

Less-than-truckload (LTL) on the other hand is not paid for per truck basis, rather per pallet in a truck. The routes can be A to B or a milk-run and can be scheduled or requested. Pricing is commonly fixed and should only be dynamic if a carrier has high-demand and low transportation costs (Qiao, Pan, & Ballot, 2019). A truck is usually assigned to several customers and serves a neighborhood of customers, where customers pay per fulfilled mission. Systems designs become significantly more complex, since it involves several different actors. Jarrah, Johnson, and Neubert (2009) in their paper on LTL network design concludes that; 'The critical issue in designing an LTL carrier's network is the determination of planned paths for all anticipated freight from the freight's origin to destination while minimizing overall transportation and other ancillary costs'. Anticipating freight, or forecasting, and keeping high service-levels to the lowest possible costs is essential, to stay competitive.

2.2.5.3 Comparing FTL and LTL

Oliver et al. (2014) argues that correctly selecting between LTL and FTL transportation can contribute to significant cost reduction through better transit time reliability, greater transport security, lower delivery error and greater speed. Furthermore, adjacent criteria related to inventory costs such as those related to maintenance, safety stock and transit can be criteria integrated into the decision between the transport types. Criteria can therefore be sorted into two groups, criteria based on costs and criteria based on operational efficiency.

Relevant costs for a transport problem are transport costs, transit inventory costs and inventory maintenance costs (Ballou, 2009). Transport cost is the sum of variable and fixed costs, where fixed costs would be depreciation, salaries and regular maintenance while variable costs would be fuel, tires and irregular maintenance. The cost of transport can either be fixed, as is the case for FTL transport, or unit based, which is the case for LTL transport (Rieksts & Ventura, 2010). Inventory maintenance costs include the cost of capital, insurance, obsolescence, losses and other risks. The cost of transit inventory are costs associated with inventory while being transported, such as storage and insurance (Meixell & Norbis, 2008).

According to Vega et al. (2021) operational efficiency criteria can be categorized into five categories according to: service level, security in service provision, customer service, and handling. The service level category encompasses transport lead time, transit time reliability, reliable collection service, low delivery error and service frequency. For LTL transportation, these factors can be improved with consolidation to improve efficiency. Though FTL will by its nature be more capable of fulfilling these criteria.

Security in service provision is defined as the stability and good performance of the logistics service provider by Aguezzoul (2014). Kokkinis et al. (2006) considers a stable carrier in the market to be one which can ensure good performance of the transport and favors close long-term relationships. Furthermore, they argue that entrusting a company which is not stable in the market can result in problems such as unreliability, delays or customs issues.

The interaction between carriers and customers in the ways of personal treatment, punctuality and courtesy is what is referred to as customer service. Kokkinis et al. (2006) conducted a study which found that interpersonal behavior helped improve the service provided, mainly as a result of the direct exchange of information between the customer and the carrier. Some companies try to amend the gap in information sharing through implementing information systems to facilitate communication and execution of their logistical operations (Jharkharia & Shankar, 2007). Adequate customer service is both of increased importance and more difficult to maintain in LTL shipments as the number of stakeholders per transport increases.

As described by Aguezzoul (2014), the handling criteria relates to things such as how a customer perceives the ease of making changes in loading or unloading and other general factors relating to the carrier's ability to adapt to new conditions or customer requirements. Oliviera et al. (2014) highlights that this, along with customer service criteria, relates to the sharing of company’s values and culture as well as their ability to maintain long-term relationships. The handling factor can be understood as the ability of a customer and the carrier to work toward common goals.

2.3 Routing strategy

According to Produção, et.al (2021) deciding between FTL or LTL, or a combination of both, as a transportation method is often not straightforward, rather a combination is preferred. Which indicates that both alternatives should be considered a service alternative for a supplier. Looking at a FTL or LTL, an optimization problem that arises is famously known as the Vehicle Routing Problem (VRP), it addresses issues related to the fleet limitations and the two transportation modes (Soleilhac, et al., 2022). Carriers can provide either FTL or LTL, or a combination of both, as a transportation mode to its customers. When providing an FTL flow it is optimized on the shortest distance, and speed is prioritized (Produção, et.al, 2021). On the contrary they argue that providing an LTL flow is still optimized on the shortest distance, but minimizing costs are prioritized above speed. When servicing customers are served with both LTL and FTL, the thesis takes these two flows into consideration as separate flows, unlike Soleilhac, et al. (2022) due to the added complexity. The adoption of EFVs in LTL has not been tested in real-life applications, but their theoretical implications and complexity can be analyzed. One company offers EFV FTL shipments using shortest distance optimization. The current landscape of options is presented in table 2.1.

Table 2.1 Current landscape of options and their respective methods.

	Internal Combustion Engine Freight Vehicle	**Electric Freight Vehicle**
Less-than-Truckload	Shortest distance, cost minimizing.	No current studies.
Full-Truckload	Load balancing, time minimizing.	Shortest distance (No current studies).

Carriers have the option to offer LTL, FTL, a combination of both, and finding the shortest distance while minimizing costs or speed. Offering an electrified FTL can be done, but there are no theoretical suggestions on how to optimize it. Electrified LTL is missing in both theory and real world application. The economical nature of electrified LTL and FTL transportation systems is unknown and the nature of the added complexity is yet to be understood and studied.

Solving the VRP has traditionally been a simple task but since the introduction of EFVs the VRP has become the electrical VRP (EVRP) which is more difficult to solve (Ye, He & Chen, 2022). There exists several approaches to solving the EVRP; Exact algorithms, Heuristic algorithms, Meta-heuristic algorithms, and hybrid algorithms (Ye, He, & Chen, 2022; Konstantakopoulos, Gayialis, & Kechagias, 2020). These algorithms have in turn several subsets of optimization algorithms, which can be seen in table 2.2.

Table 2.2 Algorithm classification and subset of optimization algorithms commonly used in EVRP (Ye, He, & Chen, 2022; Konstantakopoulos, Gayialis, & Kechagias, 2020).

Algorithm	**Type**	**Optimization algorithm**
Exact	NAN	Branch and Price
		Mixed Integer Programming
		Approximate Dynamic Programming
		Column Generation
Heuristic	Constructive	Clarke-Wright
	Constructive	Dijkstra
	Two-Stage	Two-Stage
	Local Improvement	Locally Improved Heuristic
Meta-Heuristic	Single-Point	Simulated Annealing
	Single-Point	Tabu Search
	Single-Point	Neighborhood Search
	Multipoint	Genetic Algorithm
	Multipoint	Particle Swarm Algorithm
	Multipoint	Differential Evolution
	Multipoint	Ant Colony Optimization

2.3.1 Exact algorithms

Exact Algorithms can find the optimal solution on a relatively small problem in a short time, leveraging mathematical laws or data structure search (Ye, He & Chen 2022). Most commonly used in today's environment are Branch and Price, Mixed Integer Programming, Approximate Dynamic Programming, and Column Generation (Ye, He, & Chen, 2022; Konstantakopoulos, Gayialis, & Kechagias, 2020). These methods are modifications to solve linear programming problems. Linear programming problems have been used to solve VRPs at least since 1983 (Laporte, 1992). Today there exists limited research interest in exact algorithms, mainly due to their computational time limitations as the problems grow (Konstantakopoulos, Gayialis, & Kechagias, 2020).

2.3.2 Heuristic algorithms

The heuristic algorithm is less advanced than its counterpart, meta-heuristic algorithms. The heuristic algorithm relies on inductive reasoning and experimental analysis with the help of intuitive judgment or trial-and-error to find the suboptimal or optimal solution with a certain probability (Ye, He, & Chen, 2022; Konstantakopoulos, Gayialis, & Kechagias, 2020). Traditionally, heuristic algorithms are divided into two categories, constructive and local improvement heuristic.

Constructive heuristic algorithms start without a solution in mind, therefore constructive, and construct a solution iteratively (Ye, He, & Chen, 2022; Konstantakopoulos, Gayialis, & Kechagias, 2020). The commonly used constructive methods for solving the EVRP are; Clarke-Wright's and Dijsktra's algorithm. Where Clarke-Wright is the most common heuristic method.

The traveling salesman problem (TSP) has been commonly solved using a constructive heuristic algorithm, see (Hoffman & Padberg, 2013; Isamail, 2019; Mestria, 2018). The TSP can be described as follows; if a traveling salesman wishes to visit exactly each of a list of m cities (where the cost of traveling from city i to j is c_{ij}) and then return to the home city, what is the least costly route the traveling salesman can take? (Hoffman & Padberg, 2013). The problem is easily stated and hard to solve (Ibid.). Moreover, the problem itself highly relates to the optimization problem of a supply chain, but here only taking the costs of travel into account.

Local improvement algorithms, unlike heuristic algorithms, start from a point or a feasible set of solutions to then iterate over new solutions. The methods within the algorithm are classical optimization methods such as local search (LS). This makes the algorithm more flawed than the heuristic since LS is prone to get stuck in local optimums rather than finding a global solution. (Ye, He, & Chen, 2022)

2.3.3 Meta-heuristic algorithms

Meta-heuristic algorithms are the most advanced algorithms currently used when solving the EVRP (Konstantakopoulos, Gayialis, & Kechagias, 2020). These algorithms are usually inspired by natural phenomena such as the evolution of species and ant colonies, but not necessarily. Examples of algorithms commonly used that are inspired from natural phenomena is; Particle swarm algorithm, Differential evolution, and Ant colony optimization. They are all so-called multipoint meta-heuristic algorithms. The multipoint meta-heuristic algorithm solves several problems simultaneously and gives back a vector of solutions.Simulated annealing, Tabu search, and Neighborhood search are single-point, which are commonly used, and are suited for single-objective EVRPs. These algorithms usually counteract the risk of getting stuck in a local optima, unlike a local improvement algorithm. (Ye, He, & Chen, 2022)

2.4 Financials

Capital budgeting is a financial technique used by firms to assess possible investments in capital assets. The most essential variables used is; Asset purchasing cost (*G*), Residual value at end of life (*S*), cash inflow (I_k), cash outflow (U_k), cash flow difference (a_k), interest rate (*i*), economic lifespan (*n*) (Nilsson & Persson, 1999). *G* accounts for the one-time payment, or investment, in an asset. *S* is the value of the asset at time *n*. The interest rate *i* is the alternative cost of the investment. Thus, this is a comparison between different investments, where *G* could be invested elsewhere. Moreover, there exist four different methods to estimate the cash flows, which are needed since expenditures and payments can occur during separate times. These four are according to Nilsson and Persson (1999), net present value (NPV), internal rate of return (IRR), equívalent annual cost (EAC), and payback method. The NPV method and IRR can be used when assessing investment alternatives which share the same lifespan. The EAC is commonly used to compare investments with different lifespans.

The lifespan between EFVs and ICEVs can be different, which should be considered if they are not leased, then the EAC method should be leveraged to compare the alternatives. Common practice among non-owner-operated-type companies in the transportation industry is to lease freight trucks, which suggest that the lifespan should be assumed the same when comparing an ICEV with a EFV. Thus, the NPV method is used in this thesis. The method evaluates the difference between the present value of expected cash inflows and the present value of the investment's costs, see equation (i). (Gallo, 2014)

$$NPV = \sum_{i=0}^{n} \frac{(Cash\ Flow)_i}{(1+Discount\ Rate)^i} \qquad \text{(i)}$$

In the thesis, capital expenditures and operational expenses will be accounted for whilst cash inflows will be disregarded. Moreover, the lifespan will be assumed to be the length of a normal lease for an EFV. Thereafter, it's also important to take depreciation of the asset into account. The cash inflows is assumed to be the same for each comparative solution. See equation (ii).

$$\sum_{i=0}^{n} \frac{(Cash\ Outflow)_i}{(1+Discount\ Rate)^i} \qquad \text{(ii).}$$

2.5 Theory summary

The purpose of this thesis is to combine existing LTL theory with regard to the financial consequences of LTL routing strategies in a cluster using EFVs. The theory has been established to support findings, the empirical analysis, and subsequent conclusion. Especially, the three theoretical horizons presented in this paper, technology shifts, supply chain management, and routing strategy, will allow for triangulation of the economics behind the specified purpose. See figure 2.2. Moreover, the four-field model allows us to illustrate the missing theory and real-world application of an EFV LTL transportation system, and also the possibility to triangulate the data from the other three fields of knowledge.

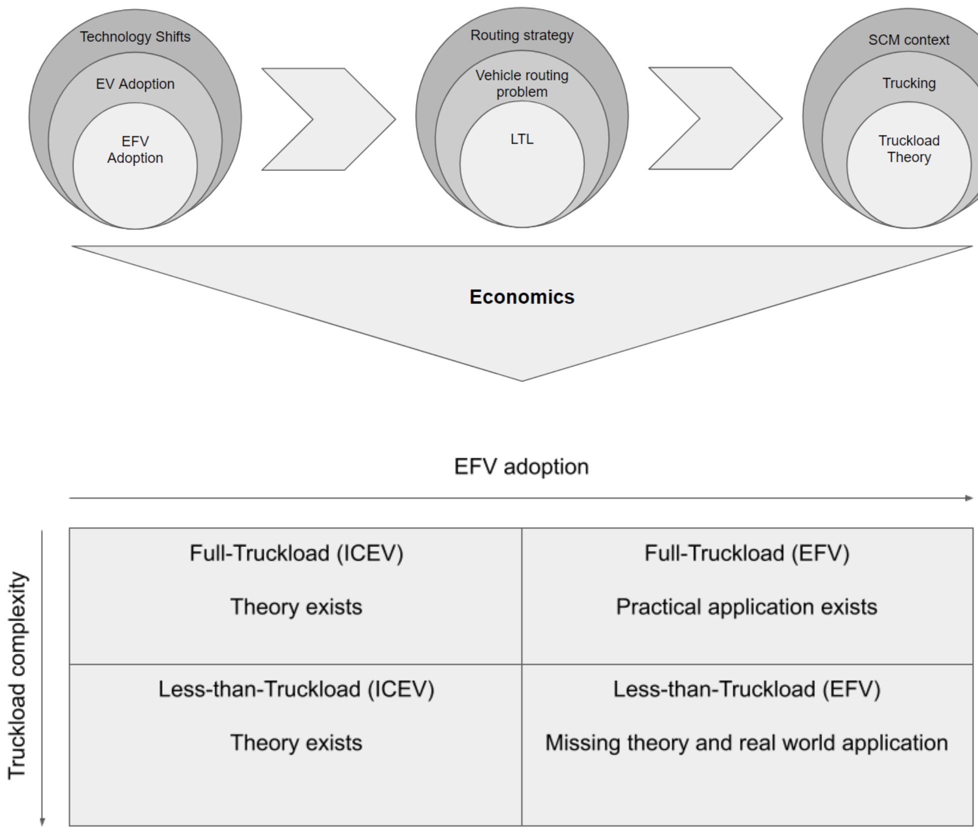

Figure 2.2: Illustration of the theoretical framework and theoretical methodology

3. Methodology

The methodology is the chosen approach for completing the Master Thesis. There are various methodologies to choose from, each suitable for different purposes. The main purposes of a Master Thesis are: (1) descriptive studies, which aim to understand and describe how a research subject operates or is carried out; (2) exploratory studies, which seek to gain a deep understanding of how a research subject operates or is carried out; (3) explanatory studies, which aim to find explanations or causes for how a research subject operates or is carried out; and (4) problem-solving studies, which seek to find solutions to identified problems. It should be noted that the above can be combined into a mixed approach in a singular thesis. (Höst et al., 2006, p. 29).

