Identifying barriers in a technological shift: The introduction of battery-electric buses in Swedish public transport

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Master of Science Thesis
Stockholm, Sweden 2016

Identifikation av barriärer i ett teknologiskt skifte: Introduktionen av batteri-elbussar i Svensk kollektivtrafik

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Abstract

Concern regarding sustainability and climate change is increasing, which is forcing countries world-wide to take action. The Swedish government has set a goal of fossil-free traffic until 2030. Battery Electric Buses (BEB) might be one of the solutions needed in order to reach this goal. However, currently its prevalence is at an early stage.

The purpose of this study is to investigate how the technological transition towards BEBs in Sweden affects the public transport operators (PTOs). Moreover, to investigate how a third party service provider of Fleet Management System (FMS) services can support the PTOs in this transition.

The research has been carried out in co-operation with a PTO and a FMS service provider. The research contributes to their current understanding of how they will be affected by the emerging technological transition. This thesis also contributes with new empirical data of the technological transition towards electric vehicles within public bus transport, seen as a Large Technical System. Conceptually it contributes, by exploring how external companies can support the technological transition towards BEBs, with the application of Technological Transitions theory and the Multi Layer Perspective framework.

The methodology used is a case study of the technological transition towards BEBs in Sweden. Data was collected through twelve semi-structured interviews with researchers, PTOs, public transport authorities (PTA), a BEB manufacturer and a FMS-service company. Parallel to this a questionnaire was distributed to the twenty largest PTOs in Sweden. Moreover data was collected from company visits, pilot-project results and internal documentation.

Our findings show that there are thirteen perceived barriers present among the PTOs, in the process of BEB adoption. Six of these barriers relate to component aspects of BEBs, and seven relate to managerial aspects. Perceived barriers linked to component aspects of BEBs are; Variation in solutions and lack of technical standards, the Charging infrastructure, Shorter range or decreased load capacity, Unknown functionality in cold climate, Reliability and Durability. Perceived barriers linked to managerial aspects of BEBs are; Lack of knowledge and experience, Behavioral change, Economy, Maintenance, Ownership of infrastructure and buses, Business models and Varying requirements from PTAs.

The barriers FMS-service providers can address are primarily, due to the technological nature of the services, present at niche level. PTOs together with FMS-service providers are encouraged to together strive towards gaining deeper knowledge about the new emerging technologies. Through this, PTOs could be enabled to overcome the aforementioned barriers.

Three reverse salients were also identified, linked to the aforementioned barriers. If the reverse salients are assessed, BEB acceptance among PTOs could be increased. The three identified reverse salients are; the battery technology, the charging infrastructure and the contracts/ownership.

The co-operation with the commissioning PTO and FMS-service provider has led to valuable access to Swedish public transport actors, and has aided in a deeper understanding of the phenomena. Although, this co-operation might have exposed us to a risk of being influenced.

Keywords: Battery Electric Bus, BEB, Electric Vehicle, EV, Electrification of Public transport, Technological transition, Multi Layer Perspective, reverse salient.

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Sammanfattning

Hållbarhet och klimatförändring får allt större uppmärksamhet i opinionen, vilket tvingar länder till handling. Den svenska regeringen har uppsatta mål om att fram till år 2030 ha en fossilfri trafik. Batteri-elbussen kan vara en viktig komponent i lösningen att nå målet. Dock, så är batteri-elbussarnas utbredning fortfarande i ett tidigt stadium.

Syftet med denna studie är att utreda hur den tekniska övergången till batteri-elbussar i Sverige påverkar bussoperatörerna i kollektivtrafiken. Dessutom undersöks hur tredjepartsleverantörer av Fleet Management system (FMS) kan stödja bussoperatörer i denna övergång.

Forskningen har genomförts i samarbete med en bussoperatör och FMS-tjänsteleverantör. Forskningen bidrar till en djupare förståelse om hur de kommer att påverkas av den annalkande teknologiska förändringen. Examensarbetet bidrar med empiri kring den teknologiska övergången till elektriska fordon inom svensk kollektivtrafik, som är sett som ett Stort tekniskt system. Konceptuellt bidrar arbetet även med att undersöka hur externa företag kan stödja den teknologiska övergången till elbussar, genom applicering av kunskapsfälten teknisk förändring och flerskikts-perspektiv.

Metoden är en case-studie av den teknologiska förändringen mot batteri-elbussar i Sverige. Empiri samlades in genom tolv semi-strukturerade intervjuer med forskare, bussoperatörer, en kollektivtrafik-myndighet, en elbusstillverkare och en FMS-tjänsteleverantör. Parallellt med intervjuerna distribuerades ett frågeformulär till de tjugo största bussoperatörerna i Sverige. Dessutom samlades information in genom studiebesök, insamling av pilot-projektresultat och interna dokument.

Resultatet visar på att det finns tretton upplevda barriärer bland bussoperatörerna i teknologiska övergången till batteri-elbussar. Sex av dessa barriärer relaterar till batteri-elbussar på komponent-nivå, och sju relaterar till förvaltnings-aspekter. Upplevda barriärerna länkade till komponentnivån är: Lösningsvariation och brist på standarder, Laddnings-infrastrukturen, Kort räckvidd eller låg passager-arkapacitet, Osäker funktionalitet i kallt klimat, Reliabilitet och hållbarhet. De upplevda barriärerna länkade till förvaltnings-aspekterna är: Brist på kunskap och erfarenhet, Beteendeförändring, Ekonomi, Underhåll, Ägande av infrastruktur och batteri-elbussar, Affärsmodeller och varierande krav från kollektivtrafikmyndigheter.

Barriärerna FMS-tjänsteleverantörerna kan åtgärda är främst närvarande på nisch-nivå, på grund av dess teknik-nära natur. Bussoperatörer och FMS-tjänsteleverantörer uppmuntras till att gemensamt sträva efter att nå fördjupad kunskap inom den framväxande nya teknologin. På så sätt kan bussoperatörer övervinna de ovan nämnda barriärerna.

Dessutom identifierades tre ”reverse salients” länkade till de ovannämnda barriärerna. De identifierade tre ”reverse salients” är: batteriteknologin, laddnings-infrastrukturen och kontrakt/ägande. Lyfts dessa tre identifierade ”reverse salients” upp i diskussionen och tas i beaktande, så kan det leda till ökad acceptans av batteri-elbussar bland Sveriges bussoperatörer.

Samarbetet med bussoperatören och FMS-tjänsteleverantören har lett till en värdefull tillgång till aktörer inom den svenska kollektivtrafiken och även möjliggjort en fördjupad förståelse av fenomenet. Dock, kan detta samarbete ha utsatt oss för en risk för påverkan.

Sökord: Batteri-elbuss, elfordon, elektrifiering av kollektivtrafik, teknologisk förändring, Flerskikts-analys, reverse salient.

Acknowledgements

This master thesis has been conducted in collaboration with Transdev AB and Fleetech AB during five months, which has been an exciting and educative journey. We would like to express our gratitude towards our company supervisors, Assar Svensson at Transdev and Lars Ericsson at Fleetech, for providing us with this opportunity, and for their support and insights on the Swedish public transport. We would also like to thank all the participants in our interviews and respondents to our questionnaire, for sharing your knowledge and experiences, it has been of great help. Lars Anneberg at the Swedish bus and coach federation deserves a special mention, thank you for the introduction to the bus industry, for your support and making the questionnaire possible. We are grateful to our academic supervisor Pär Blomkvist, for the guidance in concepts of Industrial Dynamics, feedback and for helping us in linking theory with practice. Finally, we would like to direct a special thanks to our families and friends for their everlasting support.

It has been a thrilling experience conducted at an exciting time, the Swedish public bus transport is once again on the verge of dramatic transformations, that will affect many travelers in their future daily lives.

The future brings many new exciting opportunities!

Stockholm, June 2016
Adam Ekström and Robert Regula

Abbreviations

BEB	Battery Electric Bus
BEV	Battery Electric Vehicle
CAN	Controller Area Network
DOD	Depth Of Discharge
DTC	Diagnostic Trouble Code
EU	European Union
EV	Electric Vehicle
FMS	Fleet Management System
GHG	GreenHouse Gas
HDV	Heavy-Duty Vehicle
HEV	Hybrid Electric Vehicle
HVO	Hydrotreated Vegetable Oil (replacement for diesel)
ICEV	Internal Combustion Engine Vehicle
ICT	Information and Communications Technology
ID	Industrial Dynamics
IO	Industrial Organization
IoT	Internet of Things
ITS	Intelligent Transportation Systems
KTH	Royal Institute of Technology
LTS	Large Technical System
MDE	MethaneDiesel (Mix of gas and diesel, marketed by Volvo)
MLP	Multi Level Perspective
PHEV	Plug-in Hybrid Electric Vehicle
PTA	Public Transport Authoritiy
PTO	Public Transport Operator
RME	Rapeseed-oil Methyl Ester (replacement for diesel)
SOC	State of Charge
TCO	Total Cost of Ownership
TT	Technological Transition
TU	Telematic Unit
UITP	The International Association of Public Transport

Contents

Chapter 1

Introduction

In this chapter a brief background and problematization for the phenomena under investigation is presented, followed by the research purpose and questions this thesis is going to address. Finally, the delimitaions of the research is discussed and the disposition of the thesis is presented.

1.1 Background

Issues regarding sustainability and climate change are increasing in importance on a global level. In December 2015, 196 member countries of the UN Framework on Climate Change met in the 21st Conference of the Parties on global climate change. At this meeting the parties signed a legally binding contract to limit the global warming to well below 2°C (UNFCCC, 2015*a*). Before the meeting, the member countries submitted national climate action plans, where they each made a plan on how to meet this goal (UNFCCC, 2015*b*).

Furthermore, the United Nations has set up seventeen sustainable development goals to handle the new situation. Two sustainable development goals from 2015 (9.4 and 11.2) state that by 2030 all countries should take action to; upgrade the infrastructure with greater adoption of clean and environmentally friendly technologies, and to provide access to transport systems for everyone by expanding the public transport (United Nations, 2015). The transport sector has increasingly made up a larger part of total greenhouse gas (GHG) emissions within the EU 28 member countries. In 2013, the GHG-emissions from the road transport constituted 20% of the total GHG-emissions (Eurostat, 2015), see figure 1.1.

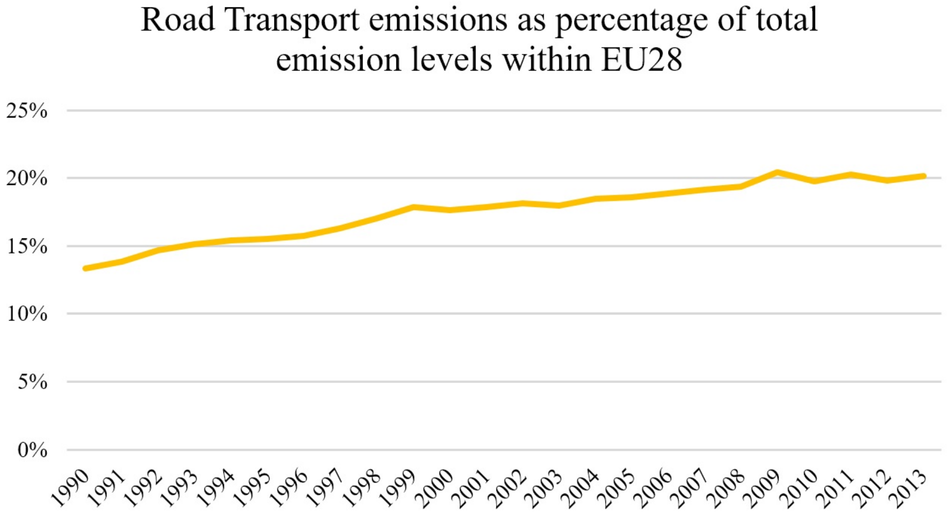

Figure 1.1: Road transport GHG-emissions, source: Eurostat (doi: env_air_gge)

According to European Comission (2014) about a quarter of CO_2 emissions from road transport within the EU is produced by Heavy-duty vehicles (HDV) (trucks, buses and coaches). This represents a greater share than international aviation and shipping combined. Therefore the European Commission has established goals with the aim to reduce CO2 emissions. The EU heads of state agreed to aim at lowering emissions from HDV by 30% from 2005 levels (Naturvårdsverket, 2015).