Since fully electrified LTL transportation systems are, at the time of writing, yet to be implemented by any carrier, real world examples are generally non-existent. Thus, the thesis was an exploratory study since it seeks new insights and aims to assess the phenomenon in a new light (Yin, 2018). The approach throughout was that of a case study. The case study strategy allowed triangulation of data collected from several different sources and allowed the highlighting of conclusions otherwise overlooked. Moreover, a case study usually has a considerable ability to generate answers to 'why?' and 'how?' questions (Ibid.). Both qualitative and quantitative data was collected to create the final result, which is a case scenario. The approach was therefore a mixed-model where academic research and industry knowledge was combined into several scenarios which were investigated.

There are several steps in the iterative process which is a case study. Robert K. Yin's book on Case Study Research (2018) will be used as a northern star in the thesis. The steps described are;

I. Plan - Research approach
II. Design - Research process
III. Prepare - Researcher preparation
IV. Collect - Data collection
V. Analyze - Data analysis
VI. Share - Research publication preparation

Step I-VI will be described in detail, in relation to the thesis, further in the sub-sections below.

3.1 Research approach

The research approach describes the type of logical reasoning which was used as well as the nature of the thesis and the data within, in terms of qualitative or quantitative. However, it should be noted that this thesis used a flexible approach. The research approach can either be fixed, as in all the rules of the study being determined before commencing, or flexible, which allows the study to adapt throughout to adequately answer the research question. The flexible approach is generally considered appropriate for a case study (Höst et. al, 2006)

3.1.1 Deductive and Abductive Reasoning

There are three main types of logical reasoning which are presented in table 3.1.

Table 3.1 Types of logical reasoning (Timmermans & Tavory, 2012, pp 167, 170-171)

Type of reasoning	Example
Inductive	Consider that all observations confirm that X>Y and Y>Z. Inductively, X>Z and the probability of this increases as the number of observed cases increases
Deductive	Consider X>Y and Y>Z Deductive reasoning leads to X>Z
Abductive	A fact X is observed. If Z is true, X would matter of course. Therefore, Z might also be true due to abductive reasoning.

An important factor to consider when determining the research approach is whether the study will be done through inductive, deductive or abductive reasoning. The reasoning for this thesis, a case scenario, will not be mainly inductive. A deductive approach could have been possible, using the general rules of LTL or the general rules of electric trucking to point toward specific conclusions. Though, the approach of this thesis was to produce a general conclusion in the form of a case scenario based on incomplete data, making a abductive approach most favorable. (Timmermans & Tavory, 2012, pp. 167, 170-171)

Using a case study, academic literature and interviews to deduce a case scenario and good-to-haves for something yet to be implemented in real-life, electric LTL trucking, is best done through abductive reasoning. Using a combination of available adjacent data to build an understanding of how an electrified LTL trucking system would look like and the key factors for an economically feasible implementation. The study used an iterative approach to continuously analyze and respond to the data collected, with the goal of gaining a thorough understanding of the factors that impact the feasibility of an electrified LTL system.

3.1.2 Quantitative vs. Qualitative Approach

There are various methods for analyzing data in research, which are typically divided into three categories: quantitative, qualitative or a combined approach (Denscombe, 2010). Quantitative data consists of numerical information that can be analyzed using statistical techniques, while qualitative data consists of words, descriptions, and other detailed information that can be analyzed through methods such as sorting and categorization (Höst et al., 2006). The choice between a quantitative or qualitative approach can affect the level of researcher involvement in the data collection process. Quantitative research often relies on standardized instruments to gather objective data, while qualitative research involves a more personal approach and may be influenced by the researcher's own experiences, values, and biases (Denscombe, 2010).

Quantitative research tends to involve larger-scale studies, as the use of computers allows for the analysis of large amounts of data, which can lead to more reliable results. On the other hand, qualitative research is often associated with smaller-scale, in-depth studies due to the time-consuming nature of data collection and analysis, which is typically done without the aid of computers. Rather, it depends on in-depth analysis and research of the researchers (Denscombe, 2010).

This thesis focuses on qualitative data in the form of interviews, best practices and academic literature. Though it should be noted that in many cases, best practices and research papers are quantitative in nature. A clear example of this methodology is within the field of conventional LTL trucking research. Papers in this field are often focused on some sort of optimization model and are heavily quantitative, though the parameters suggested for mathematical route optimization of conventional trucks and the discussions on the impact of specific parameters can be used as groundwork for a qualitative model, a bottom-up approach. An approach adopted in this thesis. The thesis therefore used insights from both qualitative data and quantitative research to produce a qualitative framework, and the thesis should therefore be considered a predominantly qualitative one.

3.2 Research Process

3.2.1 Literature review

The literature review is considered a crucial step according to Saunders et al (2009), this is especially true for this thesis. As this thesis is based on combining existing literature with practiced knowledge. More generally, there are two main reasons to include a literature review. It aids in refining the initial research idea by introducing new perspectives and it ensures that the research is based on a solid foundation of research (Saunders et al, 2009). In this thesis, existing theories and research in the field of LTL trucking with conventional trucks was used to generate new research within the new field of electric LTL trucking. A variety of sources was used, and due to the nature of the research question, mainly primary and secondary sources. The process itself is commonly iterative where a researcher revisits existing literature several times, each time with a new focus or scope, to generate a summary of relevant findings in existing literature. While a literature review can be conducted in slightly varying ways, it usually follows the general steps outlined in figure 3.1.

The literature review process is an iterative process in which the researchers go through several cycles to produce a critical review of the literature. The process begins when the researcher outlines the questions and objectives as well as defines the main topics for the research. Next, a search for literature is conducted, and the literature is obtained and evaluated. The findings are then collated, and the researcher redefines the topics of research, continuing to delve deeper with steer from previous iterations. This process continues until the critical review of the literature is completed. (Saunders et al, 2009, p. 60) In this thesis the literature review used an unstructured approach to gather clearly defined adjacent literature due to the lack of literature on Electrified LTL Trucking, the list of adjacent topics considered increased iteratively as the research process continued. Examples of adjacent topics used in the literature review are electric vehicle (EV) adoption, electric freight vehicle (EFV) adoption and conventional LTL literature.

Figure 3.1The literature review process (Saunders et. al, 2009)

3.2.2 Case study

When trying to understand a specific situation or an organization's approach to a specific situation, a case study is often appropriate. It is an exploratory method that allows researchers to ask specific questions about the organization and gather data through interviews, observations, and analysis of materials provided by the organization. Case studies can provide both insights specific to the subject of the study and more generalizable insights. A case study often relies on interviews for its findings, which can be structured, partly structured or open interviews. These different methods of data collection can impact the results of the study, so it is important to carefully consider which approach is most appropriate. (Höst et al, 2006)

Observations can also be a valuable source of data for a case study and can be conducted by either participating or non-participating observers. While interviews and observations are effective methods to gain an understanding of a situation, analyzing documents and other material produced by the case subject can provide deep insights. Qualitative and quantitative data from previous projects, initiatives or miscellaneous internal communication can provide useful information given that it is understood from the context of its creation. (Höst et al, 2006)

3.2.3 Case study's purpose

The purpose of the case study for this thesis was to understand an organization's approach to an adjacent field, electric FTL trucking, as well as the organization's view on electric LTL trucking. The Case Company was chosen due to their unique position as a first-mover in electric trucking and is currently the only major actor in this market. No company provides electric LTL trucking in a dynamic demand fashion the way conventional spot-markets or carriers operate. Performing LTL trucking in addition to the FTL trucking it currently operates is a key milestone toward The Case Company's vision to electrify the trucking industry. Furthermore, The Case Company's unique experience in electric FTL trucking makes it a prime candidate to expand into LTL coverage using experience gained in electric FTL trucking, this is a key question answered with this case study.

To understand the theoretical environment, a literature review has been conducted to give the reader a grasp of the existing and missing theory, as well as the theoretical framework created to describe the issue. Thereafter, a competition analysis has been conducted to give the reader an understanding of the nature of the industry. Thirdly, the theoretical framework is used moving forward to understand the implications on each subset of theory. Lastly, a summary of the empirical data presented is done to answer the research question.

3.2.4 Study design

There are several potential designs for studies of this type, but as this thesis will investigate the economic feasibility of an electrified LTL transportation system, only one was deemed suitable, see table 3.2.

Table 3.2 Relevant Situations for Different Research Methods, Source: COSMOS Corporation.

Method	(a) Form of Research Question;	(b) Requires Control Over Behavioural Events?	(c) Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
Case Study	How, why?	No	Yes

The case study was the only research method where questions (a), (b), and (c) aligned with our purpose. We worked with 'how's and 'why's which rules out surveys and archival studies. Moreover, experiment was ruled out since it would require a level of control over processes which we could not attain even if there were observable real-life implementations of electrified LTL transportation systems. The design is essential to get from the question(s) to the answer(s). Every empirical study has an implicit, if not explicit, research design. The most critical part in a case study is to firstly, define a research question, secondly, the scope of the case and the case itself. The form of the research question should be in terms of ‘how?’ and ‘why?’. Thereafter, deciding upon using a single- or multiple-case and a holistic or embedded approach. Linkage between data and the propositions is also key. Lastly, criteria for interpreting the findings needs to be in place. (Yin, 2018)

The research question of this thesis fulfills the criterion on its formulation. The question is open-ended and a new research area with no definite or real-world answer, as of today. Thus, the labeling as a case study is valid. Moreover, the approach is holistic. The reasoning is as follows; (i) Interviews were conducted both internally at The Case Company and externally with professionals in SCM with relevant knowledge and (ii) the answer to the research question is generally applicable. In conclusion, (i) suggests that the case can be considered a multi-case, since there are several entities involved, and (ii) validates the case as a holistic case, since it is generally applicable. Linkage between data and propositions was carried out iteratively through the paper as we connect interviews with theory – as well as filling theory gaps with industry practices and/or current best-known approaches. As there exists no players in the electrified LTL transportation industry a validation criterion was not used.

3.3 Research Preparation

3.3.1 Researcher preparation

Researchers must possess a variety of qualities in order to effectively conduct a study. Curiosity is one of these important qualities as it drives their desire to learn and discover new things (Dewey, 1938). Attention to detail is also important, allowing them to carefully analyze and interpret data (Mertens, 2005). Critical thinking skills are essential for researchers as it allows the objective analysis of information as well as the evaluation of the strengths and limitations of different approaches (Paul & Elder, 2006). The ability to problem-solve is important for researchers; it enables them to identify and solve problems in a logical and systematic way (Polya, 1957). Communication skills are crucial for researchers as it enables them to effectively share their findings with a variety of audiences (Gustafson & Johnson, 2004). Researchers should also be committed to ethical conduct and consider the impact of their work on society (National Research Council, 2002). Finally, researchers must be able to manage their time effectively and meet deadlines as communicated to stakeholders (Dolle, 2019).

The preparation phase of a case study is crucial to ensure that the research is conducted effectively while preserving the integrity of The Case Company. It is important for researchers to have or develop certain skills and values in order to be successful in this phase. Some of the desired attributes for researchers include the ability to ask good questions, be a good listener, stay adaptable, and have a thorough understanding of the issues being studied. Additionally, it is important for researchers to consider and evaluate competing explanations and theories in order to provide a nuanced and well-rounded perspective on the subject (Yin, 2018).

3.3.2 Research Credibility

Research credibility refers to the trustworthiness of a study; to what degree can the research be trusted to have done everything in their ability to produce honest and useful research? There are several factors that contribute to the credibility of research, including objectivity, validity, reliability and generalizability (Denscombe, 2010).

Objectivity refers to the lack of biases in a study and can be increased through openness in entertaining alternative explanations (Denscombe, 2010). It is important for researchers to strive for objectivity in their research as most researchers hold some personal beliefs in regard to their research. This can be achieved by using unbiased methods and measures, and avoiding personal bias or preconceptions. By being objective, researchers can help to ensure that the results of their study are free from unjust influence and can be trusted.

Validity refers to the extent to which a research study measures what it is intended to measure. There are several types of validity, including internal validity, external validity, and construct validity (Denscombe, 2010). Internal validity refers to the extent to which the results of a study can be attributed to the variables being studied, rather than to other factors. External validity refers to the extent to which the results of a study can be generalized to other populations or settings. Construct validity refers to the extent to which a measure or instrument used in a study accurately reflects the concept or construct that it is intended to measure. In the case of qualitative data, validity can be increased through the use of triangulation, respondent validation, and grounded data (Denscombe, 2010).

Reliability refers to the consistency and stability of the results of a study. There are several types of reliability, including test-retest reliability, inter-rater reliability, and internal consistency reliability (Denscombe, 2010). Test-retest reliability refers to the consistency of results when the same test or measure is administered to the same group of people at two different points in time. Inter-rater reliability refers to the consistency of results when the same measure is administered by different raters or observers. Internal consistency reliability refers to the consistency of results when different items or questions on a measure are intended to tap into the same concept or construct. Researchers can increase the reliability of their study by providing detailed information about the methods, analysis, and decision-making processes used in the study (Denscombe, 2010).

Generalizability, or external validity, refers to the extent to which the findings of a study can be applied to other similar situations. This can be increased by adequately describing the cases studied so that to allow readers to judge the degree to which the conclusions of this thesis can be applied to their query (Denscombe, 2010).

To increase overall credibility of a study, researchers must take steps to fulfill these objectives and thoroughly explain the research method. This may involve gathering data from various contrasting sources and critically understanding the applicability of older sources in the current context. It may also involve using audio recordings or transcriptions to ensure the reliability and validity of the data collected through interviews, and to ensure replicability. If necessary, the study may also include assumptions to fill gaps where no reliable data is available. These estimations should be clearly identified in the thesis to ensure transparency.

Objectivity within the research paper has been kept throughout, since there have not existed any biases to prove or disprove the feasibility of an electric LTL from either The Case Company nor the researchers. Furthermore, controversies have been nuanced from several sides. Validity-wise the research question has been answered, with and without the assumptions one can still draw their own reasonable conclusions from the thesis. If one decides to replicate the study, they would be able to conduct the same study step-by-step and land in a reliable conclusion. Lastly, this study could be replicated in a generalized way and applied to other sectors and give fruitful conclusions.