1.1.1 Swedish action towards a fossil-free vehicle fleet

There are further visions set by the Swedish government issuing a fossil-free traffic in 2030 (Regeringskansliet, 2008; Jernbäcker and Svensson, 2015). From 1st of July 2011 the Swedish legislation forces municipalities to include various environmental characteristics when performing purchases of buses and services in public transport. The purpose of the legislation is to promote and stimulate the market for effective and non-polluting vehicles (Regeringskansliet, 2011).

This has resulted in a Swedish industry-wide environmental program, issued by the main transportation organizations[1] which is to be used as support for its members when defining environmental policies and performing procurements. It dictates that emissions, air-quality and noise levels are key values to consider. The emissions are vital in regard to the greenhouse effect and also in respect to the perceived air-quality in cities that grow in population and become more agglomerated (Partnersamverkan för en fördubblad kollektivtrafik, 2013).

1.1.2 Effects on public transport operators

The global policies interact with regional policies and concerns on global and national level trickle down as implementations in each region. These trends have through the public transport authorities (PTAs) influenced the public transport operators (PTOs), who are responsible for the operation of the public transport buses, to investigate buses powered by electricity. Since electric buses could be one of the solutions to the increased global concern of increased CO2 emissions. An overview of the actors within Swedish public bus transport could be seen in Figure 1.2 and will be covered more in depth in chapter 4.

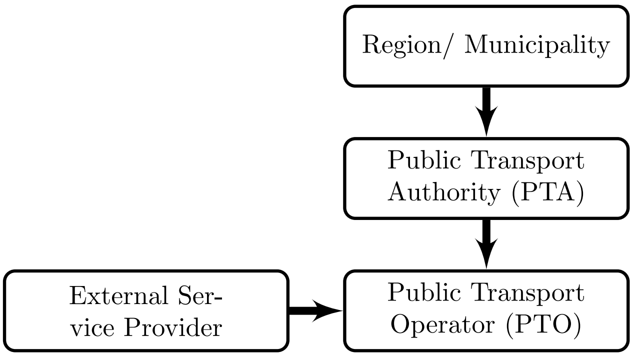

Figure 1.2: Actors within the Swedish public bus transport

In Sweden there are currently several pilot projects that is testing and evaluating electrically driven buses on public routes of different models and configurations. In 2011 the municipality of Umeå purchased an all-electric bus from Hybricon for evaluation. In Gothenburg, Volvo is performing tests with own developed Battery Electric Buses (BEBs). The municipality of Eskilstuna has purchased two BEBs from the bus manufacturer BYD which are currently on evaluation in collaboration with Transdev. In Kalmar and Karlskrona the manufacturer Ebusco is performing tests with their latest model. The PTO Karlstadsbuss is in the process of testing three all-electric buses from Optares. Parallel to this, Scania are in two joint projects testing solutions for electric trucks together with Bombardier and Siemens. The projects are conducted in Germany and Sweden and are involving conductive and inductive methods to collect power from the grid during operation.

Currently there is no leading solution and each manufacturer develops their own implementation. Within the industry various technical solutions have been introduced. Different kinds of battery-technologies and electric-propulsion solutions exist.

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[1] The Swedish Public Transport Association, Swedish Association of Local Authorities and Regions, The Swedish Bus and Coach Federation, the Swedish Taxi Association and The Swedish Transport Administration.

1.1.3 Roles of support systems during the transition

The short driving range of electric buses due to the limited energy capacity of the batteries on-board enhances the need to manage the bus energy consumption. At present some PTOs subscribe to third-party-services in order to collect information about the status of their vehicle fleet. Using information and communications technology (ICT) is one way to develop intelligent transportation systems (ITS) (Van Der Heijden and Marchau, 2002). Fleet management system (FMS) services helps the PTOs to manage their fleet in a more efficient way work towards creating ITS (Georgakis et al., 2002). These systems collect information from an on-board computer on the bus and sends it via wireless connection to a server for real-time visualization. Information regarding fuel consumption and speed profile could be used to measure driver-performance and promote a more eco-friendly driving-behaviour. With the support services from Fleetech (our first commissioning company), the PTO Transdev (our second commissioning company) has been able to decrease fuel costs by motivating Eco-driving on their diesel- and gas-driven buses.

FMS-services may aid in influencing driver behavior and create the possibility of remote-diagnostics. The system could early inform PTOs about abnormal bus-states or diagnostic-trouble-codes which could take action and prevent unexpected servicing costs and unsatisfied passengers. There is an insecurity associated with BEBs because of their short presence on the Swedish market and limited experience among users. FMS-services may help in reducing this uncertainty and enhance the adoption of BEBs.

1.1.4 Description of definitions

To make the reading experience easier, some of the abbreviations used in this thesis will be explained. The thesis investigate a topic around Battery Electric Vehicles (BEV) that is a sub-category of Electric Vehicles (EV). BEVs generally contain all types of vehicle types that run on a battery. In our thesis, we are particularly interested in the Battery Electric Bus (BEB) which is one of these, since this is the type of bus currently undergoing testing by our commissioning company Transdev. Although, since lot of the research and literature circles around EV or BEVs in general, these abbreviations will also be used in this thesis.

The same goes for vehicle types such as Internal Combustion Engine Vehicle (ICEV) which are the powertrain most popular today, for example using gasoline or diesel. Then, there are Hybrid Electric Vehicles (HEV) that combine electric and internal combustion motor. One specific type of HEV is the Plug-in Electric Vehicle (PHEV), which essentially mean that it is capable to charge the battery from the grid. All these will be used when investigating BEBs. The relation of the vehicle types could be visualized as in Figure 1.3.

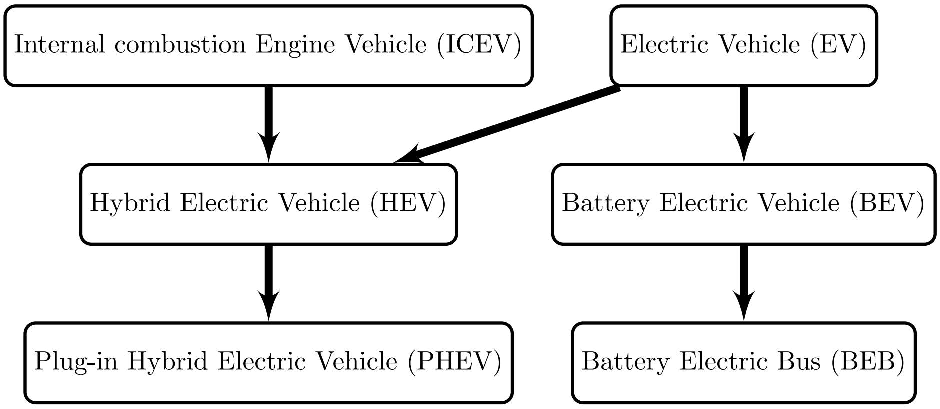


Figure 1.3: Relation of vehicle types used in this thesis

1.2 Problematization

Legislations, policies and technological advancements on a global level has caused big shifts at the functional level (new types of buses in Swedish public bu transport). The diversification of the new electric-bus-technology creates an uncertainty on the market for PTOs as how to meet this change and its consequences. At the moment it is also unclear which changes in FMS-services are needed in order to facilitate this change.

When products and systems are exchanged, new interfaces between different systems appear which create needs for new functionalities and behaviors. This in turn, form new demands on PTOs, the bus drivers and FMS-services supporting them in meeting strategic goals set by PTAs. There is a need to overview and determine the state of the market. Both its advancements of BEBs on the Swedish market and the influence of the coupled socio-technical systems.

1.3 Purpose

The purpose of this study is to investigate the technological transition within the bus industry and how FMS services can be developed to increase the adoption of electric buses within public transportation. This implies understanding the technological shift from fossil fuel powered buses to electric buses and how FMS services would be able to support the PTOs in this transition.

1.4 Research questions

The purpose will be fulfilled by answering the following two research sub-questions:

RQ1: What barriers among public transport operators hinder the technological transition towards a battery electric bus?

RQ2: How can fleet management system services assist the public transport operators in this transition?

1.5 Delimitations

This thesis will cover only the technological shift on the Swedish public bus transportation market. Although, benchmarking against other markets will be made through international literature. The study is also limited to focus on the specific type of electric bus powered by batteries, called BEB. Therefore, other techniques such as electrified roads, rail systems, plug-in hybrids etc. will not be covered.

Moreover, as an effect of commissioning companies, the study will take the perspective of the PTOs throughout the report. This resluts in a analysis mainly focusing on how the transition is affected by and affects the PTOs, with less focus on for example policy implications. Which otherwise could be expected of a study using the Multi-layer Perspective framework.

1.6 Disposition

This thesis is structured into eight chapters. After the introduction, the theoretical foundation is elaborated and explained in chapter 2. Chapter 3 describes the method used to investigate and collect the empirical data. In chapter 4 to 6 the empirics are presented together with an analysis of the data. Chapter 5 focus on answering research question one and chapter 6 answer research question two. This is then summarized in chapter 7 and conclusions are drawn in respect to the purpose of this thesis. Chapter 8 topics for future research is presented. This is followed by a reference list and appendices.

The structure of the chapters:

1. Introduction
2. Literature and theory
3. Method
4. Empirical setting
5. Barriers against adoption of BEBs
6. FMS-service opportunities
7. Conclusion
8. Future research

Chapter 2

Literature and theory

In this chapter we present the existing research within Industrial Dynamics, which was used to form the theoretical framework which this study utilized. First related theories and concepts are presented, followed by a short overview of the current research of electric vehicles. The chapter ends with a review and discussion of the developed theoretical framework.

2.1 Introduction

In order to structure the problem described previously theory from *Industrial Dynamics*, *Innovation theory* and *Technological Development* will be used. The public transport bus sector is on the verge of a transition where the technological shift demands new functionalities of supporting products. The aim of the literature study is to place the problem formulation in a relevant academic context with the aid of Industrial Dynamics theory. By utilizing a composition of frameworks and concepts described below the current state of the industry and the role of BEBs, in Sweden can be explored. The BEB is viewed as an innovation or development, striving towards becoming part of a larger LTS, the transportation regime. The components and artifacts of this regime can first be identified, secondly categorized as a way to understand their relationships and finally, be used to understand the state of the industry, and aid in answering the research questions.