3.3.3 Research Ethics

It is important for researchers to understand the ethical implications of their research, both during the research stage and when publicized. In the context of business research, this may involve obtaining informed consent from participants, protecting the confidentiality and privacy of participants, and avoiding any potential harm to participants.

There are a variety of key considerations in research ethics that should be taken into account when writing a thesis or conducting research in a business setting.

Informed consent: Researchers must obtain informed consent from participants before collecting any data or using their information in their research. This involves clearly explaining the purpose of the research, the risks and benefits of participation, and the participant's right to withdraw at any time.

Confidentiality and privacy: Researchers should take steps to protect the confidentiality and privacy of participants, especially when collecting sensitive or personal information. This may involve using anonymous or pseudonymous data as well as taking steps to secure and protect the data collected.

Avoiding harm: Researchers should take steps to minimize any potential harm to participants, both physical and psychological. This may involve providing appropriate safeguards or support to participants as well as carefully considering the potential risks and benefits of the research.

Deception: Researchers should not deceive participants about the nature or purpose of the research and should be transparent about any manipulations or experimental treatments being used.

Two significant ethical considerations were identified during the writing of this thesis. The confidential nature of The Case Company and the privacy of the individuals providing information. By keeping open and continuous communication with The Case Company this thesis has been cleared for publication, containing no mission critical information which could potentially harm or otherwise endanger The Case Company's position in the market. The individuals providing information are both employees of The Case Company and employees of external actors, the integrity of these individuals is guaranteed by clearing any information communicated for use in a published thesis as well as by thorough anonymization.

3.4 Data Collection

As discussed, data can be either quantitative or qualitative, and there are several methods for collecting it; including interviews, surveys, observations, and literature reviews (Höst et. al, 2006). For this thesis interviews, research papers, and quantitative data from The Case Company, such as variables and measurements from optimization models. These sources were collected in a database and well documented with information on where, who, and when they were obtained, creating a chain of evidence which is essential for a high-quality case study. It is important to use multiple sources of evidence, maintain a database of case study materials, and be cautious when using social media as a proxy, such as conducting an interview through chat, in order to validate the data and ensure its reliability (Yin, 2018; da Mota Pedrosa, Näslund & Jasmand, 2012).

Two main methods were used to collect data for this thesis: a literature review and a case study at The Case Company.

3.4.1 Literature Review

A literature review was used as a key part of this thesis as it provided a comprehensive overview of the existing research and knowledge on the topic of LTL trucking compared to FTL trucking. The literature review process was iterative in nature, initially analyzing literature on LTL, FTL, and electric trucking, as well as more general papers on transportation networks. After evaluating the findings, efforts were focused on extracting information that was relevant to an electric LTL transportation system. This process was repeated until a solid and credible theory was developed. The sources used in the review included primary, secondary, and tertiary materials. Overall, the use of a literature review was crucial in informing the analysis and conclusions of the thesis and provided a foundation for the examination of the complexities of electric LTL trucking compared to electric FTL trucking.

3.4.2 Company data

Internal company data, knowledge, and experience was used as an essential part of this thesis, providing valuable insights and context for the state of electric trucking and the use of electric freight vehicles (EFV). The data and information collected from The Case Company allowed for a more nuanced and current understanding of the industry as well as its challenges and opportunities. Additionally, the expertise of The Case Company's employees provided valuable perspectives and insights which were used to inform the analysis and conclusions of this thesis. Overall, the use of internal company data, knowledge, and experience served as a benchmark for current the state of electric trucking which allowed for a more grounded and realistic assessment of the industry.

3.4.3 Interviews

Interviews were conducted to gather primary and qualitative data on various related topics. Interviewees were selected in collaboration with The Case Company and included individuals from The Case Company, academia, and the transport industry. To ensure that no potential approach was missed, at the end of each interview, the interviewee was asked to explain how they would approach the problem. For competitive reasons, the identities and positions of the interviewees were kept anonymous. Most of the interviews followed a partly structured format, and a full list of interviewees and general questions can be found in the sources and appendix. The use of interviews was an important part of the research process and crucial in assessing the current citation of Transport-as-a-Service (TaaS) and the electric trucking market.

The interviewees were selected to provide useful information where there was a gap in the academic research, and to validate our prior research, within their area of expertise. These were picked from three different categories, internal sources at The Case Company, external sources as other actors within the business segment, and external sources as experts within the area. The choices were guided by The Case Company supervisors.

3.4.4 Publicly available data

In order to comprehend the overall background and trends as they pertain to the transportation business, particularly trucking, publicly available data was employed in this thesis. This information came from a variety of sources, including government departments, business associations, and research centers, and it was often statistical and economic in nature. The study was able to describe the current situation of the industry by examining this data, discovering trends and patterns which guided the analysis and thesis's conclusions. In order to provide a broad overview of the transportation business and to situate the research within the larger market, the utilization of publicly available data was crucial.

3.5 Data Analysis

The process of looking over and evaluating gathered data in order to come to conclusions and make wise judgments is known as data analysis. Data analysis can be divided into two categories: quantitative and qualitative. To comprehend trends and patterns, quantitative analysis uses numerical data and statistical methods. Comparatively, qualitative analysis entails the evaluation of non-numerical information like words and pictures in order to comprehend the meanings and experiences of persons. It is often important to anonymize sensitive variables in a competitive business environment in order to safeguard confidentiality, including interviewee information, market data, and company-specific information. (Höst et. al, 2006)

3.5.1 Quantitative Analysis

Utilizing numerical data and statistical methods, quantitative data analysis aims to comprehend trends, patterns, and relationships. Examining quantitative data, or data that is numerical or can be represented numerically, is done using this form of analysis. The application of statistical approaches in quantitative data analysis is primarily driven by two goals: comprehending data exploration and hypothesis testing and relationship evidence. Common techniques for analyzing quantitative data include ANOVA (Analysis of Variance), regression analysis, correlation analysis, descriptive statistics, and inferential statistics. These methods enable researchers to infer conclusions from their data and make well-informed decisions. (Höst et. al, 2006).

3.5.2 Qualitative Analysis

Non-numerical data, such as words and images, are referred to as qualitative data and are utilized to better understand the motivations and experiences of people. It is frequently utilized in disciplines like sociology, psychology, and education and is frequently gathered via techniques like focus groups, interviews, and observation.

According to Höst, Lindgren, and Hermansson (2006), there are several methods of analyzing qualitative data, including:

1. Quasi-static methods: These techniques count the occurrences of particular phrases or groupings of words in various texts to ascertain the significance of particular terms and ideas to various readers.
2. Template-based methods: These techniques look for the appearance of terms in qualitative data using a prepared list of keywords as a surrogate for knowing who is using those phrases. Instead than focusing on how often a word is used, consider who is using it.
3. Editing methods: These techniques, like template-based techniques, try to classify subjects based on the data. However, editing techniques do not use a fixed list of keywords like template-based techniques do.

Instead, they look for keywords in the data and develop categories in accordance with the analyst's judgment.

4. In-depth methods: This is a method where the analyst deepens their understanding of the material through creativity and intuition, trying to motivate and explain their interpretation of the data.

When working with qualitative data, it's critical to provide transparency and confidentiality in addition to these analysis techniques. The practice of thoroughly documenting the research process and making the data and analysis methods available for inspection is known as transparency. On the other hand, confidentiality is the protection of participants' privacy and the maintenance of the secrecy of their personal data.

Schmidt (2015) asserts that transparency and confidentiality are crucial factors to take into account in qualitative research since they support the trustworthiness and ethical integrity of the study. Researchers can demonstrate their commitment to ethical research techniques and contribute to the development of trust with participants and other stakeholders by adhering to best practices in these areas.

3.5.3 Data analysis for case studies

Case study research involves the in-depth investigation of a single case or a small number of cases in order to understand a particular phenomenon. While there is no end-all analytic procedure for case studies, this lack of structure can also be considered a strength, as it allows the researcher to be more flexible and adaptable in their approach.

According to Yin (2018), there are four general strategies that can be used in case study research:

1. Relying on theoretical propositions: This involves using existing theories as a starting point for the research and testing them against the data collected in the case study.
2. Working the data from the "ground up": This entails starting with the data collected in the case study from which theories and conclusions are drawn inductively.

3. Developing a case description: This involves describing the case in detail and analyzing it in order to understand the specific context and factors that may have contributed to the phenomenon being studied.
4. Examining plausible rival explanations: This entails considering alternative explanations for the phenomenon being studied and evaluating their plausibility.

In order to develop an electric LTL framework, this thesis combined the application of theoretical arguments from recent LTL research with an analysis of The Case Company's electric FTL business. This made combining strategy one and three as the most appropriate analysis techniques for this thesis.

3.6 Methodology summary

This section gives the reader an overview of the process which the researchers followed in this master thesis to reach our conclusions, see figure 3.2.

(I) Four different theoretical aspects have been researched: technology shifts, supply chain management, routing strategy, and financial theory. The first three have established a framework to acknowledge the theory gap and missing real world application of the electric freight vehicle (EFV) Less-than-Truckload (LTL) transportation system. All adjacent subject theories, internal combustion engine vehicle (ICEV) LTL, and EFV Full-Truckload (FTL) have been researched to triangulate the theory gap.

(II) Thereafter, interviews will be conducted internally, at the case company, and externally to understand the variables affecting ICEV FTL and LTL transportation systems. Firsthand research will be conducted by analyzing internal data and proprietary data models. After the interviews and firsthand research, the variables will be mapped out in conjunction with knowledge gathered internally for an electrified LTL transportation system.

(III) Scenarios will be drafted from the gathered knowledge and insights. These scenarios will consist of a couple of EFV LTL and ICEV LTL transportation systems. Thereafter, the scenarios will be put in a financial context by comparing costs for specific routing strategies, EFV specific costs, and ICEV specific costs, using internal data models. Other factors adjacent to LTL or EFV will be analyzed in the context of these specific scenarios.

(IV) The paper will conclude with the contribution of knowledge that will assist companies in decisions relating to electrification of an LTL transportation system, and its implications in a greater transportation context.

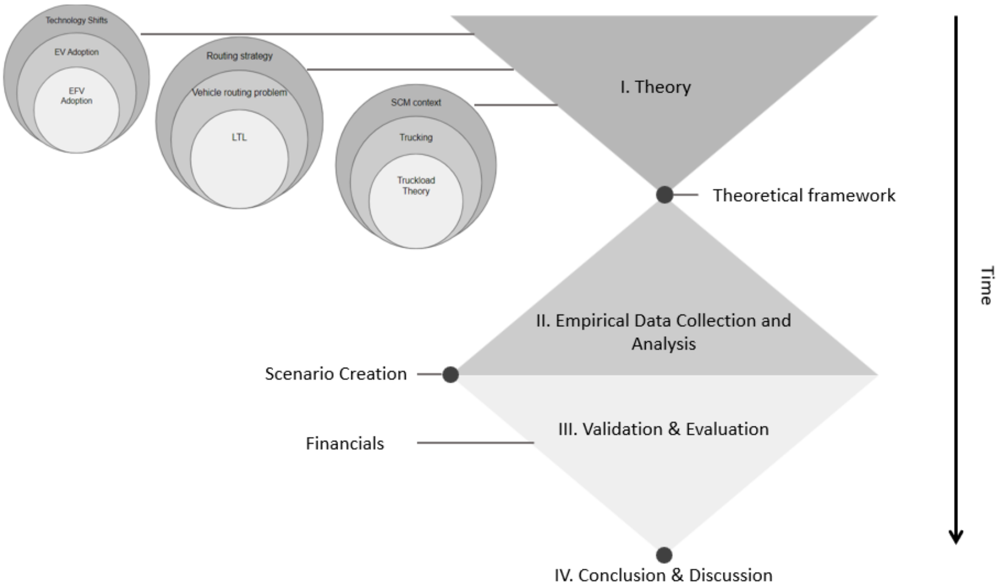

Figure 3.2 The methodology framework and its relation to the theoretical framework.

3.7 Research publication preparation

Before being published, the thesis needed to be reviewed and revised to ensure that it was well-written, clearly organized, and followed the appropriate format and citation style. Permissions also needed to be obtained for using copyrighted materials or for sharing sensitive or confidential information. To improve the quality of the research, feedback from peers or mentors was sought before publication. The published thesis was then shared with The Case Company, peers, and other stakeholders. A summary and a lay version of the thesis has also been written. The final step in the case study process involved the sharing of the conclusions from the study both in writing and orally. The case study method places a lot of emphasis on the reporting of results and methodology, as approaches can differ greatly (Yin, 2018).

4. The Case Company

4.1 Introduction to The Case Company

4.1.1 Introduction

The Case Company is a stand-alone company which is best placed in the scale-up category. Its mission is to disrupt and revolutionize the transportation industry by increasing efficiency and reducing emissions through the application of electrification, digitalization, and automation of trucks and logistical practices. The company is collaborating with several original-equipment-manufacturers (OEMs) to purchase and develop cutting-edge technology within the transportation industry. Thus, the Case Company is well positioned to meet the growing demand for eco-friendly and efficient transportation solutions. The company's customer base is thus rapidly growing, as more and more companies are recognizing the benefits of the Case Company's service. It has numerous customers in Europe and the Americas, as well as a growing market in the APAC region. With this growth the workforce is also rapidly growing, attracting talent to help drive its mission forward.

In conclusion, the Case Company is a dynamic and forward-thinking company that is leading the way in electrification, digitalization, and automation of the transportation industry. With innovative solutions, a rapidly growing customer base, and expanding workforce, the company is well positioned to continue its growth and success for years to come.

4.1.2 Market strategy

The Case Company offers Transport as a Service (TaaS) which implies that it offers, in this case a fully electric, transportation solution to its customers. The company occupies a rather unique position in the market; its core business can be best compared to an electric haulage company. However, by providing in-depth support in adapting to electrification as well as digitalization support, it transcends the role of a conventional haulage company. This is needed due to the low adoption rate of electric freight vehicles in current markets and its subconscious implications on potential customers.

Electrification poses a challenge to efficient and profitable execution with its increased complexity, compared to its diesel counterpart. Therefore, a less challenging market is preferable to ensure smooth operations and step-by-step improvements and implementation of new technologies. Customers with large and regular internal flows of goods are viewed as less complex and are currently preferred business partners. It allows for the case company to establish a supply network at said partner with static volumes and enables synergy effects with future efforts, such as supporting companies with small and irregular flows of goods. The support would be enabled by the supply network in a neighborhood of the large supplier, often referred to as a cluster. Thus, this is a key sweet spot with electric freight vehicles as it aids in reaching high utilization of the vehicles. Though it should be noted that the target market for the envisioned service is any actor looking to transport a pallet or more to any location.