This chapter is divided into seven sections where the first section (section 2.2) frames and gives an introduction to the problem of the Industrial Dynamics field. Sections 2.3 - 2.6 discusses separate theoretical frameworks in detail which later on are used in section 2.7 to define the theoretical framework which will be used further in this thesis in analyzing the industry. Furthermore, section 2.7 also gives an short historical overview of the academic literature regarding the introduction of electric vehicles and how this transition has been approached earlier.

2.2 Industrial dynamics

Starting off in the beginning of the 20th century, Joseph Schumpeter and Alfred Marshall began to form what could later be termed the roots of the industrial dynamics (ID) field (Krafft, 2002; Carlsson, 1987). Industrial dynamics are rooted in many fields of study such as evolutionary economics, entrepreneurship, industrial organization, economic history, economic development and the view of innovation as the driver of economic growth (Trott, 2005; Carlsson et al., 1989; Carlsson, 1987). The field differentiates itself from Industrial Organization (IO), although, both of them are covered under the term "Industrial Economics" (Carlsson, 1987). According to Carlsson (1987), ID focuses more on individual firms or a sub-part of a firm compared to the IO-tradition that focuses on the structure and competition of many firms. He later on states that the focus could be more on the technology itself and it puts more emphasis on the transformation processes within the industry (hence the name "dynamics"), whereas IO tends to focus more on giving a "static picture" of the analysis. According to Carlsson (1992, p. 8) there are four main themes that constitute the analytical framework of ID:

1. The nature of economic activity in the firm
2. The boundaries of the firm and the degree of interdependence among firms
3. Technological change and its institutional framework

4. The role of public policy

The first field covers the structure of an organization and how it convert inputs to outputs through leveraging on its different capabilities. The second field elaborate more on how the structure of firms has developed over time. The last two, "Technological change and its institutional framework" and "The role of public policy" aims at discussing how technological systems develop and how public policy influences this development. The last two are deemed the most interesting for this thesis. Carlsson (1992, p. 14) states that both fields discuss a technological system which can be defined as:

> "...a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure...and involved in the generation, diffusion, and utilization of technology."

Technological transitions, which is one of the two areas mentioned by Carlsson (1992) and especially transitions within Large technical systems will start of this chapter. this is used to understand the transision towards the BEB bus. In the process of identifying barriers, literature about reverse salients will then be used. The barriers can be categorized into several levels, as mentioned in in the secion about Multi Layer perspective. The process of adoption will then be framed in time using theories called Technology adoption life cycle and finally, these theories will be merged into our proposed research framework.

2.3 Large technical systems and technological transitions

Mayntz and Hughes (1988) claim that a new field of study began to emerge when Hughes (1983) published his book *Networks of Power* in 1983. They recognize the existence of modern technology as complex large technical systems (LTS), which extend into the socio-technical domain. The interplay between technology and society has influenced both the industrialization and development as well as societal way of life. The interplay is origin to both synergies and problems, which has led historians and social scientists to cooperate in analyzing the evolution and effects of LTS in modern society. (Mayntz and Hughes, 1988) Research in LTS create a deeper understanding of how societal processes and the technological development affects and influences each other.

Hughes (1987) expresses that technological systems contain components of various nature, which affect each other. Those components may be artifacts (both physical and nonphysical) or components in technical systems such as transformers and transmission lines in electric power system. Furthermore, organizations, such as manufacturing firms and research programs or scientific tools such as books and articles, can figure as components. The difference between an artifact and component is that the component possesses a degree of freedom, e.g. inventors, engineers or managers. Also, natural resources or regulatory laws may act as components because of their contribution to a common system goal. The relationship between components and their function is fluid, if a component is removed the system as a whole will compensate by altering the remaining artifacts accordingly. Hughes (1987) states an important point that when analyzing a system one should delimit the level of analysis, artifacts can be analyzed as a system and as well as a component in an encircling system.

The development of a large technical system according to Hughes (1987) begins and is mainly formed by the actions of engineers and entrepreneurs, by invention and development. The engineers and entrepreneurs are called *system builders*, who solve critical problems resulting in innovation. As the development continues manager-entrepreneurs make important decisions aiding in competition and growth. Finally individuals with political knowledge solve problems regarding growth, expansion and momentum. In order for the innovation to prevail success during the whole process is needed, although Hughes (1987) emphasizes that the above mentioned phases overlap and backtrack, the process is not sequential.

"As systems mature, they acquire style and momentum" (Hughes, 1987, p. 56). The phenomenon that occurs when investments in machinery, labor, organizations, infrastructure and resources are made, Mayntz and Hughes (1988) calls momentum or dynamic inertia. As the technology spreads and involves more stakeholders it becomes autonomous, with a direction or set of goals (Hughes, 1987).

By analyzing the Swedish public transport sector with the concepts of LTS and technological transitions the current situation of the technological transition can be determined. By determining the current progress and by identifying the current stakeholders and their roles, one can determine how the stakeholders are influenced by the transition. Further their possibilities in affecting the transition could be determined.

2.4 Salients and reverse salients

Hughes (1992) introduced the concept *salients* and *reverse salients*, where a salient is a part of a technological system that is more efficient, more economical or in some other way better that the other components within the system. In the same manner, a reverse salient is a component that lags behind. This could metaphorically be described as a chain not being stronger than its weakest link or as Hughes (1992) prefers to visualize it; as an advancing military front. In the military front visualization a salient is one part of the military group that is advancing ahead of the others where the reverse salient is lagging behind, causing a weakness in the frontier.

It is important within this theory to determine the system goal, in order to be able to measure and rank different groups relatively to each other. Another important area within this theory is to understand the concept of *critical problems*, which should not be confused with, but must be defined together with salients and reverse salients. Salients are discovered by problem-solvers and inventors, as a result of expanding technological systems, whereas *critical problems* arise from human volatility (Hughes, 1992). For technical system growth, identification of reverse salients and solutions to underlying critical problems is required (Joerges, 1988). Solutions to technical reverse salients can be characterized into two types, *conservative* and *radical* inventions/inventors. When a solution is radical, often invented externally to systems' managing organizations, it may produce a competing system. Whereas, a conservative invention/inventor, often invented internally within managing organizations, produce improvements to existing LTS's (Joerges, 1988). *"Indeed, independent inventor-entrepreneurs could be shown to specialize in identifying critical problems and related 'reverse salients' on broad technological fronts."* (Joerges, 1988, p. 14)

By identifying the reverse salients that appear in the technological transition one can identify areas of interest for stakeholders in the industry to assess. By highlighting the areas of interest more resource can be directed properly into increasing knowledge and experience, thus support the evolution of the industry.

2.5 Multi Layer Perspective

In order to understand the changes and trends in the industry one should investigate how TTs come about. Frank W. Geels' article *"Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study"* is therefore being utilized in this thesis. He combines two evolutionary views, (i) evolution as a process of variation, selection and retention, and (ii) evolution as a process of unfolding and reconfiguration". He treats three chosen mechanisms in technological transitions: *"niche-cumulation, technological add-on and hybridization, riding along with market growth"* (Geels, 2002).

Geels' view of technology, in his analysis of TT, is that it itself has no function, until it is associated with human participation, social structures or organizations. Hughes (1987) has coined the notion of a *"seamless web"*, consisting of social practices, organizations and communities. TT happens when a socio-technical configuration changes from one to another. It involves alterations or substitutions of technology, which does not easily take place. The nature of socio-technical configurations, as linked and aligned elements, obstructs mutability. Therefore change is even more difficult to achieve with radically new technologies, because of the alignment of the elements (regulations, infrastructure, best practices) to existing technology. The multi-level perspective is used as a tool to combine observations from different literatures. The complex dynamics of socio-technical change is made more comprehensible by division into several levels (Geels, 2002), see Figure 2.1.

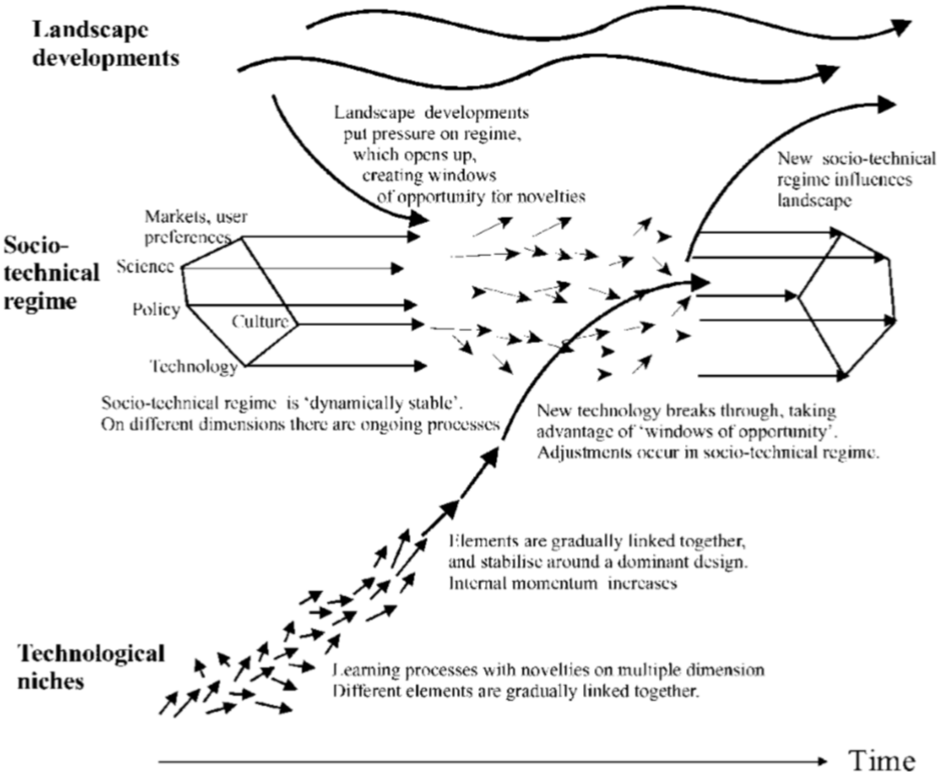


Figure 2.1: The Landscape, Regime and Niche levels in the MLP theory, source: Geels (2002)

By applying the MLP theory on the Swedish public bus transport and dividing discovered problem areas (barriers) into the different levels, the phenomena in the industry will be easier to analyze. The categorization into different levels will aid in figuring out which actors can influence or solve each of the barriers.

2.6 Technology adoption life cycle

In the book *"Crossing the Chasm - Marketing and selling disruptive products to mainstream customers"* Moore (2014*b*) builds upon a model called the Technology Adoption Life Cycle, originally developed by Rogers (1962). The model was originally based on research with purpose of investigating purchasing patterns of new strains of seed amongst American farmers (Rogers, 1962; Moore, 2014*b*). In modern use, the model tries to describe how the life cycle of technological products evolve and it divides the customers for high-tech products into groups based on their reaction towards new innovative technological products (Moore, 2014*b*). The groups are called Innovators, Early Adopters, Early Majority, Late Majority and Laggards, where the two majority groups are corresponding to the main part of the market (Moore, 2014*b*).

What Moore (2014*b*) articulates as the key learnings in the work is tree-fold. First, it is important to understand how the different needs of the customer groups change the demand on the product as a technology works its way from left to right in the technology adoption life cycle.

Second, how the strategy and product offer have to evolve through these stages, from an early "proof-of-concept" technology towards a "whole product", a marketing word for a product that offer the full solution, for example including a full support- and service network. He also emphasize that one important strategy to cross the chasm is to target a "beachhead" segment in order to highly focus on a specific part of the market with all the resources in order to succeed.

Third, and maybe the most important, is the difficulty in going from a technological innovation for a selected few enthusiasts at an early market, towards a full-feathered product capable of satisfying the needs of the major market (Moore, 2014*b*). This difficulty is visualized in Figure 2.2 where the different customer groups are separated with some space in between to further show the different preferences of these groups. As could be seen, the space between the early adopters and early majority is noticeably larger than the other gaps. The left side of this "gap" is called the early market and the right side is called the majority market. It is a way to represent the difficulty to reach the majority market and Moore (2014*b*) has named this gap "the Chasm".

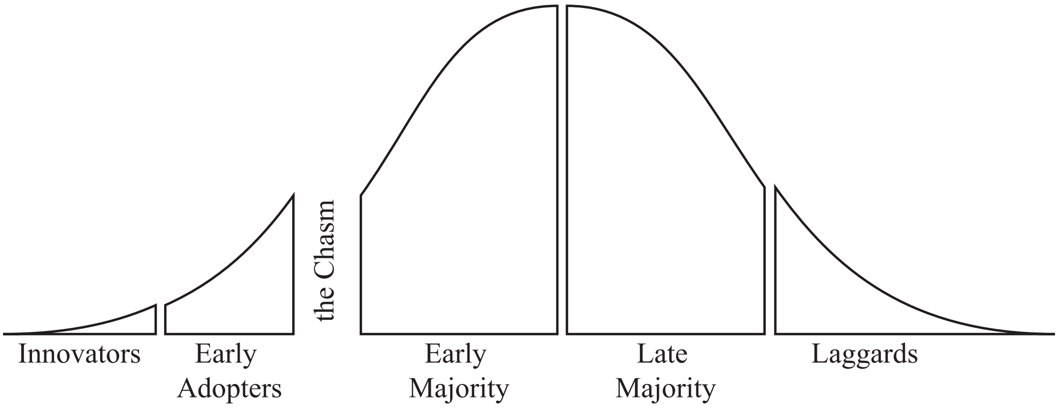


Figure 2.2: The technology adoption life cycle with the Chasm, modified from Moore (2014*b*)

The technology adoption life cycle was originally developed from research aimed at a business-to-consumer market. Although, Moore (2014*b*) claims that after his re-work it is "...at heart a B2B [Business-to-Bussiness] development model" and that it has been used both for educational purposes and for strategic decisions by companies of disruptive high-tech products. This seems to be an explicit move after the last version of the book and in a comment on the new version release of the book, Moore writes:

> "Overall, the key takeaways [About the new version of the book] are two. First, crossing the chasm is a B2B model. B2C requires its own treatment..." - Moore (2014*a*)

The theory and approaches to cross the chasm has been popular among firms in bringing high tech products to larger markets (Trott, 2005). In his book, Moore (2014*b*) give examples with B2B products connected to enterprise IT and software-as-a-service products such as Salesforce, Lithium, Infusionsoft and Box. Now, we plan to use this model to gain insights in the situation for the BEB. The model focuses on the critical stage in the product adoption process where many firms loose momentum and products fail to reach the mainstream market (Moore, 2014*b*; Trott, 2005). Some research about the technology adoption life cycle has previously been conducted as a way in trying to understand the specific knowledge and perceptions among early adopters of EVs (Egbue and Long, 2012). Bauner (2010) also used it to analyze the introduction of consumer EVs in 2010.

2.7 Research framework

Nykvist and Whitmarsh (2008) started to investigate the current situation for an upcoming change within the transport regime and compared the situations in the UK and Sweden. They investigated and collected empirical evidence for three currently ongoing mobility *regimes* based on the transitions literature; technological change, modal shift and reduced travel demand (Nykvist and Whitmarsh, 2008). By using *"...the processes of co-evolution, divergence and tension within and between niches"* (Nykvist and Whitmarsh, 2008, p. 1373) reached the conclusion that novel transport technologies where the driving force of the transition. However, different technologies were more successful in each country. Nykvist and Nilsson (2015*b*) continued to investigate this phenomena in 2015 through a multilevel perspective for socio-technical transitions of a city in Sweden, Stockholm. The focus was in trying to understand the progress of BEVs, and especially why the transition had been slow in Stockholm despite its favorable conditions (Nykvist and Nilsson, 2015*b*). For a illustrated figure of their viewpoint, see Figure 2.3. The study arrived at three conclusions; there is a lack of niche developments which act as a preserving factor for skepticism among policy makers and consumers, there is limited regime action due to regime actors' ambivalence towards BEVs and a lack of strong policy signals for BEVs that maintains the uncertainty for the technology (Nykvist and Nilsson, 2015*b*).

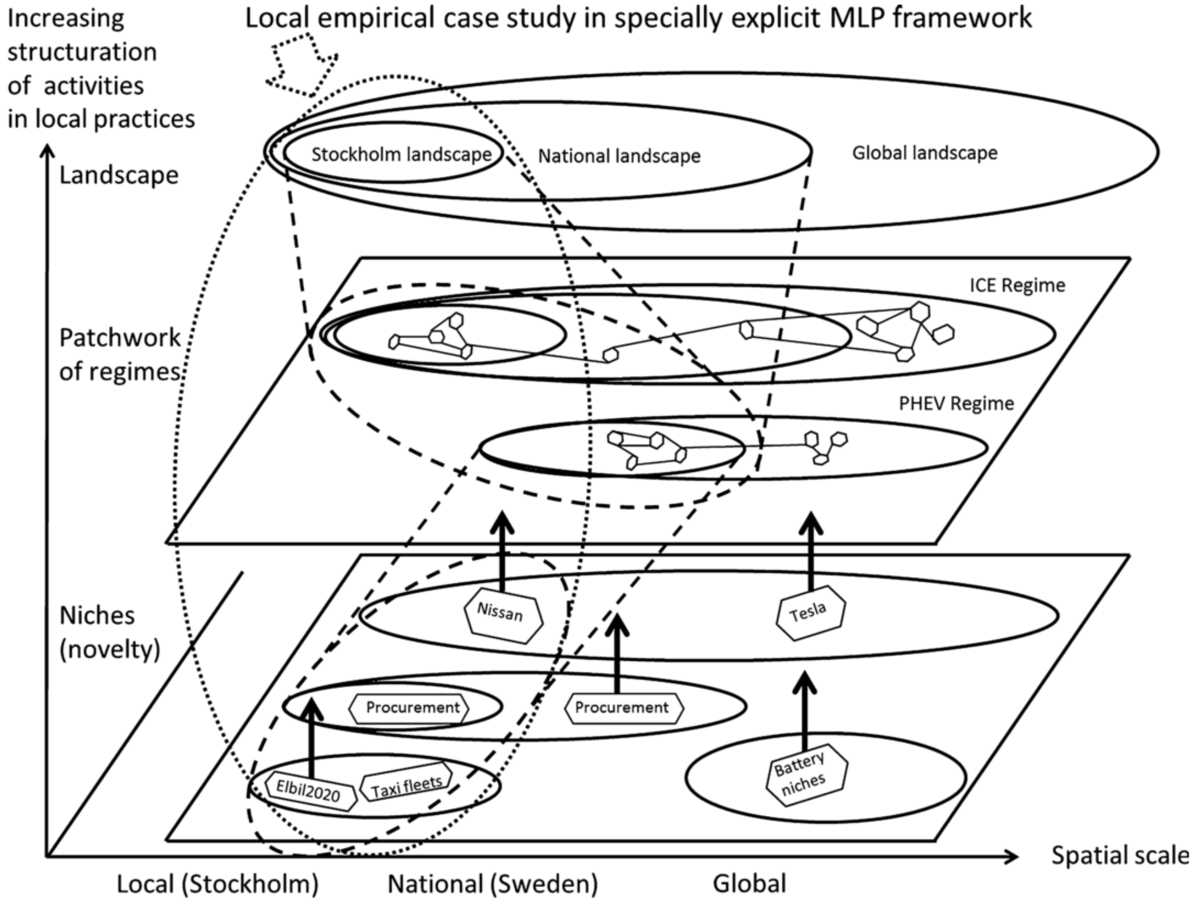


Figure 2.3: A modified MLP framework for a case study of BEVs in Stockholm, source: Nykvist and Nilsson (2015*b*)

Wikström (2015) investigated the conditions for introduction of EVs in public vehicle fleets in Sweden. In her doctoral thesis, she used an interdisciplinary research approach, covering the perspectives of technology, public policy and the user in order to see the situation within its context. The main findings are first that a clear policy allocation is lacking, both between policy areas and different levels. Second, the so called policy entrepreneurs can help placing the EVs on the policy agenda. Thirdly, it is favorable to aim at using the public sector as an trigger for EV adoption within the transport sector in general. Finally, in order to understand the transition to EVs and the social drivers and behaviors involved, an interdisciplinary approach is needed (Wikström, 2015). The results cover three main research topics; a demonstration project for plug-in EVs (the technology procurement scheme 'Elbilsupphandlingen'), a demonstration project of hybrid ethanol buses with a discussion about electrification of public transport buses and third, an analysis of the policy practice in Stockholm (Wikström, 2015).

A common denominator regarding the current research about EV's is that it focuses on vehicles as a broad category (Geels, 2005; Nykvist and Nilsson, 2015*b*; McKinsey & Company, 2014) or on cars (Lee and Lovellette, 2011; Sierzchula et al., 2012*b*) in particular. Research regarding the role of the bus industry is relatively sparse, the topics covered are mainly focusing on the fuel efficiency on hybrid buses (Wikström, 2015) or the TCO of BEBs (Nylund and Koponen, 2012; Pihlatie et al., 2014). The same tendency could also bee seen among the companies producing EVs, where the newest models are within the car-segment (Sierzchula et al., 2012*a*), see figure 2.4.

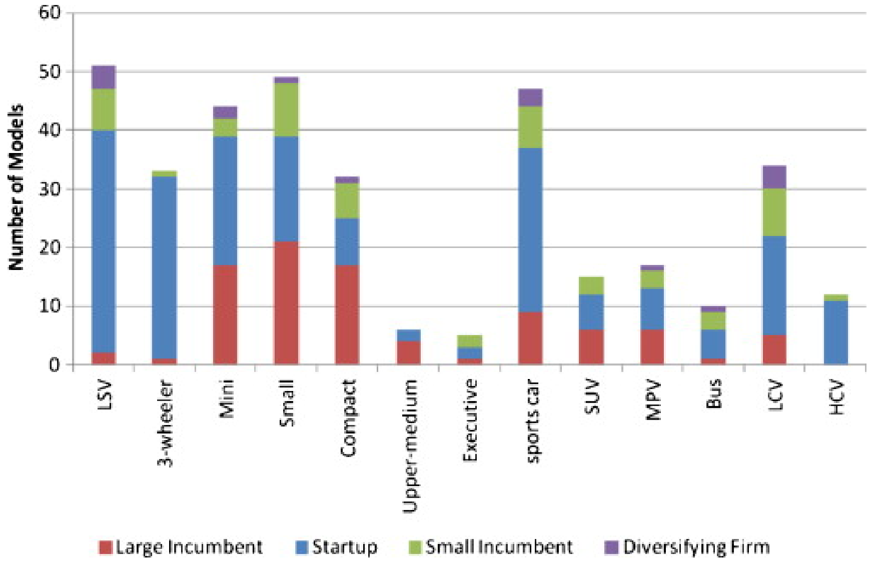


Figure 2.4: EV classification by manufacturer type, source: Sierzchula et al. (2012*a*)

However, Wikström (2015) concludes in her interdisciplinary doctoral thesis, that it would be favorable to start the electrification of the current mobility regime within the public transport sector. Pihlatie et al. (2014) make the same point that BEBs are the first BEV that is justified both commercially and environmentally, as compared to a personal BEV. Moreover, Glotz-Richter and Koch (2015) draws on one example where they compare the effect of electrifying buses versus electrifying cars. They conclude that the pollution would be reduced by a factor of 100 and at the moment it is not receiving the corresponding financial and political attention.