4.1.3 Market vision

The envisioned service is that of providing a freight transportation service using only EFVs in both dynamic and static demand markets in global road shipment, to ensure large-scale impact. To maintain a transportation network with a minimal entry barrier, allowing anyone to transport a pallet from point A to point B. The envisioned service might be best described from a customer point of view; "A customer should be able to enter a pick-up point, a delivery point and a number of pallets – and we will handle everything from there". The way in which this is done, from the autonomy of the solutions to the routes chosen, should not be a concern for the user - as long as it is electric. This is to guarantee a decrease in the environmental impact of road haulage.

4.2 LTL competitor analysis

A European third-party logistics company, with LTL operations, known as Company Alpha has been the subject matter in this analysis of conventional LTL competitors. Company Alpha is one of the market leading logistics companies in Sweden (statista, 2023c). Their goods flow, information flow, and ways-of-working has been described in detail by Dzenan Bakalbasic

(2008) in his bachelor's thesis. This detailed report will be used as the foundation of this overview of the current LTL landscape.

The distribution system can be seen as threefold in a logistics company's operations; inbound, outbound, and reverse logistics flows. Each flow can in turn be seen as two sub flows, an information flow and a goods flow.

The service purchaser usually notifies Company Alpha when goods are expected to be transported. This notification starts the process of scheduling inflow. In some cases, this is notified by the client or the client's hired service provider, as in the case of Shell's inflow to Company Alpha inflows are notified 50% of the time directly from Shell. Usually, the flow of information depends on the type of transport, often the hired service provider informs Company Alpha if it is delivered via rail and/or container. The types of transport to the distribution center can be several, to allow intermodular transportation such as container flows. The pallet types might also differ depending on country of origin, as EU-pallets are used in the EU, but other standards could be found elsewhere. Depending on the transportation form, e.g. fax or digital, the information flow might differ as well.

When a delivery arrives at Company Alpha it might contain both return goods and outflowing goods. The goods are always checked to ensure that it's the right quantity of the right product. Thereafter, a quality control is carried out to ensure that the goods are intact and in good condition. If a deviation is found, Company Alpha will contact the service buyer and try to resolve the problem together. The next step, if the pallet is not an EU-pallet, is to load everything onto a EU-pallet. Lastly, the pallets are moved into the warehouse to either a rack or a 'free picking zone' (high turnover goods are placed here).

When the client decides to schedule a delivery, an outflow for Company Alpha, it is notified through the customer's computer system. It is unclear how the customer's computer system communicates with Company Alpha's system – and might differ from customer to customer. Moreover, the outflow is highly dependent on the customers location, e.g. if the shipment is outbound for Iceland it can go by truck or container depending on the weight of the goods.

When orders are set to be outbound, they all start to be loaded and shipped after 16:30. All orders are released at the same time. This implies that there might exist prioritized delivery locations, but individual goods are treated equally, no prioritization of a certain goods is done. After scheduling special orders, like containers to Iceland, one evaluates the daily situation and plans the movement of resources. Thereafter, order clusters are sorted so the picking process becomes easier. Lastly, the goods are picked in their respective clusters and packed with delivery notes and possible certificates.

5. Empirics & Analysis

5.1 The technology shift

As new technologies make electrical vehicles a reality, and societal forces push for electrification of several industries, new challenges and possibilities appear. The success of electric vehicles should not single handedly be assumed to be due to coercive (governmental) or non-coercive forces, rather a collective effort. The challenges will be several due to the nature of new technology, both where to apply it and how. Possibilities will appear and disappear as society matures in conjunction with technology. As an example, the passenger car industry produced 3.1 million cars in 2020, and since then it has doubled in units per year (statista, 2023d). It is evident that a technology shift is under way in the transportation industry, it does not have to mean that fossil fuels are replaced, but a coexistence of the two is a reality.

In this ferment era of adoption new ideas are realized. There exists a prominent technology that could be adopted alongside electric vehicles, autonomous technology. In a report by McKinsey (2019) the authors outline that autonomous technology within logistics is on the brink of exponential growth or evanescing to some degree. This is obviously highly dependent on application areas and feasibility, some technologies used within logistics are already automated like fully automated warehouses, other technologies are envisioned and in a pilot state like automated freight vehicles. The automated freight vehicles exist at this critical point whereas it is either successfully implemented or will vanish.

The lithium-ion batteries on the other hand have been through its era of ferment change and is one of the great enablers for the electrification of vehicles. The development of lithium-ion batteries has brought down today's price to a quarter of 2011’s price per kWh (Statista, 2023g). This is mainly due to a higher energy density in the battery, and the density is projected to increase (Duan et.al., 2020).

5.1.1 Electric vehicle adoption

Electric vehicles have achieved a high degree of growth in recent years, Statista (2023e) estimated that ~6.7 million units was sold globally in 2021.

The estimation would stand for around ~10% of global vehicle sales, as global sales of vehicles was estimated to be ~64 million units in 2021 (statista, 2023f). Moreover, forecasts predict electric vehicles will account for 11-28% of the global fleet by 2040 (Kapustin & Grushevenko, 2020).

As the adoption of electric vehicles has progressed beyond its infancy, more specific literature on the adoption of electric vehicles is available. The contrary is true for the adoption of electric freight vehicles, resulting in research on the subject being significantly sparser. Though, many of the drivers and barriers to electric vehicle adoption can be implied to be applicable to electric freight vehicles, such as environmental pressures and economic incentives. Kumar & Alok (2020) identified some key incentives to be business model development, governmental regulations and varying forms of governmental subsidies in *Adoption of electric vehicles: A literature review and prospects for sustainability*. Another study highlighting the barriers to electric vehicle adoption in the Nordics by Noel et al. (2020) suggest that range, price, charging opportunities and public mindset are key barriers to adoption. Here also, it can be assumed that some of the barriers to adoption can be applicable for electric freight vehicles.

Studies on electric vehicle adoption have identified a range of factors which motivate adoption by individuals, which include technical advantages and environmental as well as economic benefits (Biresselioglu et al., 2018). Personal and socio-demographic factors as well as personal influences and attitudes also play an important role in electric vehicle adoption (Priessner et al., 2018; Jansson et al., 2017). Many of these factors are significantly less relevant in a business-to-business environment, though studies suggesting that driving range and financial incentives, and rebates on energy bills, parking fees and upfront rebates may be more relevant in a business context (Kim & Heo, 2019; Gong et al., 2020). According to Thøgersen and Ebsen (2019), even with incentives and infrastructure in place, the adoption of electric vehicles in Denmark has been slow. This suggests that there may be other barriers that are hindering the fast transition to EVs.

The barriers cited as key vary by geographical area. A literature review focused on European electric vehicle adoption by Biresselioglu et al. (2018)

include barriers such as lack of charging infrastructure, economic and cost-related concerns, technical and operational limitations, a lack of trust in the technology, a lack of information and knowledge about electric vehicles, limited availability of electricity and raw materials, and concerns about the practicality of electric vehicles. This along with, according to Thøgersen and Ebsen (2019), Denmark's slow adoption of electric vehicles compared to its Nordic neighbors showcase the importance of considering electric vehicle adoption on a more confined regional level. To conclude, there are several electric vehicle adoption drivers and barriers which are relevant in an electric freight vehicle context though what matters to adoption is heavily contextual.

5.1.2 Adoption of electric trucks

Research on adoption of electric freight vehicles is sparse. A study by Anderhofstadt and Spinler (2019) conducted in Germany and found that the main drivers for adopting EFVs were the ability to enter low-emission zones, total cost of ownership, and reducing emissions. In this study, barriers to adoption were identified as being the initial investment, lack of charging infrastructure and concerns with range. Another study, also conducted in Germany, suggests that there is a lack of governmental initiatives to support charging infrastructure as well as public tenders not requesting emission free vehicles e3. An Italian study supports the German findings suggesting that increased government support is needed to overcome barriers to EFV adoption, such as simplifying processes related to installing charging points, promoting green zones and providing incentives for EFVs purchase (Galeti et al., 2021). On the other hand, some studies, such as the one conducted by Ablola et al. (2014) in London, suggest that key barriers were cost and vehicle performance. While Skippon and Chappell (2019) study suggests that governmental policies work against adoption of EFVs since procurements contracts restrict contractors' choice of vehicles. A comparative study of EFV initiatives in five European countries suggest that lack of profitability, limited range, smaller payloads and lack of servicing facilities are common barriers (Taefi et al., 2016). The study also suggests that the green image is the main driver as well as highlights the need for giving EFVs operational privileges in specific zones. The barriers and incentives for EFV adoption in Europe suggest what high-level considerations should be included in a check-list framework.

5.2 Analysis of the technology shift

5.2.1 Identified opportunities and challenges in electrification.

The macro-perspective of electrification should not be neglected. Pereirinha et.al. (2018) states that the demand for electrification within the transportation sector has been increasing rapidly since the Kyoto protocol 1997 and the Paris Agreement at COP 21 in 2015. Further they add that improvements on batteries in a short period of time might allow electric vehicles TCO to become lower than for ICEVs. Development does not come without drawbacks. As electric vehicles develop, and subsequent adoption occurs at a larger scale the supporting infrastructure structure must also develop at the same pace. The electrification does not only require investments in charging infrastructure for the vehicles but also investments in rudimentary functions such the power grid and power plants. Sweden as an example is looking to increase its yearly power generation by 60% to support the growth in energy consumption by 2050, taking electric vehicles into account (Energimyndigheten, 2021).

There exist several opportunities for electric freight vehicles in today's business environment. Adoption within last-mile delivery has been highlighted and mainly beneficial due to inter-city restrictions on ICEFVs (Behnke, 2019). Although there are some speed bumps ahead. The high capital expenditure for an electric vehicle is a great short-term barrier for it to be adopted, long-term charging infrastructure is also a great barrier; since it is cheaper for a company to build and maintain their own network rather than purchasing the service (Behnke, 2019). This poses a conundrum in general, as where a sole infrastructure owner would benefit the industry, but a privatized one would be more beneficial to its owner – alike to the tragedy of the commons.

Delving deeper into the economics of electric trucks, their profitability can differentiate a lot compared to a diesel truck. Energy costs are lower for an electric vehicle. The correlation between electricity costs and oil costs makes this close to a constant (Bencivenga, Sargenti & D’Ecclesia, 2010). Depreciation costs on the other hand is better for a diesel truck, which can be expected due to its lower purchasing cost. But acknowledging the electric truck's shortcomings and leveraging its strengths might prove it to be more profitable under certain circumstances.

Having lower energy costs means that there is a significantly lower cost per kilometer driven. This implies that an electric truck should maximize its time on the road. Usually, the shortest distance is prioritized in a LTL transportation system since it is the main driver of costs for a diesel truck. The electric trucks have a potential to disrupt the status quo by leveraging its comparative advantage and not optimize for the shortest distance. Rather committing to a shortest distance algorithm an optimization of other factors might be of interest, e.g. utilization of vehicles. Moreover, a strategy with no sorting terminal could be achieved under the right conditions where the cost is significantly lower simply by picking up the goods in the order of delivery, or vice versa.

5.2.2 Implications of the technology shift

As per large-scale adoption of electric vehicles, it is moving along the s-curve towards more prosperous growth and is close to the ‘sweet-spot’ where economical entry barriers are low and adoption rate is high. Some articles presented adoption barriers that are industry wide, which covers all types of electric vehicles. Barriers which are widely concerning for both businesses and individuals are; driving range, pricing, charging infrastructure, and geographical limitations such as topology and average temperatures.

Looking specifically at freight vehicles the barriers are similar. Main barriers were found to be; driving range, infrastructure, pricing, smaller payloads, lack of servicing facilities, and vehicle performance such as range and charging time. Judging from where one of the studies were carried out, in Germany, one can realize that geographical limitations are not that great of a concern since elevation and temperature are even throughout the country. Thus, an argument is made that geographical limitations should be addressed as well. Moreover, businesses were focused on governmental support and interference in the industry to give greater incentives to go electric. Incentives such as rebates on electric bills and vehicles, improving infrastructure for changing, and promoting so called ‘green zones’.

Table 5.1 Table of the identified barriers and its affected sector

Barrier	**Affected**
Driving range	Industry wide
Pricing	Industry wide
Charging infrastructure	Electric Industry
Geographical limitations	Electric Industry
Vehicle performance	Electric Freight industry
Payload capacity	Freight industry
Lack of servicing	Electric Freight industry

The first three listed barriers are deemed to resolve themselves as natural improvements to the technology occur, as predicted by others, where the TCO of an electric vehicle is lower than its other counterparts and driving range is improved due to battery improvements or charging infrastructure is improved. Geographical limitations will always affect the vehicle performance, but as technology improvements are done continuously the limitations will become less impactful. Looking at total vehicle performance, it is important for the freight business as the limitations can impair operations and efficiency, here payloads also come into play. Lack of service is most likely a product of a small freight vehicle market and will adjust itself when it grows.

Table 5.2 Barriers, the affected sectors and their needs

Barrier	**Affected**	**Needed**
Driving range	Industry wide	Technology improvements
Pricing	Industry wide	Technology improvements
Charging infrastructure	Electric Industry	Governmental investments
Geographical limitations	Electric Industry	Technology improvements
Vehicle performance	Electric Freight industry	Technology improvements
Payload capacity	Freight industry	Technology improvements
Lack of servicing	Electric Freight industry	Electric freight vehicle growth

5.3 Routing strategy

5.3.1 The scenarios

In the scenario comparison, a certain number of pick-up points were selected to match actual product flows in terms of volumes and routes. These pick-up points were major industrial areas around Stockholm that have no connection to The Case Company. The start and end point of the routing strategy was placed at an approximately appropriate distance from the city center, close to a major highway. This location was chosen to reflect a hypothetical scenario and has no actual relation to actual plans or operations of The Case Company. The selection of these pick-up points and start/end points aimed to replicate real-world conditions and provide an accurate comparison of the two routing strategies in terms of cost, distance, and time. In both routing strategies we assume the use of three trucks and that the number of pallets is such that a similar fill-rate is achieved regardless of routing strategy.

Four scenarios were created to compare two routing strategies in terms of cost, distance, and time. Conventional diesel trucks and a comparable electric truck were compared in the context of the two routing strategies which involved the use of either diesel or electric vehicles. The comparison was based on the cost of fuel or electricity, the distance traveled, and the time it took to complete the route. The routing strategies were:

Shortest Distance (SD): The SD routing strategy is the paradigm in transportation logistics. It involves finding the route with the shortest physical distance between the start and end points. This strategy aims to minimize the distance traveled, reducing fuel consumption and travel time, which in turn reduces costs. The shortest distance strategy is commonly used by transportation companies, carriers, and logistics providers to optimize their operations and ensure efficient and cost-effective delivery of goods. To determine the shortest distance, transportation planners typically use mapping software or route optimization tools that take into account factors such as road network, traffic conditions, and weight restrictions. This strategy does not take the destination of the shipment into account. This can result in inefficiencies in an LTL transportation system, where multiple shipments are combined into a single trailer and delivered to a terminal. At the terminal, the pallets are sorted and placed into other trailers that are heading to the correct destination. This additional handling at the terminal adds time, cost, and complexity to the transportation process and may not result in the most efficient delivery.

In this case, three trucks start from the Start-point and the shortest distance route between the predetermined locations is driven, the routes end at the start-point. In practice this means that one truck is assigned to the northern part of the city, one is assigned to the harbor, and one is assigned to the more central areas of the city, see figure 5.1. Note that only straight-lines are visualized as proprietary internal software was used to calculate exact distances and time.

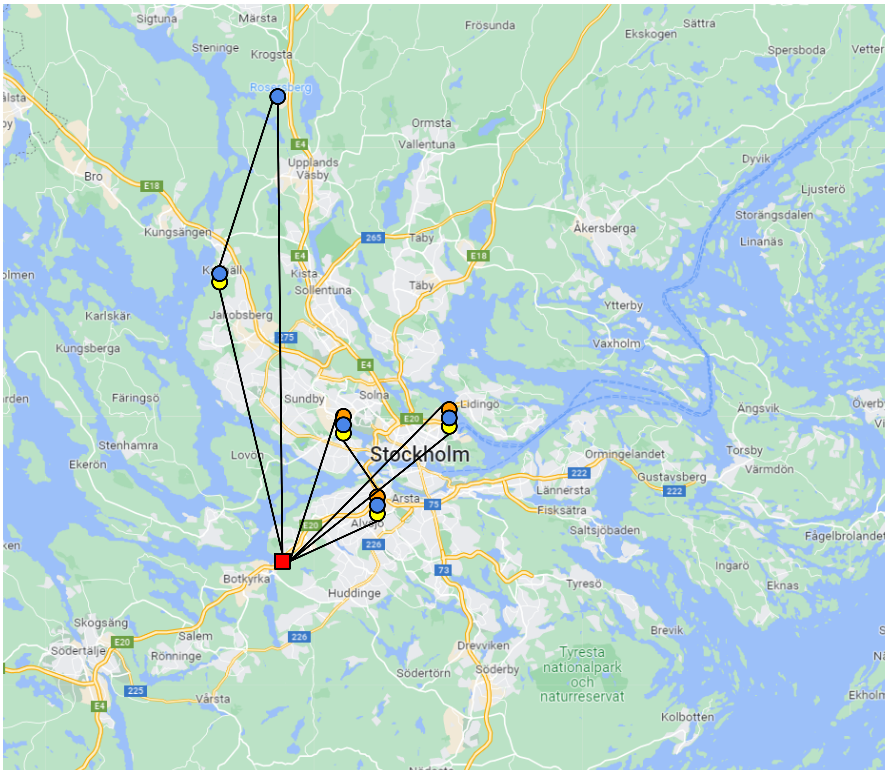

Figure 5.1 Example route of using trucks using SD routing.

Destination Based (DB): DB routing is a transportation strategy that takes the destination of the shipment into account, in addition to the physical distance between the start and end points. This type of routing aims to find the shortest route between pick-up points that are all headed to the same destination. Destination based routing can only be as short or longer than the shortest destination-based routing, as it adds the constraint of the destination. This means that the route may be longer in distance compared to the shortest destination-based routing. The potential benefits of destination-based routing include a lower barrier of entry for LTL transportation systems, as it eliminates the need for additional handling at the terminal. Additionally, electric vehicles may gain an advantage over diesel counterparts when distances increase, as the efficiency and cost-effectiveness of electric vehicles typically improve with longer distances.

In this case, three trucks start from the start-point and are routed to the predetermined locations according to the destination to which the load is headed, see figure 5.2. One truck will perform three pick-ups, one four and one five. Here, the benefit of them all having similar routing is isolating the effect of additional pick-ups and this routing strategy would imply that more than one truck might visit a site where only one truck would be enough in a terminal reliant system. Note that only straight-lines are visualized as proprietary internal software was used to calculate exact distances and time.

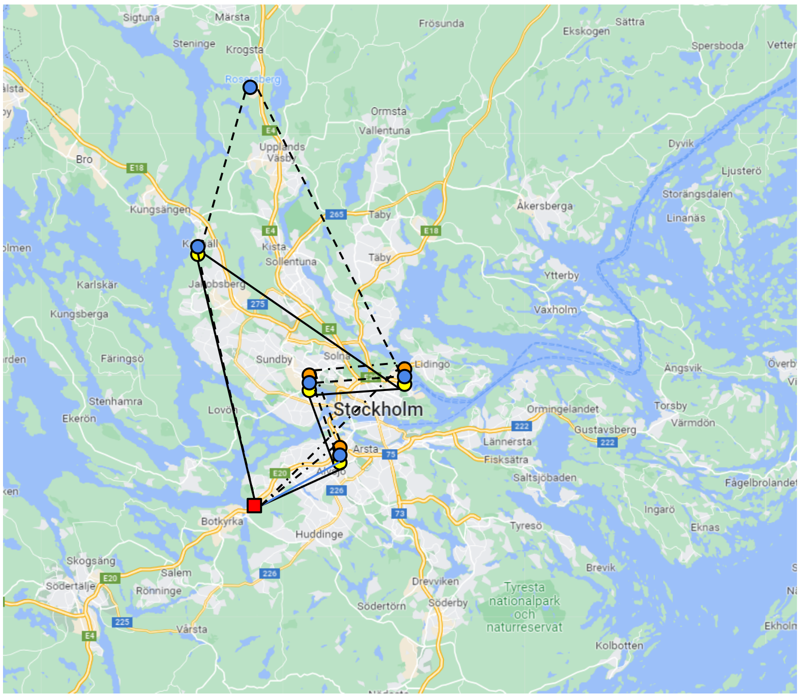

Figure 5.2 Example route of trucks using DB routing.

5.3.2 The calculations

The routing calculations were made using internal software which takes some additional EFV relevant parameters into account, but is otherwise similar to those used by other trucking companies. This software was used to output a distance and expected time for travel between destinations given that the vehicle was a standard tractor + trailer combination, which introduces variables such as weight, height, length and speed limits. Calculations were performed with the assumption that three tractor + trailer combinations perform the routes every day and that the vehicles are used for other purposes for the remainder of each day, to achieve a utilization of 16h every weekday. Depreciation is therefore applied on a per time unit used, which is also true for the labor cost. Labor is applied on a per time unit driven and per time unit at stops basis, since labor cost is the main cost driver when stopped for pick-up. Pick-up times vary, with 45 minutes being the average time for a route with one pick-up and 25 minutes for a route with two pick-ups. For all routes where pick-ups are performed more than two times en route a flat 15 minutes is assumed, taking diminishing returns into account. These stop time assumptions further imply that the number of pallets picked during a run adds up to, or gets close to, the maximum capacity of 33 pallets.

Table 5.3 Assumptions and their implications

Assumption	Implication
Truck + trailer carries maximally 33 EU Pallets	NAN
Three truck + trailer combinations	NAN
Each run is done every weekday	NAN
All vehicles and trailers are used for 16h per weekday	Vehicles perform other tasks when not in use for the LTL runs
Depreciation is based on the time spent performing LTL tasks	NAN
Labour is applied on a time spent performing LTL tasks basis	Drivers perform other tasks when not driving LTL runs
The sum of pallets for each route is assumed to be a nearly full truck	One pick-up / Full truck pick-up takes on average 45 min Two pick-ups / Half truck pick-up takes on average 25 min Three or more pick-ups / Three or more pick-ups takes on average 15 min

A pick-up schedule was created to illustrate the time consumed and the distance traveled. For the shortest distance routes, it totally consumed 395 time units to run the whole route, see table below. For the three DB routes it consumed 559 time units, about 1.4 times longer than for SD – as well as more KM's covered.

Table 5.4 The routes - Includes stop-time for loading for each route.

SD routing	**Distance**	**Time**
Harbour	40.5	97
North	117.4	184
Central	38.3	114
Total	***196.2***	***395***
DB routing	**Distance**	**Time**
3 pick-up (Västerås)	52.5	128
4 pick-up (Malmö)	95.1	189
5 pick-up (Göteborg)	128.8	242
Total	***276.4***	***559***

Thereafter, the cost units per distance driven was calculated to compare the cost of the two strategies, see table 5.5. Notably, this does not include the labor costs, but interestingly the CU per DU is cheaper in the unpopular strategy, DB, for both Diesel and Electric. This is due to the costs being dependent on distance driven and rewards high utilization.

Table 5.5 Costs- calculated by proprietary internal models given in CU per KM excluding labor.

SD routing	**Diesel**	**Electric**	**DB routing**	**Diesel**	**Electric**
Depreciation F.	0.714	2.138	**Depreciation F.**	0.667	1.516
Tax	0.261	0.325	**Tax**	0.185	0.185
Insurance	0.589	0.911	**Insurance**	0.418	0.418
Other Fixed	0.588	0.806	**Other Fixed**	0.418	0.572
Depreciation V.	1.666	4.989	**Depreciation V.**	1.555	3.538
Tires	1.039	1.117	**Tires**	1.039	1.039
Repair	1.13	1.481	**Repair**	1.13	1.13
Energy/Fuel	6.414	1.608	**Energy/Fuel**	6.42	1.613
Total Cost	***12.401***	***13.375***	***Total Cost***	***11.832***	***10.011***

Taking these costs into account, as well as estimating the labor to 6.4 CU per minute per driver, we can calculate the costs for each run, see table 5.6. The most expensive alternative is DB diesel, which is unsurprising due to the nature of electric vehicles performing better on longer distances. Although, the most cost effective is still the diesel SD strategy.

Table 5.6 Daily LTL routes for the four scenarios in CUs

Shortest Distance						
Diesel	Distance CU	Labor CU		Electric	Distance CU	Labor CU
Harbour	833	289		Harbour	873	289
North	2416	321		North	2530	321
Central	788	321		Central	825	321
Sub-total	4037	930		Sub-total	4228	930
Total	*4968*			*Total*	*5159*	
Destination Based						
Diesel	Distance CU	Labor CU		Electric	Distance CU	Labor CU
3 pick-up (Västerås)	1083	289		3 pick-up (Västerås)	988	289
4 pick-up (Malmö)	1962	385		4 pick-up (Malmö)	1789	385
5 pick-up (Göteborg)	2657	481		5 pick-up (Göteborg)	2423	481
Sub-total	5702	1155		Sub-total	5199	1155
Total	*6857*			*Total*	*6354*	

5.4 Analysis of route strategy result

5.4.1 Analysis of result

The results of the two routing strategies and the two vehicle types are most relevantly compared relative to each other. The results indicate that destination-based routing for EFVs result in a smaller cost increase than a comparable diesel vehicle, which is a result of the lower variable costs of the EFVs vehicle. The metrics that are most interesting are the deltas between destination based routing for diesel and electric vehicles, as well as the delta between shortest distance based for diesel and destination based for electric. These metrics allow for the cost comparison between the two types of vehicles and the two routing methods, providing valuable insights into the most cost-effective methods for different types of vehicles.

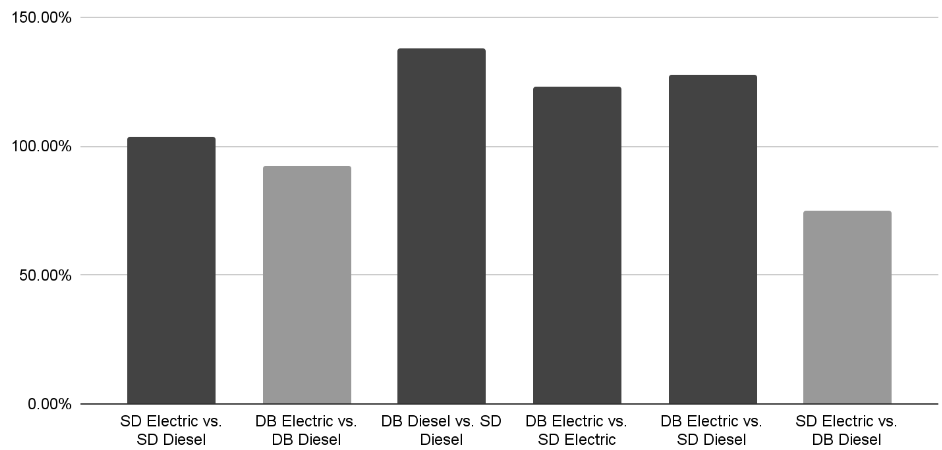

Figure 5.3 Relative cost between different strategies and propulsion systems

As seen in figure 5.3, the differences between diesel and electric propulsion are relatively small when a similar routing strategy is used, though it is key to notice that diesel is more costly than electric for destination-based routing. However, the percentage between routing strategies using the same propulsion system is significant. Also, the difference in the increase is significantly lower for electric propulsion with 15% units less penalty. Another key observation is that destination-based routing is about 28%, or 1386 CUs, more expensive than shortest destination routing for diesel trucks.

The latter comparison is most relevant when discussing destination-based routing with electric vehicles as a competitor to current major conventional LTL players.

5.4.2 The implications of propulsion choice

Table 5.7 Propulsion comparison.

Comparisons	
SD Electric vs. SD Diesel	103.85%
DB Diesel vs. DB Electric	107.92%

The implications of fuel choice when using either shortest-distance or destination-based are two-fold. Firstly, the difference is rather minor and would easily be swayed by simple variations such as increases in efficiency or decreases in costs. Secondly, a switching point is noticed, a point where the distance traveled is such that the diesel and the electric option are equivalent in terms of cost. This is due to the higher variable costs of diesel vehicles surmounting the higher fixed cost of EFVs. With regard to earlier discussion regarding the maturity of EFVs and the EFV market, it can be concluded that this stitching point will continue to move in favor of EFVs. Though it should be noted in this discussion the high utilization assumptions mentioned.

5.4.3 The implications of routing choice

Table 5.8 Routing comparison.

Comparisons	
DB Diesel vs. SD Diesel	138.04%
DB Electric vs. SD Electric	123.17%

The implications of routing choice can be extended beyond the simplest conclusion, that destination-based routing can at best achieve cost parity with shortest distance routing. We see that the cost difference is significant and that the difference of routing choice affects total costs significantly more for diesel vehicles. This, together with EFVs advantage for longer distances, suggests that actors using diesel vehicles would be greatly disadvantaged in running LTL DB services.