In this study we utilize a composition of the frameworks and concepts described in the previous sections. In order to understand the current state of the bus industry and the role of the BEB i Sweden, theories from industrial dynamics is used. One can by focusing on the technology and identifying the transformation processes within the industry, identify the technological change and the role of public policy. To better understand this transformation, the BEB is viewed as an innovation or development, striving towards becoming part of a larger LTS, the transportation regime. By applying Hughes' (1983) theories, the components and artifacts of this system can first be identified, secondly categorized as a way to understand their relationships and finally, be used to understand the state of the industry. The components and artifacts could then be viewed through Hughes' (1992) *salients* and *reverse salients* concept, in order to see which of these that works towards or against a transition. The categorizing process is made on the landscape, regime and niche levels as mentioned in Geels's (2002) theories about technological transitions from a multi-layer perspective. In this way obstructions to change, such as regulations, infrastructure or existing technology can be categorized and more easily understood.

Moreover, these concepts are merged with the technology adoption life cycle, as developed by Moore (2014*b*). The theories are used to understand how the BEB could possibly be supported in the process of crossing the chasm and how this would affect the bus operators. By identifying those barriers and analyzing the current FMS-service offer it is possible to identify FMS-service opportunities that could overcome the barriers. Thus, find solutions that may allow the BEB-technology to gain momentum and enter the *early majority* market.

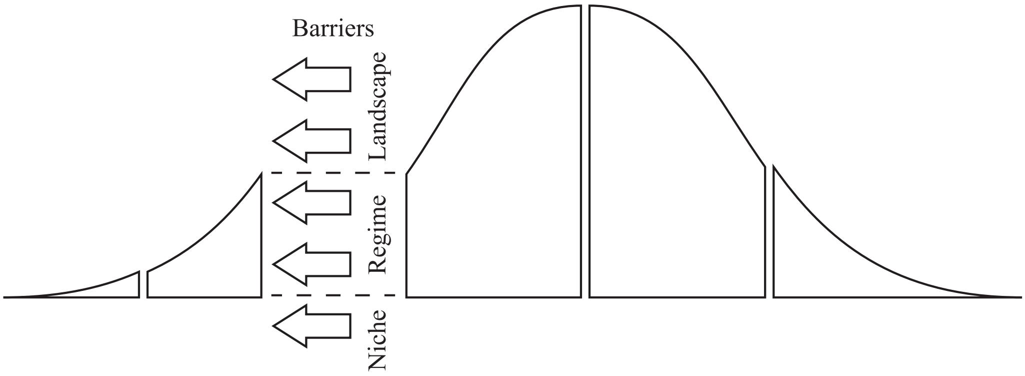


Figure 2.5: The theoretical framework used in this report

The composition of these theories are summarized in Figure 2.5 above. The development in the bus industry is seen as a technological transition in a LTS where a new technology, the BEB, is emerging, trying to cross the chasm. The barriers against this transition are within this report analyzed, categorized in three levels according to the MLP framework and using reverse salient theory to understand the linked problem. In the figure below the barriers are visualized by the arrows "holding back" the technology from crossing the chasm. They are divided into three levels by the dashed lines, reflecting their effect on landscape, regime and niche level.

Chapter 3

Method

This chapter describes the method conducted in this research. Firstly, the research methodology is presented. Second, the research process and the underlying methods are depicted and finally the risks, validity, reliability and generalizability is discussed.

3.1 Research approach

The research, and the structure of this report, has been divided into three rather distinct parts, based on the purpose and the two research questions. The first part aims in trying to define the technological shift (chapter 4) and part two in exploring at how the PTOs are affected (Chapter 5). The third part investigates how FMS-service providers can aid the PTOs in this transition (chapter 6).

The first two parts are of exploratory nature and the findings in these parts has been used as inputs to the third part, that is of a more descriptive nature. In order to answer the two research questions and to fulfill the purpose of this thesis, a case study research design covering the technological transition in Sweden as the unit of analysis was considered appropriate. More specifically an opportunistic study methodology was utilized, because of the two commissioning companies. The companies being two links of the business chain in the public transport industry gave an opportunity, due to extended access, to examine the phenomenon from several angles. This motivated the choice of using a case study approach, which Collis and Hussey (2009) has assessed. The case covers the technological transition within the Swedish public bus transportation. More specifically how the transition to BEBs is affected by the current perception among PTOs.

Since combining different sources increases validity (Collis and Hussey, 2009), the chosen methodology gave us the benefit of combining different methods, both in terms of data gathering as well as in increasing validity and reliability. Information gathering was mainly conducted through qualitative methods, using semi-structured interviews in order to obtain deeper understanding of how stakeholders are affected. This approach resulted in more flexibility, which according to Blomkvist and Hallin (2015) also enables us to find unexpected information during the research. The authors were offered a desk at one of the commissioning company and conducted regular meetings with the other commissioning company for five months. As suggested by (Voss et al., 2002), notes were taken to record ideas that emerged during discussions, interviews, meetings and during time in-between.

Moreover, an opportunity was given to send out a questionnaire to PTOs in Sweden, which could be used as a stepping stone after a first look into the industry. The results from the questionnaire were later used to triangulate findings from the interviews and also worked as a base to identify new interviewees. The information gathering methods utilized will be presented in detail in the following sections.

The boundaries of the case study were set to first identify the obstacles for the PTOs needed to adopt BEBs. Second, how FMS-services in co-operation with the PTOs could affect the technological transition in the Swedish public bus industry. This was done in order to prevent the case from becoming too broad and order to maintain a relevant perspective for the two constituent companies. Maintaining a sufficiently narrow scope is important when conducting a case study (Yin, 2013).

3.2 Research process

A methodical approach increases the likelihood of a good research (Collis and Hussey, 2009). The research was carried out using an iterative approach. Each step of the research process was continuously revised, either due to new literature or new empirical data not coinciding with the current research questions. Also regular discussions with stakeholders were conducted which affected the direction in which the research proceeded.

At first the problem formulation, purpose and preliminary research questions were formed, inspired by the wishes of our two commissioning companies. In order to gain an academic contribution, the research purpose and research questions were reviewed and discussed with our university supervisor.

The pre-study, initial discussions and observations at the commissioning companies gave a general idea of how the research should be conducted. Due to the nature of the research, covering both technology of EVs and the Swedish public bus transport sector, a mapping of the market was performed in order to identify external and internal stakeholders.

The research that followed the pre-study focused on gaining knowledge about the EV technology and public transport sector in general, both through a literature review and by introductory interviews and discussions with people in the respective field. Simultaneously a mapping of the market was performed by identifying external stakeholders. Stakeholders were identified and characterized through interviews with employees at the commissioning companies and various employees from companies in the public bus industry. Furthermore, researchers at KTH within related fields were identified, where some of them were interviewed. The performed literature review gave a well-founded analysis of the context and facilitated an understanding of the public bus industry and electric vehicle technology.

The gained information confirmed the purpose, helped in shaping the research questions and inspired the forming of questions prepared for the interviews and the questionnaire. The purpose of the interviews that followed was to gain detailed in-depth knowledge and insights, in order to capture a variety of thoughts the interviews were of semi-structured nature. Parallel to performing the interviews a questionnaire was prepared, with the aim of triangulating data and as base for more specific questions in further interviews.

The gathered data from the literature review, interviews and questionnaire was then categorized according to theme and then formed into barriers. The formulation of answers to both research questions was circular, e.g. by identifying a barrier through the literature review or interview, possible opportunities were discussed with the interviewees or employees at the commissioning companies. As the discussion of an identified barrier developed, so did the discussion of the related opportunity.

The funnel-formed first part of the research approach enabled us to more easily identify areas of interest and in forming the research questions. Then, as the research progressed, by narrowing the researched topics we could acquire and capture detail-specific characteristics.

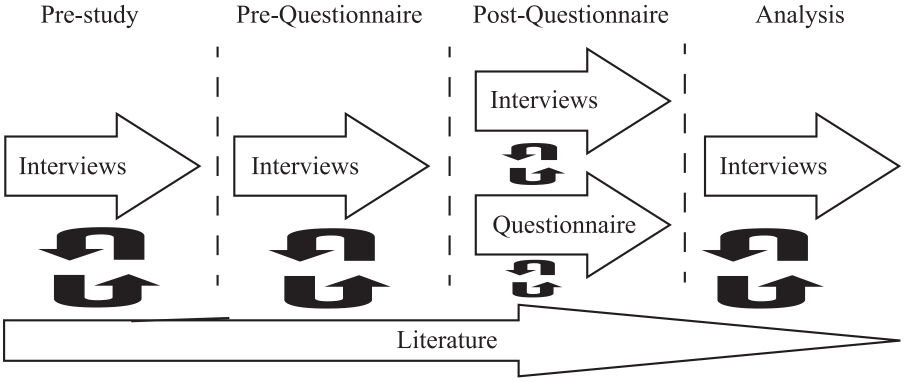


Figure 3.1: The research process carried out in this thesis

3.2.1 Pre-study

Prior to the research a pre-study was conducted. The objective of the pre-study was to form a research topic that could contribute to academia as well as be of value to the commissioning companies. The preliminary investigation covered the BEB-technology, Swedish public bus transport and FMS-service offerings on the market. The results from the pre-study gave an overview of the problematization and clarified the context in which the research was to be conducted. The context helped us on focusing on the particular characteristics of the EV technology and public bus transport industry, thus aided in keeping the scope of the research sufficiently narrow.

3.2.2 Literature review

The purpose of the literature review was to serve as a foundation to the research and to account for the chosen methodology and scope. The pre-study insights formed and focused the literature review to cover research methodology, Industrial Dynamics, EV-technology and the Swedish public bus transport, topics which were read upon in parallel. The review aided in the analysis and comprehension of the findings and was a recurring process throughout the research process.

The literature review covering research methodology gave us insights in how other researchers have conducted their studies and suggestions on how data could be analyzed. The literature review is not just a collection of earlier research, but a ”critical evaluation of the existing body of knowledge” (Collis and Hussey, 2009, p. 82). All read articles were critically assessed and conclusions drawn were corroborated with other sources.

The second theme concerning ID, gave us insight in how collected empirics regarding the classification of the technological transition and its application on the Swedish public transport sector. Research in how earlier technological transitions had been identified and discussed was searched and analyzed. By identifying relevant and applicable theories mentioned in chapter 2 a mapping of the market could be performed.

The third researched theme, EV-technology, turned out to be a extensively researched field of study. At the beginning EV technology in general was read up on, and as knowledge about battery technology and electric driveline was gained, topics regarding BEBs were researched.

The research covering the fourth topic, the Swedish public transport, enabled us to position the empirics regarding the electric bus technology and gave a context of the industry structure surrounding and affecting the industry.