5.4.4 The implications to the status quo

Table 5.9 Status quo comparison

Comparisons	
DB Electric vs. SD Diesel	127.91%

In a market context, this comparison is the most relevant one. It represents a cost comparison between the status quo and the suggested alternative. In this specific scenario with current technology, it is significantly more expensive to use EFVs in a destination-based fashion. Though it is best to put this cost increase into a greater SCM perspective as DB routing does not require handling at a terminal. If the yearly cost increase is put into perspective by comparing to the yearly cost of an average warehouse FTE, we see that it would mean a yearly saving of about 100k assuming that every equivalent SD diesel route would need a total of one FTE during loading, sorting and reloading. This does not consider the savings of not needing an extensive terminal complex, which would further favor DB electric. Though, the most important advantage is the drastically reduced entrance barrier to the LTL shipping industry. Identifying sweet spots in this market could potentially be more profitable and more competitive than EFVs are in the FTL market.

5.5 Analysis of the supply chain management context

This chapter discusses the different implications of an electrified LTL transportation system on general supply chain topics.

Evolving electric shipping to include LTL transportation options can be future proofing and financially healthy. Inventions are enabling this transition whilst consumers and governments are promoting them. As the industry evolves towards industry 4.0, logistics should follow suit and evolve – towards electrification, as continuous improvements of the supply chain are an integral part of keeping a competitive advantage. As the demand for LTL transportation has increased since the e-commerce boom it can be assumed that it is here to stay. But here it is important to secure a financial edge on the other propulsion alternatives. The financial edge is important due to customer requirements. Mainly, one chooses to do LTL since it is seen as the cheapest option in that customers case – and as pointed out previously keeping down costs is essential to win business.

Quality, reliability, flexibility, and agility is highly important for supply chains. Quality is ensured in an electrified LTL transportation system as long as it is executed as a traditional one. Flexibility might be subject to change. The flexibility seems to become more dependent on the orchestration of the fleet as it is more constrained than a diesel fleet. Constraints such as range and charging time are not in the vocabulary of traditional LTL transportation systems, as it is not time consuming and easy to re-fuel. The constraints could impede operations if the system is poorly executed. Agility is the same as for a diesel truck as long as there is movement within the range limitations. Therefore, an emphasis should be placed on ensuring flexibility as it creates new risks for a customer swapping from diesel to electric.

Inflexibility is a risk, but there are several others as well when implementing an electrified LTL transportation system. E.g. Demand and supply risks are important here depending on the contracting. If a customer has a dynamic demand contract where they mainly pay per pallet instead of a subscription type fee, it could impact profitability significantly for that route. This is directly related to the need for high utilization of the electric freight vehicle, since it is a higher initial investment cost than a diesel truck but a lower cost of operation. Otherwise, the electrified LTL transportation system is deemed to be exposed to the same risks as a non-electrified transportation system; i.e. environmental risks, process risks, demand, and supply risks.

But there are upsides, as well, depending on implementation compared to a diesel transportation system. Supply chain resilience could improve as a result of a greater number of vehicles in the fleet. The demand for a greater fleet is due to the range limitations and charging times. This allows for quick response to certain issues within the supply chain, but it is a paradox. To lower the risks a greater amount of freight vehicles to respond quickly but simultaneously they need to be utilized as much as possible which lowers the possibility of quick responses. Thus, it is important to find a balance between too many and too few vehicles within the system.

On a final note, The Case Company's customers can implement electric freight vehicles to communicate environmental investments towards their customers, in the hopes that it drives business and covers the losses. This is improbable. This can be seen in some of The Case Company's customers, but this is smaller fleets with negligible costs. The idea itself overlaps a lot with needed development in the sector to shrink the amount of emissions released and would improve logistics – but it all comes at a cost and business within this sector mainly focuses on cost minimization.

5.6 Financial implications

Depending on routing strategy the costs will differ a lot, if a DB strategy can be implemented where the goods is sorted during the pick-up route or during drop-off it can prove to hold cost benefits compared to using a terminal. Using a SD strategy implies that a terminal is needed, which keeps handling costs as is, and is currently more expensive than the diesel alternative in the scenario analysis. It is note-worthy that there exists a clear cut-off value where SD electric beats SD diesel, but this is a far more complex scenario to analyze.

An investment case was created to calculate the TCO over time, excluding the chosen strategy, which took some factors into account. The TCO was found to be highly dependent on the battery cost and its subsequent maintenance costs (these are neglected due to the commonality of leasing trucks); it's usually better to swap the battery than to invest in a new truck. Moreover, these costs had to be estimated due too little to no accurate pricing data on battery packs on freight vehicles publicly available. Estimation method 1; Assuming that the cost of EFV is an ICEV plus the battery size, to estimate the cost per kWh. Method 2; Taking publicly available data on cost per kWh of a battery. Method 3; Taking costs of battery replacement services for EV's to estimate the cost per kWh (here labor is included). Furthermore, internal data on cost per kWh was used to validate the found span. This confirmed that the battery of an EFV stands for 51%-60% of the truck price. Thereafter, the battery improvement trend was taken into account, which is roughly 1.5% per year, annual prices improve by 17% annually according to Ziegler and Trancik (2021).

As per the theory chapter the trucks are assumed to be leased on a 60-month basis, 5 years, and thereafter a new truck is leased. Which led to assumptions in down payment cost, down payment interest rate, and the interest rate. The investment case was built on a 24 year horizon due to the nature of the rapidly changing technology it's done to capture the potential long-term upsides and downsides. There exist three scenarios, the low estimate, the mid estimate, and the high estimate. The low estimate is an optimistic assumption which mirrors that of a fast breakthrough advancement in battery technology and price drop significantly faster than current trends. The mid estimate assumes a similar cost of today's battery costs. The high estimate assumes a higher price standard than as of today. Furthermore, to conclude a trucks average mileage per year an industry expert in Sweden was interviewed to conclude the following; Routes differ a lot depending on the attractiveness of a route, say Malmö to Stockholm is attractive where a utilization can be upwards of 20 hours per day on a six day workweek (Interviewee Epsilon, 2023). This indicated a need to create a 'route-attractiveness' scale as well, to further nuance the investment case, as it is highly dependent on the mileage of the trucks.

Other assumptions have been made such as on interest rates and inflation. The interest rates are set to 5% to mirror that of banks interest rates on borrowed capital to large firms and the inflation rate is set to 2%, although the current economic outlook it is expected to return to normal. Furthermore, electric trucks excluding the battery have been done – which is a fraction dependent on the expected total improvement of electrical trucks estimated at Statista (2023).

Table 5.10 Assumptions made for the NPV calculations.

Subject	Unit	Amount
(Low) Battery Cost per kWh	(SEK/kWh)	10,639.28
(Mid) Battery Cost per kWh	(SEK/kWh)	11,271.80
(High) Battery Cost per kWh	(SEK/kWh)	15,744.82
(Low) Battery Pack Cost	SEK	3,191,784.63
(Mid) Battery Pack Cost	SEK	3,381,541.11
(High) Battery Pack Cost	SEK	4,723,446.79
Inflation	%	2.00
Interest Rate	%	5.00
Battery improvement Y-o-Y	%	1.50
ICEV Cost Y-o-Y	%	100.28
EFV Cost Y-o-Y (year 0-10)	%	97.01
EFV Cost Y-o-Y (year 10-)	%	100.00
Down payment	%	15.00
Down payment Interest Rate	%	25.00
Lease Interest Rate	%	6.00
Electricity per Liter Diesel	unit-less	3
Diesel Moving Average	SEK	20.58
Diesel Price increase per year	%	2.00
Mileage on High Attractiveness Route per Year	KM	499,200.00
Mileage on a Normal Route per Year	KM	299,520.00
Mileage on Low Attractiveness Route per Year	KM	156,00.00
Electricity Consumption of the EFV	kWh/KM	1.10

It is evident from the NPV-calculations that the current single cost of purchasing an EFV and operating it in the classical way as an ICEV is not financially viable, even in the low estimate. As, no single estimate is able to beat the current practice, assuming that all revolving costs are exactly the same.

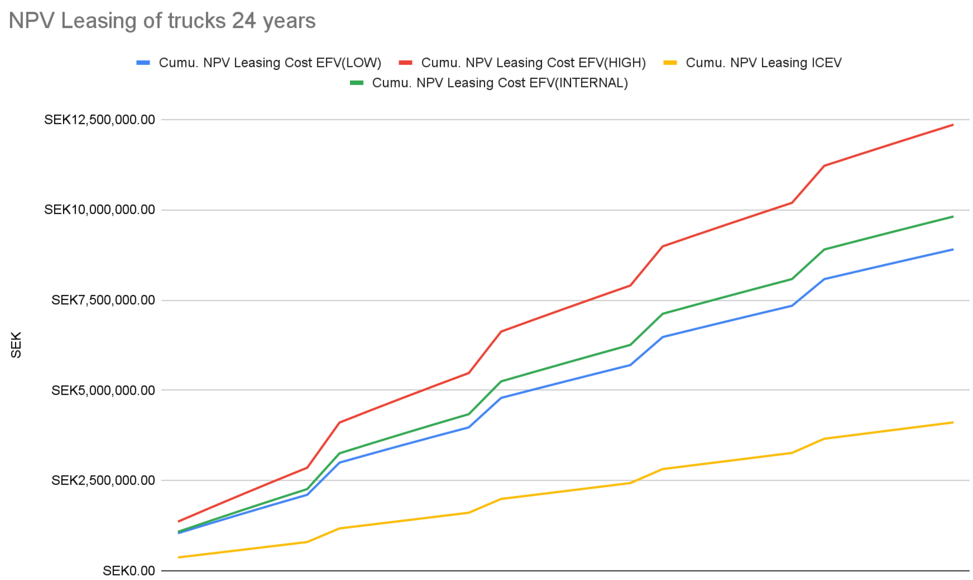

Figure 5.4 NPV of current diesel trucks vs. electric truck scenarios

But the cost-structure of the two alternatives is not the same. There exists some leverage in the electrical propulsion. It is cheaper than diesel and will stay cheaper. Thus, even with assumptions that every cost besides fuel will stay the same, a break-even point can be found. Therefore, a break-even analysis has been carried out. The break-even points approximated for the three different estimates, see table 5.11, gives no context without accounting for how much a truck drives per year as this is in KM over 24 years.

Table 5.11 Break-even points for estimates

Low	**Internal**	**High**
4,065.60	1,210,00.000	4,180,000.00

Leveraging these calculations with the yearly KM on a route per year we get the following 3x3 table of results in which the break-even point in added driving years, for each cost estimation and route.

Table 5.12 Average added driving year to achieve break-even between EFV and ICEV

	High Attractiveness (~400 000 km/year)	**Normal Attractiveness (~250 000 km/year)**	**Low Attractiveness (~156 000 km/year)**
Low Estimate	3.7 days	1105.9 days	3820.4 days
Mid Estimate	5.9 days	1769.4 days	6112.6 days
High Estimate	9.5 days	2831.1 days	9780.1 days

6. Conclusion

This master thesis explored a sub-subject of the shift towards electrification in the transportation industry, specifically it examined the economic feasibility of electric less-than-truckload (LTL) transportation. The analysis revealed several key drivers for the shift, including battery improvements, governmental and societal pressure to reduce carbon emissions. Automation was also found to be a driving force behind electrification, as it enables the adoption of electric technology to greater extent.

Electric vehicles were found to be further along the S-curve of adoption than electric freight vehicles (EFVs). Most barriers pertaining to electric vehicles were found to be generalizable for EFVs, with the exception of three unique barriers: vehicle performance, payload capacity, and lack of servicing. Overcoming these barriers will be crucial in increasing the adoption of EFVs in the transportation industry.

The adoption of electrification is driven by both hard and soft values. The economic benefits of reducing carbon emissions and meeting sustainability goals are key drivers behind the shift towards electrification. At the same time, the ethical and societal benefits of reducing air pollution and improving public health also play a role in driving the adoption of electric technology.

The analysis also revealed that destination-based routing is generally more expensive than shortest distance diesel routing, but that electric destination-based routing can be more cost-effective than diesel routing in certain scenarios. Specifically, the cost of handling and sorting must be less than the additional cost of electric destination-based routing when compared to shortest distance diesel routing for destination-based routing to be economically advantageous.

Electric LTL transportation was found to fit well into the megatrend of Industry 4.0. The flexibility of electric transportation was identified as its greatest supply chain management (SCM) vulnerability. Battery pricing was also found to be a key factor in determining the feasibility of certain routes, though an investment case can be found even in these routes – independent of strategy.

Financially, electric freight vehicles investments for LTL routes can already be justified; granted that a satisfactory utilization can be achieved, and battery improvement rates remain stable. Further, it was understood that the utilization rate for LTL is highly correlated on the attractiveness of a route. Under current assumptions, it could be suggested that routes with ~400 000 km/year were the safest bet, and that lower than is unfeasible if battery prices do not decrease at the estimated rate of 1.5%, see table 6.1. Routes considered low in attractiveness will not be feasible in the foreseeable future, with today's improvement rates and expected improvement rates.

Table 6.1 Average added driving time per year to achieve break-even between EFV and ICEV. Green means viable, yellow means possible, red implies not feasible.

	High Attractiveness (~400 000 km/year)	Normal Attractiveness (~250 000 km/year)	Low Attractiveness (~156 000 km/year)
Low Estimate	3.7 days	1105.9 days	3820.4 days
Mid Estimate	5.9 days	1769.4 days	6112.6 days
High Estimate	9.5 days	2831.1 days	9780.1 days

To summarize, the feasibility of electric LTL transportation was found to be dependent on several factors, including vehicle performance, payload capacity, and servicing availability. Adoption of electrification in the transportation industry is driven by both hard and soft values, such as the economic benefits of reducing carbon emissions and meeting sustainability goals. Mainly, there are two main key takeaways from this thesis describing the general LTL landscape as it pertains to electrification. Firstly, there are some high-utilization LTL routes where EFVs already present a compelling investment case when compared to their conventional counterparts. Secondly, leveraging the low variable cost of EFVs by challenging common LTL routing practices could increase the profitability of certain routes as well as entire transportation systems which would result in a greater share of LTL routes being considered feasible. Ultimately, the feasibility of electric LTL transportation is not dependent on a single issue, and the transportation industry must continue to challenge current practices, especially as it relates to routing and transport planning, in order to fully realize the potential of electrification in supply chain management.

7. Contribution & future research

7.1 Contribution

The academic contribution of this thesis is found in the new space of electric LTL transportation, where there are still no actors. Though it is clear that the preferred direction of LTL transportation is towards electric as seen through both existing carriers adopting a few electric vehicles to up-and-coming companies betting entirely on electrification. Electric LTL transportation brings entirely new parameters to consider in everything from cost structures and infrastructure. Therefore, the academic gain of this thesis will be the investigation of the validity of current LTL theory for electric vehicle-based systems as well as the suggestion of possible modifications to current best approaches within LTL transportation.

The contribution for The Case Company is the investigation of the current feasibility of electric LTL transportation as a company currently only operating under an FTL model. Hopefully, this thesis will contribute with enough understanding to base a move into this market for The Case Company.

7.2 Future research

In order to build upon the findings of this master thesis, future research should focus on three key areas: developing a more comprehensive mathematical model, investigating the interplay between freight vehicles and autonomy, and understanding the potential of the electric LTL market.

Firstly, a more comprehensive mathematical model should be developed, using a large data set of possible scenarios. This would enable for a more thorough analysis and generalized results of where an electrified LTL transportation system could be implemented. The current analysis focused on a specific Scandinavian scenario, and expanding the scope of the analysis to include other regions and scenarios would provide a more comprehensive understanding of the feasibility of electric LTL transportation. Additionally, the model could be expanded to consider other factors, such as the impact of weather and road conditions, to provide a more accurate assessment of the potential benefits and drawbacks of electrification.

Secondly, the interplay between freight vehicles and autonomy should be investigated in future research, separate from routing strategy, as the financial benefits could be substantial for both diesel and electric solutions. The use of autonomous freight vehicles could reduce labor costs and improve efficiency, and understanding the potential benefits and drawbacks of this technology in both diesel and electric systems would be valuable for future planning and investment decisions. Additionally, the integration of electric technology with autonomous systems could provide even greater benefits in terms of reducing carbon emissions and improving efficiency.

Lastly, the subject area itself should be investigated further, as the potential in the market is obvious. Electric LTL transportation has the potential to revolutionize the transportation industry, reducing carbon emissions and improving efficiency, and further research into this area could help to overcome the remaining barriers to adoption. This could include investigating the feasibility of developing charging infrastructure for electric LTL vehicles, exploring potential financing mechanisms to support the adoption of electric technology, and examining potential policy changes that could incentivize the adoption of electric LTL transportation.

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9. Appendix

A.1 Interviewees

Director of Logistic Strategy at The Case Company (Interviewee Alpha)
Context interview: January 2023

Solution Developer at The Case Company (Interviewee Beta)
Context interview: November 2022 - March 2023

Solution Developer at The Case Company (Interviewee Gamma)
Context interview: December 2022 - February 2023

Optimization Engineer at The Case Company (Interviewee Delta)
Context interview: January 2023

Industry Expert with Insight into The Logistics Industry (Interviewee Epsilon)
Context interview: February 2023

A.2 Financial Calculations

Battery Span Calculations							$/SEK
Span 1. (EV - ICEV)	Anonymized #1	Anonymized #2	Anonymized #3		K SEK		
Pricing of a ICEV	1,770	1,770	1,770				
Pricing of an EV	3,725	4,857	1,900				
Difference	1,955	3,087	130				
Average	**SEK1,724.00**					<- Battery price	
Battery Capacity	300	340	800				
Average cost per kWh	**SEK6.52**	**SEK9.08**	**SEK0.16**				
Span 2. (Avg. Battery Cost)	Anonymized #1	Anonymized #2	Anonymized #3		SEK		
# kWh	300	340	800				
Pricing on battery ($/kWh)	101	151	141				
Average pricing on battery	**$131.00**					<-	**SEK1,397.77**
Price of battery in SEK	**SEK419,331.00**	**SEK475,241.80**	**SEK1,118,216.00**				
Average price of battery	**SEK670,929.60**						
Span 3. (Battery replacement costs)	Anonymized #1	Anonymized #2	Anonymized #3		SEK		
Price of battery replacement at vendor	SEK149,380.00	490820	624195				
Battery size (kWh)	60	80	78				
Cost per kWh	**SEK2,489.67**	**SEK6,135.25**	**SEK8,002.50**				
Average price per kWh	**SEK5,542.47**						
Approximation	Anonymized #1	Anonymized #2	Anonymized #3				
Battery cost	**SEK1,662,741.67**	**SEK1,884,440.56**	**SEK4,433,977.78**				

Battery Span	**SEK / kWh**
Low	**SEK10,639.28**
Mid	**SEK11,271.80**
High	**SEK15,744.82**

E-Truck cost breakdown (300 kWh)	**Low**	**High**	% LOW	% HIGH		**Mid**	**Mid %**
Battery Pack	SEK3,191,784.63	SEK4,723,446.79	64.33%	72.74%		SEK3,381,541.1	52.42%
Truck excl. Battery	SEK1,770,000.00	SEK1,770,000.00	35.67%	27.26%		SEK3,069,398.8	47.58%
Total	**SEK4,961,784.63**	**SEK6,493,446.79**	100.00%	100.00%		**SEK6,450,939.9**	100.00%

NPV Comparison	**Inflation**	**Interest rate**	**Battery Improveme**	**Rolling Leasing**	Staista	10 years ICEV	10 years EFV
Settings	2%	5%	1.58%	5		102.86%	46.52%
					per year	100.28%	97.91%

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Compound Battery Improvement	100%	101.58%	103%	105%	106%	108%	110%
Compound Battery Price per kWh(Low)	SEK3,191,784.63	SEK3,142,063.75	SEK3,093,117.42	SEK3,044,933.5	SEK2,997,500.2	SEK2,950,805.9	SEK2,904,838.97
Compound Battery Price per kWh(Mid)	SEK3,381,541.11	SEK3,328,864.25	SEK3,277,007.98	SEK3,225,959.5	SEK3,175,706.2	SEK3,126,235.8	SEK3,077,536.09
Compound Battery Price per kWh(High)	SEK4,723,446.79	SEK4,649,866.04	SEK4,577,431.51	SEK4,506,125.3	SEK4,435,929.9	SEK4,366,828.1	SEK4,298,802.67
Compound ICE-Truck Improvement	1	100.28%	101%	101%	101%	101%	102%
Compound E-Truck excl. Battery Improvement	1	97.91%	96%	94%	92%	90%	88%
Compound ICE-Truck Improvement Price	SEK1,770,000.00	SEK1,774,993.28	SEK1,780,000.64	SEK1,785,022.1	SEK1,790,057.7	SEK1,795,107.6	SEK1,800,171.74
Compound E-Truck excl. Battery Price	SEK1,770,000.00	SEK1,732,924.48	SEK1,696,625.58	SEK1,661,087.0	SEK1,626,292.8	SEK1,592,227.5	SEK1,558,875.73
ICEV Price	SEK1,770,000.00	SEK1,774,993.28	SEK1,780,000.64	SEK1,785,022.1	SEK1,790,057.7	SEK1,795,107.6	SEK1,800,171.74
EFV Price (LOW)	SEK4,961,784.63	SEK4,874,988.24	SEK4,789,743.00	SEK4,706,020.5	SEK4,623,793.1	SEK4,543,033.4	SEK4,463,714.70
EFV Price (Mid)	SEK5,151,541.11	SEK5,061,788.74	SEK4,973,633.56	SEK4,887,046.5	SEK4,801,999.1	SEK4,718,463.3	SEK4,636,411.82
EFV Price (HIGH)	SEK6,493,446.79	SEK6,382,790.52	SEK6,274,057.09	SEK6,167,212.3	SEK6,062,222.8	SEK5,959,055.6	SEK5,857,678.41

Battery
Truck excl. Battery
Total

<- Should be assumed to be convergent

7	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
112%	113%	115%	117%	119%	121%	123%	125%	127%	129%	131%	133%
SEK2,859,588.0	SEK2,815,042.0	SEK2,771,190.0	SEK2,728,021.0	SEK2,685,524.5	SEK2,643,690.1	SEK2,602,507.3	SEK2,561,966.0	SEK2,522,056.3	SEK2,482,768.3	SEK2,444,092.3	SEK2,406,018.8
SEK3,029,594.9	SEK2,982,400.6	SEK2,935,941.4	SEK2,890,206.0	SEK2,845,183.1	SEK2,800,861.5	SEK2,757,230.3	SEK2,714,278.8	SEK2,671,996.4	SEK2,630,372.7	SEK2,589,397.3	SEK2,549,060.3
SEK4,231,836.9	SEK4,165,914.3	SEK4,101,018.7	SEK4,037,134.0	SEK3,974,244.4	SEK3,912,334.6	SEK3,851,389.1	SEK3,791,393.1	SEK3,732,331.7	SEK3,674,190.3	SEK3,616,954.6	SEK3,560,610.5
102%	102%	103%	103%	103%	103%	104%	104%	104%	105%	105%	105%
86%	84%	83%	81%	81%	81%	81%	81%	81%	81%	81%	81%
SEK1,805,250.1	SEK1,810,342.8	SEK1,815,449.9	SEK1,820,571.4	SEK1,825,707.3	SEK1,830,857.8	SEK1,836,022.7	SEK1,841,202.2	SEK1,846,396.4	SEK1,851,605.2	SEK1,856,828.7	SEK1,862,066.9
SEK1,526,222.5	SEK1,494,253.3	SEK1,462,953.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8
SEK1,805,250.1	SEK1,810,342.8	SEK1,815,449.9	SEK1,820,571.4	SEK1,825,707.3	SEK1,830,857.8	SEK1,836,022.7	SEK1,841,202.2	SEK1,846,396.4	SEK1,851,605.2	SEK1,856,828.7	SEK1,862,066.9
SEK4,385,810.6	SEK4,309,295.4	SEK4,234,143.8	SEK4,160,330.9	SEK4,117,834.4	SEK4,075,999.9	SEK4,034,817.1	SEK3,994,275.9	SEK3,954,366.2	SEK3,915,078.2	SEK3,876,402.2	SEK3,838,328.7
SEK4,555,817.5	SEK4,476,653.9	SEK4,398,895.2	SEK4,322,515.9	SEK4,277,492.9	SEK4,233,171.3	SEK4,189,540.2	SEK4,146,588.7	SEK4,104,306.3	SEK4,062,682.5	SEK4,021,707.2	SEK3,981,370.2
SEK5,758,059.4	SEK5,660,167.7	SEK5,563,972.5	SEK5,469,443.8	SEK5,406,554.3	SEK5,344,644.4	SEK5,283,699.0	SEK5,223,703.0	SEK5,164,641.5	SEK5,106,500.1	SEK5,049,264.5	SEK4,992,920.4

Battery Span Calculations							$/SEK
Span 1. (EV - ICEV)	Anonymized #1	Anonymized #2	Anonymized #3		K SEK		
Pricing of a ICEV	1,770	1,770	1,770				
Pricing of an EV	3,725	4,857	1,900				
Difference	1,955	3,087	130				
Average	**SEK1,724.00**					<- Battery price	
Battery Capacity	300	340	800				
Average cost per kWh	**SEK6.52**	**SEK9.08**	**SEK0.16**				
Span 2. (Avg. Battery Cost)	Anonymized #1	Anonymized #2	Anonymized #3		SEK		
# kWh	300	340	800				
Pricing on battery ($/kWh)	101	151	141				
Average pricing on battery	**$131.00**					<-	**SEK1,397.77**
Price of battery in SEK	**SEK419,331.00**	**SEK475,241.80**	**SEK1,118,216.00**				
Average price of battery	**SEK670,929.60**						
Span 3. (Battery replacement costs)	Anonymized #1	Anonymized #2	Anonymized #3		SEK		
Price of battery replacement at vendor	SEK149,380.00	490820	624195				
Battery size (kWh)	60	80	78				
Cost per kWh	**SEK2,489.67**	**SEK6,135.25**	**SEK8,002.50**				
Average price per kWh	**SEK5,542.47**						
Approximation	Anonymized #1	Anonymized #2	Anonymized #3				
Battery cost	**SEK1,662,741.67**	**SEK1,884,440.56**	**SEK4,433,977.78**				

Battery Span	**SEK / kWh**
Low	**SEK10,639.28**
Mid	**SEK11,271.80**
High	**SEK15,744.82**

19	**20**	**21**	**22**	**23**	**24**
135%	137%	139%	141%	143%	146%
SEK2,368,538.4	SEK2,331,641.9	SEK2,295,320.1	SEK2,259,564.1	SEK2,224,365.2	SEK2,189,714.5
SEK2,509,351.7	SEK2,470,261.6	SEK2,431,780.4	SEK2,393,898.7	SEK2,356,607.1	SEK2,319,896.4
SEK3,505,144.2	SEK3,450,541.8	SEK3,396,790.1	SEK3,343,875.7	SEK3,291,785.6	SEK3,240,506.9
105%	106%	106%	106%	107%	107%
81%	81%	81%	81%	81%	81%
SEK1,867,319.9	SEK1,872,587.7	SEK1,877,870.4	SEK1,883,168.0	SEK1,888,480.5	SEK1,893,808.0
SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8	SEK1,432,309.8
SEK1,867,319.9	SEK1,872,587.7	SEK1,877,870.4	SEK1,883,168.0	SEK1,888,480.5	SEK1,893,808.0
SEK3,800,848.3	SEK3,763,951.7	SEK3,727,630.0	SEK3,691,874.0	SEK3,656,675.0	SEK3,622,024.4
SEK3,941,661.5	SEK3,902,571.4	SEK3,864,090.3	SEK3,826,208.6	SEK3,788,917.0	SEK3,752,206.3
SEK4,937,454.0	SEK4,882,851.7	SEK4,829,100.0	SEK4,776,185.6	SEK4,724,095.5	SEK4,672,816.8

MOD	0	1	2	3	4	0	1
Leasing % of truck							
Downpayment	15%	15%	15%	15%	15%	15%	15%
Lease residual value	25%	25%	25%	25%	25%	25%	25%
Downpayment interest rate	25%	25%	25%	25%	25%	25%	25%
Lease interest rate	6%	6%	6%	6%	6%	6%	6%
FLAT Leasing Cost EFV(LOW)	SEK1,041,974.77	SEK292,499.29	SEK287,384.58	SEK282,361.23	SEK277,427.59	SEK954,037.02	SEK267,822.88
FLAT Leasing Cost EFV(MID)	SEK1,081,823.63	SEK303,707.32	SEK298,418.01	SEK293,222.79	SEK288,119.95	SEK990,877.31	SEK278,184.71
FLAT Leasing Cost EFV(HIGH)	SEK1,363,623.83	SEK382,967.43	SEK376,443.43	SEK370,032.74	SEK363,733.37	SEK1,251,401.6	SEK351,460.70
Indiv. NPV Leasing Cost EFV(LOW)	SEK1,041,974.77	SEK273,363.83	SEK268,583.72	SEK263,889.00	SEK259,278.12	SEK891,623.39	SEK250,301.76
Indiv. NPV Leasing Cost EFV(HIGH)	SEK1,363,623.83	SEK382,967.43	SEK376,443.43	SEK370,032.74	SEK363,733.37	SEK1,251,401.6	SEK351,460.70
Indiv. NPV Leasing Cost EFV (MID)	SEK1,081,823.63	SEK303,707.32	SEK298,418.01	SEK293,222.79	SEK288,119.95	SEK990,877.31	SEK278,184.71
Indiv. NPV Leasing ICEV	SEK371,700.00	SEK106,499.60	SEK106,800.04	SEK107,101.33	SEK107,403.47	SEK376,972.60	SEK108,010.30
Cumu. NPV Leasing Cost EFV(LOW)	SEK1,041,974.77	SEK1,315,338.60	SEK1,583,922.32	SEK1,847,811.3	SEK2,107,089.4	SEK2,998,712.8	SEK3,249,014.59
Cumu. NPV Leasing Cost EFV(HIGH)	SEK1,363,623.83	SEK1,746,591.26	SEK2,123,034.68	SEK2,493,067.4	SEK2,856,800.7	SEK4,108,202.4	SEK4,459,663.18
Cumu. NPV Leasing Cost EFV(MID)	SEK1,081,823.63	SEK1,385,530.96	SEK1,683,948.97	SEK1,977,171.7	SEK2,265,291.7	SEK3,256,169.0	SEK3,534,353.73
Cumu. NPV Leasing ICEV	SEK371,700.00	SEK478,199.60	SEK584,999.63	SEK692,100.96	SEK799,504.43	SEK1,176,477.0	SEK1,284,487.34