The literature comprised of articles from journals and books accessed through scholar databases (Google Scholar and KTH Primo), also website specialized in covering news about EV-technology were visited. Several of the ID articles were read upon by recommendation from our academic supervisor and some by the researchers interviewed, but most of them were acquired by searching for articles covering the aforementioned topics. The search phrases often included words like: ”electric vehicle”, ”ITS”, ”transportation”, ”FMS”, ”MLP”, ”LTS”, ”salient and reverse salient”, ”public bus transport” or ”EV batteries”. At the beginning the articles were chosen according to their citation frequency. As we read further, and gained more knowledge, the articles and search keywords became more specific. Many articles were found by investigating the article references.

About 400 articles have been covered in more or less detail. In order to facilitate the documentation of the literature we utilized working documents where important information discovered, was categorized and noted for future reference, accordingly to their content. This helped us in keeping a record of what had been discovered and enabled us to quickly recap earlier read material in order to keep and overview.

3.2.3 Company visits and observations

The main part of the research has been conducted at Fleetech's premises in Stockholm, which has provided valuable quick feedback during the research process. Also frequent visits to Transdev have been done during the timespan of the project. We have also participated at an educational day in Stockholm on the 24th of November 2015. During the day, the newly acquired BYD buses (procured by Eskilstuna municipality) were introduced and the technology was elaborated by employees from BYD, in order to educate Transdev workshop personnel. On the 18th of March 2016 a visit to Transdev in Eskilstuna was made, in order to interview the Coordinator of the bus drivers and discuss experiences of the newly acquired BEBs.

The 12th of April 2016 we visited the Swedish BEB manufacturer Hybricon Bus System, in order to gain knowledge of how they build their buses and to conduct interviews with a senior business developer and a design engineer. The goal with this visit was to understand the current limitations in the BEB technology and more specifically how cold climate was handled. It also gave an opportunity to discuss the charging infrastructure that is needed, in which they have experience since having developed a "ultra-fast" charging concept.

3.2.4 Interviews

When the key stakeholders were identified they were chosen to be interviewed using a semi-structured approach, with questions prepared with the help of earlier researched literature, information that has emerged from the stakeholder identification process and from the questionnaire. With this approach we were able to identify relevant stakeholders and form well defined questions. Within ID there is a strong tradition to use qualitative methods, compared to more "pure macro economic-"" or "IO-" traditions, which have been part of the criticism of "lack of scientific rigour" within the field by Carlsson (1987). This would be deemed appropriate for this exploratory part of the study. With the semi-structured approach we had the advantage of being able to obtain in-depth knowledge and thoughts of the interviewees, as well as ease discovery of new information. Mainly open questions were formulated because of their exploratory nature (Collis and Hussey, 2009) during the interviews. Open questions also helped in reducing bias from the interviewers, not being able to influence the response from the interviewee. Interviews held by only one interviewer were recorded after permission was granted by the interviewee, shortly after the interview the recordings were transcribed and summarized in order to maximize recall and to keep the material concise. During interviews held by two interviewers, each had their own role. One interviewer was tasked to ask questions while the other took notes of the responses from the interviewee. Shortly after the interview the notes were transcribed and discussed in order to validate the results and reduce bias. Afterwards, if clarification was needed the interviewee was asked additional information by e-mail. All interviewees were asked whether they knew someone that might be of interest to interview, by those means we could find more suitable individuals to interview. The interviews can be describes as have been done in two phases, phase one considers the time before sending out the questionnaire (pre-questionnaire) and the second after the questionnaire (post-questionnaire) was distributed. The questionnaire was distributed the 21th of March 2016.

Pre-questionnaire, the identification of interviewees was a part of the stakeholder identification process. The stakeholders were needed to be identified in order for the authors to understand the context of the market and the new technology. During this process, it became apparent that we needed to attain a solid ground of knowledge about the industry in order to understand the current situation in the Swedish public bus transport sector. The contacts within our commissioning companies served as a good start, although more interviews were soon deemed to be needed. It seemed legitimate to start with interviewing Lars Annerberg at the Swedish bus and coach federation, a association of PTOs in Sweden with around 370 member companies. He is currently an industry developer working with issues to develop Swedish public bus transport and has played a part in raising the awareness of BEBs within the industry for the last years. Since he posses' a good overview of the current situation for PTOs.

The interview with David Bauner was conducted soon after the interview with Annerberg. The purpose with this interview was to get a better understanding of how the topic of EV has evolved within the academia. Since he has performed previous research on EVs using Industrial Dynamics theory as an analytical tool, especially around the upswing for EVs in the 1990's. This complemented the more industrial viewpoint of Annerberg. Both of them gave us a better understanding of the system where the technological transition was situated.

The interview with Anders Lundström, was very relevant and of much interest, since he posses' specific knowledge from the user perspective of driving EVs and visualization of Eco-driving in EV applications. The purpose with this interview was to gain more insights in how FMS-services could aid the drivers in EV-driving and which barriers EV-drivers presently experience. This interview was more linked to the technology of EVs.

Post-questionnaire, the interviews aimed more specifically at understanding the situation of the PTOs. The questionnaire was distributed to a larger number of PTOs, while interviews were conducted with the three largest PTOs in Sweden, according to The Swedish Bus and Coach Federation (2016*b*) (these PTOs did also answer the questionnaire). During the interviews, their answers in the questionnaire could be elaborated and questions asked circled around three large areas; the market, the ownership of buses and their relation to FMS-services. Questions regarding the market elaborated on what influence PTAs have on PTOs and how this differs between regions. Also, if the PTOs thinks that influence from PTAs is promoting or impede a transition to BEBs. Regarding the ownership, questions were asked about their currently positive and negative experiences with BEBs, and what differences they experience compared to other types of buses. Finally we asked questions regarding their usage of and expectations on FMS-services.

Moreover, in the previous interviews we asked for more possible candidates. This resulted in the opportunity of interviewing the bus manufacturer Hybricon Bus Systems and the PTA in Uppsala (UL).

When interviewing the Development manager at the PTA UL the questions covered three main topics; influences that affect PTAs, the relation to PTOs and their view on BEBs. Here we could gain a better understanding of the division of ownership and responsibilities between PTOs and PTAs and a possible future situation regarding charging infrastructure and BEBs. At Hybricon, the two interviews with the senior business developer and the design engineer contributed with valuable knowledge. Specifically in how their BEB is built and how they handle the cold climate, which during previous interviews had been mentioned to be a general problem area. Moreover, we could ask specifically about the their charging stations, and more technical questions regarding the BEB components that had remained unanswered in the previous interviews. This information was also triangulated with questions sent to maintenance manager Lasse Tiikka at Transdev in Finland. Tiikka is also project manager for the eBus-project. Which is a project investigating many aspects of BEBs such as functionality in winter climate, TCO of BEBs and measurements of performance and range.

The interviewees could be categorized into three over-arching groups, people with a system overview, PTOs and people connected to technology and FMS-services, see table 3.1on page 18. As mentioned by Eisenhardt and Graebner (2007), the challenge with interviews is to find a sufficient number of knowledgeable informants who can view the phenomena and give focus from diverse perspectives. This has been done by interviewing people from the three areas mentioned above. However, it would be valuable to have the opportunity to interview more subjects in order to gain an even wider perspective and more security regarding reliability in the results. E.g. we could have interviewed more PTOs, more bus manufacturers or more people connected to research about EVs, which was hoped for. Although, without positive responses from the asked subjects. There is also a risk connected to the diverse group of interviewees that the understanding of the phenomena would too shallow. We were aware of this risk, and the tight co-operation with the commissioning companies and the questionnaire was a way for us to amend this risk. However, this also constitutes a risk of influence, that we have inherited their view, after five months of tight co-operation with the commissioning companies. In the following chapters of the report the interviewees will be referred to by their surname.

Name, Role	**Company**	**Description**
System Overview		
Lars Annerberg, Industry developer	the Swedish bus & coach federation	Knowledge of Swedish public bus transport, has worked with raising the awareness of electric buses within the industry. Questions were asked around the current situation within Swedish public bus transport.
David Bauner, Industry Researcher	KTH	Has performed previous research on EVs using industrial dynamics theory. Questions related both to the academia and industry regarding the technological transition.
Development manager	UL	Understanding of the division of ownership between PTOs and PTAs. Questions connected to influences that affect PTAs, the relation to PTOs and PTA's view on BEBs.
PTOs		
Business developer	Transdev	Insights regarding the situation for how to motivate drivers of the buses. Questions covering operational issues connected to bus usage.
Coordinator bus drivers	Transdev	Understanding of how drivers experience driving an BEB. Questions regarding experiences of BEBs and issues connected to the new BEB buses.
Service Manager	Transdev	Knowledge about how to conduct maintenance on buses and how to set up maintenance schedules. Questions and discussion around maintenance for a BEB and important aspects of maintenance.
Fleet manager	Nobina	Experience and knowledge about the bus fleet, since responsible for it. Questions were asked regarding the market, the ownership of buses and their relation to FMS-services.
Fleet manager	Keolis	Experience and knowledge about the bus fleet, since responsible for it. Questions were asked regarding the market, the ownership of buses and their relation to FMS-services.
Technology		
Anders Lundström, Researcher EV-driving	KTH	Knowledge from the user perspective of driving and how to visualize eco-driving on EVs. Questions related to FMS services for EVs and barriers EV drivers meet.
Senior Business Developer	Hybricon	Valuable knowledge about BEB and how they handle the cold climate. Questions were asked about the standardization process for charging stations and issues connected to BEBs.
Design engineer	Hybricon	Knowledge about the components in the BEB and how these perform. Questions were asked around technical details such as charger, battery and bus performance.
Lars Ericsson, Supervisor	Fleetech	Insight into FMS services and the possibilities they include. Questions around the interface the between FMS services, the bus industry and the PTOs.

Table 3.1: Overview of conducted interviews

3.2.5 Questionnaire

Parallel to the semi-structured interviews a questionnaire was distributed to PTOs in Sweden. The goal with the questionnaire was two-fold.

First, its purpose was to map and triangulate data collected through the literature review and interviews. As multiple sources increase the validity of the data (Collis and Hussey, 2009).

Second, it worked as base for questions in further interviews. As mentioned in Collis and Hussey (2009), the questionnaire was used to collect further information and to gain insights from the cases in the sample. In particular those not yet covered in the interviews. In order to make sure that no important aspects were left out, when trying to interpret the phenomenon. If new data arose from the questionnaire results, this could be elaborated in the following interviews. The topics covered whether they were currently owning a BEB or not, what their experiences or expectations of BEBs, if they currently used FMS-services and which functionality was of importance in a BEB application.

By asking about the ownership of buses, we were interested in the PTO perception of BEBs compared to other types of bus types and what they see as advantages and disadvantages. This question was also asked to the PTOs not owning BEBs in order to understand their current view of BEBs. We then asked if they had plans on buying BEBs and if so, in approximately in how long time frame. They were also asked what are mainly affecting their choice.

In the second part we asked about the PTOs attitude towards FMS services and if they use it today. The we continued with asking what are the main reasons for using FMS services and if it is important that it would work on a BEB.

The respondents were selected in collaboration with the Swedish bus and coach federation. The PTOs chosen possessed a fleet of twenty public transport buses or more, resulting in twenty recipients among the member stock of the industry association. The questions formed treated earlier identified subjects with the aim of receiving data about how they are influenced by those subjects and to assess their needs.