2	3	4	0	1	2	3	4	0	1	2	3
15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
SEK263,148.64	SEK258,557.73	SEK254,048.63	SEK873,669.49	SEK247,070.07	SEK244,560.00	SEK242,089.03	SEK239,656.56	SEK830,416.91	SEK234,904.69	SEK232,584.13	SEK230,299.72
SEK273,349.05	SEK268,599.24	SEK263,933.72	SEK907,728.35	SEK256,649.58	SEK253,990.28	SEK251,372.41	SEK248,795.32	SEK861,904.33	SEK243,760.96	SEK241,302.44	SEK238,882.21
SEK345,483.57	SEK339,610.06	SEK333,838.35	SEK1,148,583.2	SEK324,393.26	SEK320,678.67	SEK317,021.94	SEK313,422.18	SEK1,084,574.7	SEK306,390.01	SEK302,955.87	SEK299,575.23
SEK245,933.31	SEK241,642.73	SEK237,428.62	SEK816,513.54	SEK230,906.60	SEK228,560.75	SEK226,251.43	SEK223,978.09	SEK776,090.57	SEK219,537.10	SEK217,368.35	SEK215,233.39
SEK345,483.57	SEK339,610.06	SEK333,838.35	SEK1,148,583.2	SEK324,393.26	SEK320,678.67	SEK317,021.94	SEK313,422.18	SEK1,084,574.7	SEK306,390.01	SEK302,955.87	SEK299,575.23
SEK273,349.05	SEK268,599.24	SEK263,933.72	SEK907,728.35	SEK256,649.58	SEK253,990.28	SEK251,372.41	SEK248,795.32	SEK861,904.33	SEK243,760.96	SEK241,302.44	SEK238,882.21
SEK108,315.01	SEK108,620.57	SEK108,927.00	SEK382,320.00	SEK109,542.44	SEK109,851.47	SEK110,161.37	SEK110,472.14	SEK387,743.25	SEK111,096.31	SEK111,409.72	SEK111,724.02
SEK3,494,947.8	SEK3,736,590.6	SEK3,974,019.2	SEK4,790,532.8	SEK5,021,439.4	SEK5,250,000.1	SEK5,476,251.5	SEK5,700,229.6	SEK6,476,320.2	SEK6,695,857.3	SEK6,913,225.6	SEK7,128,459.0
SEK4,805,146.7	SEK5,144,756.8	SEK5,478,595.1	SEK6,627,178.3	SEK6,951,571.6	SEK7,272,250.3	SEK7,589,272.2	SEK7,902,694.4	SEK8,987,269.1	SEK9,293,659.1	SEK9,596,615.0	SEK9,896,190.2
SEK3,807,702.7	SEK4,076,302.0	SEK4,340,235.7	SEK5,247,964.0	SEK5,504,613.6	SEK5,758,603.9	SEK6,009,976.3	SEK6,258,771.6	SEK7,120,676.0	SEK7,364,436.9	SEK7,605,739.4	SEK7,844,621.6
SEK1,392,802.3	SEK1,501,422.9	SEK1,610,349.9	SEK1,992,669.9	SEK2,102,212.3	SEK2,212,063.8	SEK2,322,225.1	SEK2,432,697.3	SEK2,820,440.5	SEK2,931,536.8	SEK3,042,946.6	SEK3,154,670.6

4	0	1	2	3	4
15%	15%	15%	15%	15%	15%
25%	25%	25%	25%	25%	25%
25%	25%	25%	25%	25%	25%
6%	6%	6%	6%	6%	6%
SEK228,050.90	SEK790,429.88	SEK223,657.80	SEK221,512.44	SEK219,400.51	SEK217,321.47
SEK236,499.69	SEK819,540.01	SEK231,845.42	SEK229,572.52	SEK227,335.02	SEK225,132.38
SEK296,247.24	SEK1,025,398.8	SEK289,746.00	SEK286,571.14	SEK283,445.73	SEK280,369.01
SEK213,131.68	SEK738,719.51	SEK209,025.98	SEK207,020.97	SEK205,047.20	SEK203,104.17
SEK296,247.24	SEK1,025,398.8	SEK289,746.00	SEK286,571.14	SEK283,445.73	SEK280,369.01
SEK236,499.69	SEK819,540.01	SEK231,845.42	SEK229,572.52	SEK227,335.02	SEK225,132.38
SEK112,039.20	SEK393,243.43	SEK112,672.23	SEK112,990.08	SEK113,308.83	SEK113,628.48
SEK7,341,590.7	SEK8,080,310.2	SEK8,289,336.2	SEK8,496,357.2	SEK8,701,404.4	SEK8,904,508.5
SEK10,192,437.	SEK11,217,836.	SEK11,507,582.	SEK11,794,153.	SEK12,077,599.	SEK12,357,968.
SEK8,081,121.3	SEK8,900,661.3	SEK9,132,506.7	SEK9,362,079.2	SEK9,589,414.2	SEK9,814,546.6
SEK3,266,709.8	SEK3,659,953.2	SEK3,772,625.4	SEK3,885,615.5	SEK3,998,924.3	SEK4,112,552.8

Operational Cut-Off depending on driving	Electricity	Diesel	**Diesel Moving Aver**	**Diesel Moving Average**			
Settings	1	3	€1.82	**SEK20.58**			
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Electricity per Liter Diesel	SEK6.86	SEK7.00	SEK7.28	SEK7.73	SEK8.36	SEK9.23	SEK10.40
Diesel per Liter Diesel	SEK20.58	SEK21.00	SEK21.84	SEK23.18	SEK25.09	SEK27.70	SEK31.20
Differance	SEK13.72	SEK14.00	SEK14.56	SEK15.45	SEK16.73	SEK18.47	SEK20.80
	Low	**Mid**	**High**		**Low**	**Mid**	**High**
#Difference Units	3696	1100000	3800000	#KM using Volvo	4065.6	1210000	4180000
Low	147.84	147.84	147.84	147.84	147.84	147.84	147.84
Mid	44000	147.84	147.84	147.84	147.84	147.84	147.84
High	152000	147.84	147.84	147.84	147.84	147.84	147.84
	Low	**Mid**	**High**				
Additional COST	SEK2,203,792.82	SEK2,805,567.24	SEK4,287,629.64				
Low	SEK2,028.78	SEK2,069.35	SEK2,152.96	SEK2,284.73	SEK2,473.07	SEK2,730.47	SEK3,074.95
Mid	SEK603,803.20	SEK2,069.35	SEK2,152.96	SEK2,284.73	SEK2,473.07	SEK2,730.47	SEK3,074.95
High	SEK2,085,865.60	SEK2,069.35	SEK2,152.96	SEK2,284.73	SEK2,473.07	SEK2,730.47	SEK3,074.95
Cumu. Driving Cost							
Low	SEK2,028.78	SEK4,098.13	SEK6,251.09	SEK8,535.82	SEK11,008.89	SEK13,739.36	SEK16,814.31
Mid	SEK603,803.20	SEK605,872.55	SEK608,025.51	SEK610,310.24	SEK612,783.31	SEK615,513.78	SEK618,588.74
High	SEK2,085,865.60	SEK2,087,934.95	SEK2,090,087.91	SEK2,092,372.6	SEK2,094,845.7	SEK2,097,576.1	SEK2,100,651.14
	Low	**Mid**	**High**				
Difference	-SEK2,588,162.90	-SEK2,896,426.54	-SEK3,957,785.74				
					High Attractivnes	399360	
					Normal	249600	
	Milage per year aver	156000	HIGH		Low Attractivnes	156000	
	Low	**Mid**	**High**				
Milage years added	0.02606153846	7.756410256	26.79487179				

7	8	9	10	11	12	13	14	15	16	17	18
SEK11.95	SEK14.00	SEK16.73	SEK20.39	SEK25.35	SEK32.15	SEK41.59	SEK54.88	SEK73.86	SEK101.40	SEK141.98	SEK202.79
SEK35.84	SEK41.99	SEK50.18	SEK61.17	SEK76.06	SEK96.46	SEK124.78	SEK164.65	SEK221.59	SEK304.20	SEK425.95	SEK608.36
SEK23.89	SEK27.99	SEK33.45	SEK40.78	SEK50.71	SEK64.31	SEK83.19	SEK109.76	SEK147.73	SEK202.80	SEK283.97	SEK405.58
147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84
147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84
147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84	147.84
SEK3,532.15	SEK4,138.48	SEK4,945.87	SEK6,028.98	SEK7,496.28	SEK9,507.10	SEK12,298.45	SEK16,227.54	SEK21,840.13	SEK29,981.82	SEK41,981.79	SEK59,960.34
SEK3,532.15	SEK4,138.48	SEK4,945.87	SEK6,028.98	SEK7,496.28	SEK9,507.10	SEK12,298.45	SEK16,227.54	SEK21,840.13	SEK29,981.82	SEK41,981.79	SEK59,960.34
SEK3,532.15	SEK4,138.48	SEK4,945.87	SEK6,028.98	SEK7,496.28	SEK9,507.10	SEK12,298.45	SEK16,227.54	SEK21,840.13	SEK29,981.82	SEK41,981.79	SEK59,960.34
SEK20,346.47	SEK24,484.95	SEK29,430.81	SEK35,459.80	SEK42,956.08	SEK52,463.18	SEK64,761.63	SEK80,989.17	SEK102,829.31	SEK132,811.13	SEK174,792.92	SEK234,753.26
SEK622,120.89	SEK626,259.37	SEK631,205.24	SEK637,234.22	SEK644,730.50	SEK654,237.60	SEK666,536.05	SEK682,763.59	SEK704,603.73	SEK734,585.55	SEK776,567.34	SEK836,527.68
SEK2,104,183.2	SEK2,108,321.7	SEK2,113,267.6	SEK2,119,296.6	SEK2,126,792.9	SEK2,136,300.0	SEK2,148,598.4	SEK2,164,825.9	SEK2,186,666.1	SEK2,216,647.9	SEK2,258,629.7	SEK2,318,590.0

	Usage (w/driver	Average speed (	Workweek days	KM/year
E.g. Malmö Stoc	16 h	80	6	399360
E.g. Jönköping S	10 h	80	6	249600
E.g. Malmö Små	8 h	75	5	156000

19	20	21	22	23	24
SEK295.42	SEK438.98	SEK665.35	SEK1,028.62	SEK1,622.03	SEK2,608.94
SEK886.27	SEK1,316.95	SEK1,996.06	SEK3,085.87	SEK4,866.10	SEK7,826.82
SEK590.85	SEK877.97	SEK1,330.71	SEK2,057.25	SEK3,244.07	SEK5,217.88
147.84	147.84	147.84	147.84	147.84	147.84
147.84	147.84	147.84	147.84	147.84	147.84
147.84	147.84	147.84	147.84	147.84	147.84
SEK87,350.89	SEK129,798.82	SEK196,731.71	SEK304,143.22	SEK479,603.22	SEK771,411.69
SEK87,350.89	SEK129,798.82	SEK196,731.71	SEK304,143.22	SEK479,603.22	SEK771,411.69
SEK87,350.89	SEK129,798.82	SEK196,731.71	SEK304,143.22	SEK479,603.22	SEK771,411.69
SEK322,104.15	SEK451,902.97	SEK648,634.68	SEK952,777.90	SEK1,432,381.1	SEK2,203,792.8
SEK923,878.57	SEK1,053,677.3	SEK1,250,409.1	SEK1,554,552.3	SEK2,034,155.5	SEK2,805,567.2
SEK2,405,940.9	SEK2,535,739.7	SEK2,732,471.5	SEK3,036,614.7	SEK3,516,217.9	SEK4,287,629.6

	Total. Even-Out							
	Low (ICEV)	SEK373,728.78	SEK482,297.73	SEK591,250.72	SEK700,636.79	SEK810,513.32	SEK1,190,216.4	SEK1,301,301.65
	Mid (ICEV)	SEK975,503.20	SEK1,084,072.15	SEK1,193,025.15	SEK1,302,411.2	SEK1,412,287.7	SEK1,791,990.8	SEK1,903,076.07
	High (ICEV)	SEK2,457,565.60	SEK2,566,134.55	SEK2,675,087.55	SEK2,784,473.6	SEK2,894,350.1	SEK3,274,053.2	SEK3,385,138.47

SEK1,413,148.8	SEK1,525,907.8	SEK1,639,780.7	SEK2,028,129.7	SEK2,145,168.4	SEK2,264,527.0	SEK2,386,986.8	SEK2,513,686.5	SEK2,923,269.8	SEK3,064,348.0	SEK3,217,739.5	SEK3,389,423.8
SEK2,014,923.2	SEK2,127,682.2	SEK2,241,555.1	SEK2,629,904.1	SEK2,746,942.8	SEK2,866,301.4	SEK2,988,761.2	SEK3,115,460.9	SEK3,525,044.3	SEK3,666,122.4	SEK3,819,513.9	SEK3,991,198.3
SEK3,496,985.6	SEK3,609,744.6	SEK3,723,617.5	SEK4,111,966.5	SEK4,229,005.2	SEK4,348,363.8	SEK4,470,823.6	SEK4,597,523.3	SEK5,007,106.7	SEK5,148,184.8	SEK5,301,576.3	SEK5,473,260.7

SEK3,588,813.9	SEK4,111,856.2	SEK4,421,260.1	SEK4,838,393.4	SEK5,431,305.5	SEK6,316,345.6
SEK4,190,588.3	SEK4,713,630.6	SEK5,023,034.5	SEK5,440,167.8	SEK6,033,079.9	SEK6,918,120.1
SEK5,672,650.7	SEK6,195,693.0	SEK6,505,096.9	SEK6,922,230.2	SEK7,515,142.3	SEK8,400,182.5