By distributing the questionnaire electronically it enabled us to monitor the responses and also give direct reminders to those that had not answered. In total three reminders where sent.

The authors tried to carefully formulate the questions as to avoid any offset in the answers because of different personal experiences. However, this was a trade-off between writing open ended questions and simplifying the effort of answering, and therefore gaining a higher response rate. Therefore, check-box options were used in conjunction to the alternatives a ”other” field was used, which enabled support for full text answers. As mentioned by Blomkvist and Hallin (2015), it is good to test the survey before distributing it. Therefore, the survey was tested by both the authors, our academic supervisor and two employees at Fleetech in order to avoid any previously unnoticed pitfalls.

The questionnaire generated in a total of ten responses, equaling to a 50% response rate. Out of these ten respondents, three were interviewed. The PTOs that responded to the questionnaire together own 7696 buses, which equals to 59% of totally 13 105 commercial buses in Sweden in 2015 (The Swedish Bus and Coach Federation, 2016*b*).

3.2.6 Data analysis

The data gathered from the described processes above was categorized according to its theme, a method common in analyzing qualitative empirics (Blomkvist and Hallin, 2015).

For research question one, working documents were used to structure up for example perceived advantages and disadvantages linked to the BEB. In these, every data source was labeled with a heading each and bullets were made with either a + or a - sign depending on whether it was an advantage or a disadvantage for the BEB mentioned by the source. Then this document was continuously acting as a triangulation source for new information that was gathered through new interviews. This was done in small updates continuously and two times more comprehensively. The first time was before the questionnaire was formulated in order to provide ground for the suggestions in the check boxes and questions to ask. Then a second round to finalize the respondent results together with the results from the interviews and documentation studies. The barriers were then extracted and sorted into the topics concerning the new technology and topics concerning the operation of BEBs, as presented in chapter 5. The barriers gathered were then discussed as to their impact. Follow-up questions regarding unclear aspects were asked to the interviewees, in cases that were deemed necessary.

Parallel to the work with research question one, research question two was investigated through discussions with the commissioning companies and the interviews later conducted.

3.3 Validity, reliability and generalizability

The major risk in this project was that the scope stretched beyond what was viable within the limitations of a master thesis. As an effect of this, another risk was also that it is hard to draw any conclusions from scattered questionnaire results with low response-rate. Therefore the questionnaire was given another purpose, of data triangulation and capturing various insights or thoughts. It was important to define specific areas that were going to be investigated. This increased the probability of receiving sufficient amount of answers from the questionnaire. There was also a risk during the literature review that it is hard to ensure reliable data. To minimize this risk, information triangulation via different sources was used and our findings were repeatedly discussed with Fleetech and Transdev in order to create an opportunity for feedback during this process.

Gibbert et al. (2008) discusses how to accomplish "scientific rigor" in a case study. This covers how reliability and validity is ascertained. They have analyzed all management-related articles between 1995-2001 published in the top ten renowned management journals. This, to find out how they have managed to ascertain scientific rigor and how scientific rigor has developed by focusing on *"... internal validity, construct validity, external validity, and reliability* (Gibbert et al., 2008, p. 1466). They developed a framework to assist in future applications, which was used in the ongoing thesis work, as described below.

Internal validity reflects how one analyzes the data and whether logical conclusions are being drawn between variables and phenomena. This was performed by conducting discussions in-between ourselves and with the commissioning companies. The conclusions drawn were further verified during the coming interviews. Construct validity reflects whether the studied subject is actually being studied, which can be more accurate if one presents a clear process and justifies and argues for the things being studied. Also source-triangulation can be used to further increase construct validity (Gibbert et al., 2008). Which has been the goal of this chapter.

External validity could be resembled as generalizability, how easy drawn conclusions can be applied to similar or other applications. By using multiple sources during our analysis, the validity could be increased and our comprehension and understanding of the phenomena deepened. A prerequisite for increasing generalizability (Collis and Hussey, 2009). The variants of validity depend of each-other and external validity requires the presence of the other, which is why we have used triangulation extensively.

3.4 Summary

This research was based mainly on semi-structured interviews with bus operators, fleet management service providers and experts within the electric bus technology field. By discerning the stakeholders and interviewing different sources, the aim was to cover a broader spectrum of aspects and through this generate valid and reliable research results. By formulating open questions the knowledge collected gained in validity. The questionnaire substantiated the empirics gathered from the literature review and interviews. By applying this method we aim to ensure the validity of the master thesis findings and provide a solid foundation for future supplementation in this field.

In the following chapter the electric bus industry context will be presented. It is followed by empirics gathered together with an analysis with help of the theoretical framework formed in the Literature review chapter that will carry an elaboration addressing the research questions.

Chapter 4

Electric vehicle technology & Swedish public bus transport

This chapter presents an overview of the market and the bus industry. First it describes the industrial context surrounding the public transport bus. Secondly, the components and their strengths and weaknesses are discussed in order to understand the changes in the technological shift to BEBs. Third, the actors on the market and their corresponding influences and incentives towards change are discussed. Finally, the role of FMS-services in the TT is described.

4.1 Electric vehicles

The BEBs are currently making their sought by the public, albeit slow, entrance on the Swedish public transport sector. Although the sight of them is rare, they are a popular element in the public transport sector. During the interview with Lundström, he concluded that the public transport has a good basis to an electrification of the fleets, due to their fixed routes. The routes are planned in advance and static, unlike personal electric vehicles that are used more spontaneously in comparison. The common assumption of limited range, presenting a barrier for personal electric vehicles could for a public transport bus, with planning and preparation, be minimized.

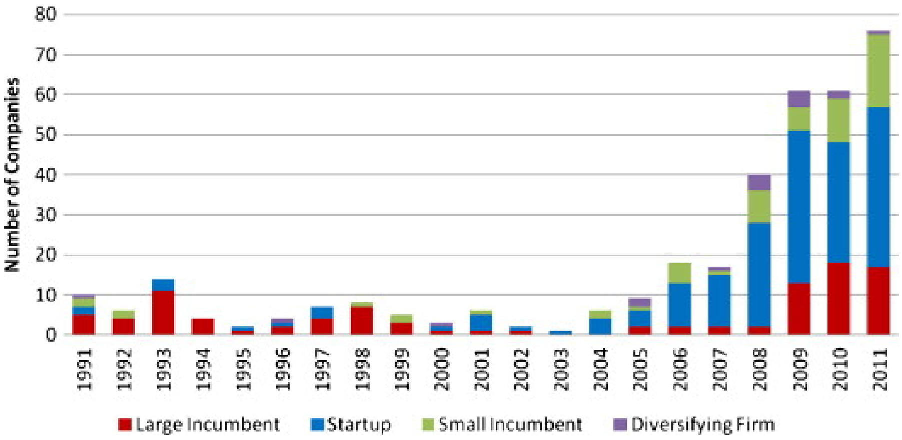
Due to the complexity of the public transport sector, with several stakeholders, we have identified the ones to be most central regarding the public bus transport sector. By first reviewing the history of the electric vehicle research we have put together a notion of whether the society seriously is going towards an electrified fleet. Then by diving into the current state of the art regarding public electric buses we have gained deeper understanding of the technology. The increased knowledge together with a screening of the public transport sector has enabled us to establish several aspects that might present barriers for the public transport operators. By further exploring the current FMS-services offering and learning the technical design aspects we have been able to illuminate opportunities with which public transport operators and FMS-service providers could create synergies.

4.1.1 Earlier electric vehicle research

The electrification of public transport started back in the late 19th century when the development of several new technologies ignited a transition towards a new transport paradigm, replacing horse-drawn carriages (Geels, 2005). The International Association of Public Transport (UITP) was formed back in 1885 when the 50 main tramway operators in Europe came together (UITP, 2014). At their first congress in Berlin 1886 one of the most important questions for the association was on how to handle the transition from horse-drawn carriages to electric trams (Ericson, 2014; Eliassen, 2015; The Swedish Bus and Coach Federation and BIL Sweden, 2014). The electric motors could carry the trams uphill, generate a higher speed, lowered the cost and eliminated the problem with horse manure (Geels, 2005). Geels (2005) investigated this fluid period from 1860 to 1930 in the American society more in detail. He explains how the concurrent development of gasoline, steam and electric cars acted as successors of horse carriages using a MLP-approach. Furthermore, he discussed how the pressures such as urbanization, parkway movement and growth of entertainment society at landscape level created an de-alignment of a the socio-technical transport regime, creating an window of opportunity for new solutions (Geels, 2005).

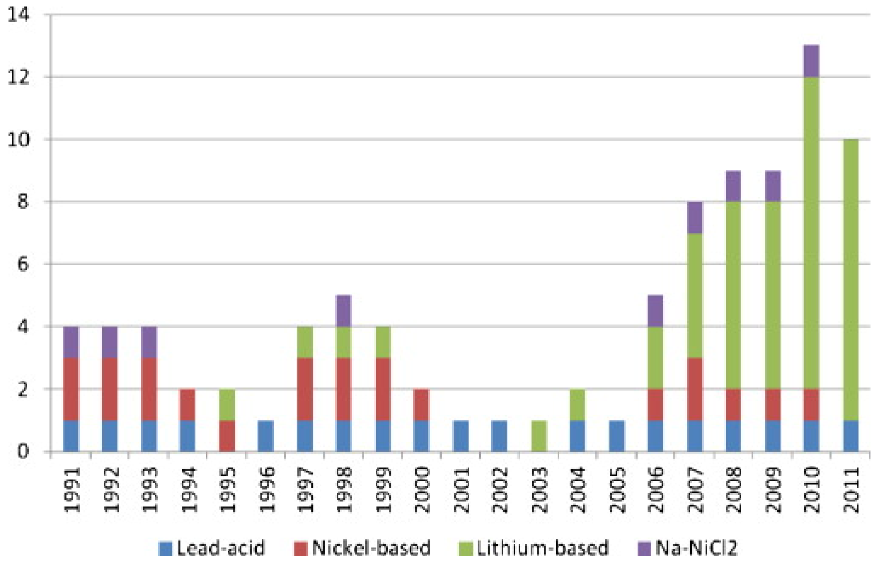
However, the ICEV emerged as the dominant automobile design (Geels, 2005) and the ID have generated a lock-in effect for the ICEV regime since then (Sierzchula, 2014).

The development of electric transport experienced a rather passive period until its second upswing in the 90's. The increased interest of EV's was primarily an effect of the California Zero Emissions Vehicle (ZEV) mandate where production of electric vehicles was enforced (Sierzchula et al., 2012*a*). For some years, this raised the attention for electric vehicles, although the initiative was not positively received from the large auto makers and after challenging it in court 2001, the attention once again decreased (Wells Bedsworth and Taylor, 2007) in (Sierzchula et al., 2012*a*). The development continued mainly for hybrid vehicles and with smaller companies during the coming years (Sierzchula et al., 2012*a*), please see figure 4.1. As can be seen in the figure 4.1, the number of companies kept rather small until around the shift of the century where it started to increase. The latest increase in number of companies could possibly be explained with the rapid decrease in price of Lithium-ion batteries (Nykvist and Nilsson, 2015*a*). The change of battery technology could be seen in figure 4.2, where the focus has shifted from the 90's nickel-based batteries to Lithium-based in the later years.



Increase in EV companies

Figure 4.1: Number of companies producing electric vehicles, source: Sierzchula et al. (2012*a*)



Change in unique battery chemistries

Figure 4.2: Unique battery chemistries in electric vehicle models, source Sierzchula et al. (2012*a*)

Pohl and Yarime (2012) conducted a case study to investigate the pioneering position that Japan earned in the new attraction for BEV's and HEV's during the years around 2005. The three main car producers in Japan; Toyota, Honda and Nissan managed to focus on creating fuel efficient cars that could meet the new strict demands in the US (Pohl and Yarime, 2012; Bauner, 2010). The period from 2005 onwards until today could be seen as a third wave of renewed interest for electric vehicles, mainly conventional HEV's (McKinsey & Company, 2014). The interest is powered mainly by the acceptance of Japanese HEV's such as Toyota Prius, lowered battery prices and increased belief in the new technology (Pohl and Yarime, 2012; Nykvist and Nilsson, 2015*a*). In 2009, several automakers had announced plans to introduce BEVs and plug in HEV's, Pohl and Yarime (2012) describe the situation as a fluid phase where several solutions and technologies where competing. More recently, McKinsey & Company (2014) in their European outlook concludes that "...Europe has gone through the initial adoption phase of electric mobility" and that a clearer view regarding actors and technology has emerged. The sales numbers of EV's are still relatively low and Norway is the front-runner with 6.2% of total car sales made from EV's in 2013 (McKinsey & Company, 2014). The Netherlands has the second largest market and France, Germany, and the UK have small markets but with high growth rates (McKinsey & Company, 2014). Other studies highlight the development in other European countries such as Belgium, Denmark, Austria and Portugal (Weeda et al., 2012), Asian countries such as India, Japan, China and South Korea (Andreasson et al., 2013; Weeda et al., 2012) and the US in the Americas (Lee and Lovellette, 2011; Weeda et al., 2012). Where Germany, South Korea and China focus the most on R&D and Norway and Austria has has the most developed public charging infrastructure (Weeda et al., 2012).

4.1.2 Battery electric buses

Currently public BEBs are a rare sight in the Swedish public transport, except a few, present in various pilot projects across the country, as mentioned in section 1.1.2. The manufacturers represented are mainly from Europe, represented by Volvo, VDL, Hybricon and Optare. Also China is represented with BYD, a Chinese electric bus manufacturer that has had a great success with their buses, with over 6000 sold buses world-wide by year 2015 (BYD, 2016). These volumes are due to generous subsidiaries in China, which enabled an early start (Daily, 2012). The European bus manufacturers have not yet had the same breakthrough, most of them have only had prototypes running in test-projects since 1-2 years. The technology used in BEBs differs between manufacturers. From the interviews with PTOs and literature we have concluded that the BEBs represented in Sweden are divided into two distinct solutions. Buses with large battery packs that have relatively long range and are slow to charge, or buses with small battery-packs with low range, dependent on fast opportunity-charging. The buses with large battery-packs utilize battery technology that is favorably priced, but with lower capacity per weight ratio. The buses relying on opportunity-charging, use more expensive batteries that can withstand higher charging currents and higher amount of wear/usage. With the combustion engine and gas tank gone the manufacturers have had more flexibility in forming the interior, due to larger degree of freedom when placing battery-packs and various electric motor driving electronics. According to the interviewees pricing of all-electric public transport buses is higher than the ICE counterpart by a factor of about two, although research shows that the total cost of ownership (TCO) is lower (Pihlatie et al., 2014). These calculations do further not include other benefits, such as almost zero emissions and low noise, requirements that may be mandatory in the not so distant future as EU regulations may become more firm.

Below is a brief description of the key components distinguishing an electric bus from its predecessors, which has come up during the education day, observations at the manufacturer, internal documents and from meetings with specialist.

Driveline

The driveline of an electric bus consists of electric motors coupled to the wheels, either directly or through a gearbox. The possibility of having a direct coupling of the motor to the wheels is due to the large amount of torque an electric motor is able to output from standstill. The advantages with these solutions is that fewer parts and less complexity lead to less maintenance or parts that could break. The technology of electric motors is seen as mature, the motors have been used in vehicles and in the industry for over hundred years as mentioned in section 4.1.1. Cities in Europe have had trolleybuses, trams and trains in traffic for the whole 20th century, thus acting as a driver for electric motor development and refining.

Although, a future challenge is the risen demand in rare earth materials used in the motors, that might increase the prices . Active development and research is investigation other, substitute materials. (Bourzac, 2011)

Due to the electric motors being able to deliver high torque from start, this entirely removes the need for idling, making an electric bus silent at standstill.

There are several benefits of using motors for propulsion as they can be used the other way around, as generators, by converting kinetic energy to electricity which is fed back to batteries. The electric drives have an efficiency of 85-95%, about three to four times the efficiency of combustion engines (Bourzac, 2013). An important note to mention is that the aforementioned efficiency only takes the efficiency of the motor into account, thus charger efficiency (about 90-95%) and the origin of the electricity must be evaluated. E.g. the efficiency of coal power plants is about 30-40% and hydropowerplants about 80%.

By using regenerative braking instead of mechanical brakes manufacturers estimate the range of a bus to increase by 30%, as described during the education day in Stockholm (section 3.2.3), often range estimations by manufacturers assume that regeneration is enabled. When using regeneration the buses can be slowed down without any use of mechanical brake (to standstill is not yet available), thus considerable brake wear is avoided, resulting in less maintenance and lower servicing costs. We have observed that the amount of regenerative power force that is used and how easily it is customizable varies between manufacturers. The majority engage regenerative braking proportionally to the release of the gas pedal (similar effect as of engine braking on ICE vehicles), the amount is in some buses predefined (programmed) and in some buses adjustable with a lever by the driver. Solutions also exist where the regenerative braking also is coupled with the brake pedal, and the mechanical brakes only are applied during hard braking or when stopping.

Conventional ICE are comprised of many moving parts which require maintenance, and add complexity. The electric motors with only a few bearings that need replacing need considerably less maintenance, which was mentioned by Björk. A PTO mentioned that there is a possibility that electric buses in the future will be seen as more comparable to trams or trains, where the life-time expectancy is several decades, with minor interior and exterior upgrades. The drivelines used in the electric buses represented in Sweden are often built into modules, where an axle module contains both the motor or motors and its driving electronics.

Winter climate

Due to the efficiency of electric buses, there is not much excess heat that can be recycled and used for interior heating of the bus. This is noticeable when the ambient temperature goes near or below zero degrees Celsius. Most BEBs used in Swedish pilot projects have used some sort of combination of electric heaters and auxiliary heater solutions, to maintain a comfortable passenger and driver compartment temperatures during cold weather. Many auxiliary heaters are fuel operated, thus releasing pollutants. The ability to maintain a acceptable temperature without having to start the auxiliary heater varies a lot. Some buses have to start it already at 5 degrees Celsius, while other buses can manage without until 20 degrees below freezing, according to Björk. The large differences are dependent on bus compartment isolation and the trade-off between how much battery energy should be used for propulsion versus heating (Tiikkaja, 2014). Other techniques utilized to further improve efficiency is the use of heat pumps or air curtains at the doors, which Hybricon has utilized according to Björk.

4.1.3 Battery technology

Batteries used in electric vehicles consist of several electrochemical cells that are coupled in parallel and series to form a battery with a specific voltage and capacity. Depending on the battery technology used the cells have a different voltage (V) and energy storage capacity, ampere hours (Ah). The amount of current a battery maximally should be charged or discharged with is defined as C or C-rate. The C-rate is a ratio in ampere (A) of the total battery capacity in Ah. For example a battery with the capacity 100Ah, with a recommended max charge current of 1C is ought to be charged with a maximum of 100 ampere. The higher the C-rate, the faster the battery can be charged. The battery level is defined as state of charge (SOC) and how much the battery is discharged is called Depth of Discharge (DOD). (Buchmann, 2016*e*)

Batteries used in combustible vehicles have for a long time been of lead-acid type, their main function has been to supply the starter motor with power during short bursts, when starting, and to supply the various vehicle equipped accessories with electricity. Lead-acid batteries should not be discharge to less than 50% of their rated capacity. From a lead-acid battery with 100Ah capacity only 50Ah should be withdrawn, otherwise the battery might be damaged, resulting in capacity reduction. (Buchmann, 2016*a*)

The lead-acid technology has been improved with different technologies to increase the battery lifetime and utilization rate as well as charging receptivity, although the technology has fallen behind new Lithium-ion technology. Lithium-ion is a collection of battery technologies, where Lithium ions move from the negative electrode to the positive, example of such technologies are Lithium cobalt oxide, Lithium iron phosphate, Lithium ion manganese oxide and Lithium titanate.

Battery life-time is defined as how many times it can be cycled, the number of full charge to discharge cycles before any significant capacity loss, industry practice is often 80% of initial capacity. Commonly with these battery technologies is that a battery should not be operated outside of its respective operating temperature, be overcharged or discharged too low, otherwise the battery takes damage. In the case of lead-acid batteries this results in permanent capacity reduction, in the case of Lithium-ion batteries they might be rendered inoperable, where even some of the batteries with Lithium-ion technologies might catch on fire or explode. (Buchmann, 2016*c*)

To prevent these disastrous incidents and ensure maximized battery life-time, Lithium-ion batteries are equipped with electronics, battery management systems (BMS), that monitor and control both charge and discharge of a battery. The BMS monitors each cell voltage in the battery. During charge and discharge of the battery the cell charge and discharge rate differs a bit. This can result in unbalanced cells, where one cell might be below or above the recommended value, while the other are within the recommended specification, resulting in a correct average battery voltage value, but a situation where this one cell is prone to serious damage. The BMS can during these occurrences disconnect the individual cells or actively direct more charging current to individual cells, until all of the cells have the same SOC, this process is called cell balancing. Another function of the BMS is to control heating and cooling of cells and estimation of available range. (Buchmann, 2016*b*)

Below is a summary of a selected variety of Lithium battery chemistries that are currently used in commercial electric buses, this is a brief overview of their core characteristics, drawbacks and advantages. When comparing battery technologies it is common to compare the energy per weight ratio, Wh/kg, higher numbers are better. Also depending on the usage cycle life is important, the cycle life is very dependent on ambient temperatures, current input and output and DOD. The lower the DOD the higher the cycle life, this is also applicable to SOC, for example if a Lithium-ion battery that is charged to only 90% and discharged to 30% gets a considerably increased amount of life cycles. An interviewee stated that a European manufacturer recommends to only utilize the range 40 to 60% of the battery SOC, thereby considerably increasing the lifetime of a battery.

The battery cycle count is directly affecting the durability of the bus. E.g. a BEB with a LFP battery only utilizing over-night charging may expect a life-time of about 8 years (bus utilized five days a week for 2000 cycles), while a BEB with a LTO battery charging 10 times a day may have an expected lifetime of about 3 years (bus utilized five days a week for 7000 cycles). The presented examples can not be compared, but give an illustration in how the cycle life affects the lifetime. In order to be able to correctly compare options the current battery price, route design and utilization rate must be determined. Due to the prices of Lithium batteries varying and constantly decreasing those are not presented in this thesis.

An important note is that the presented values below only are approximations weighted from different sources, each technology has variation and specialty cells with differentiated characteristics, the values below values can be used as an assessment of differences between the technologies. Another note worth mentioning is that it generally is not recommended to charge Lithium-ion batteries during degrees below zero, due to negative impact on durability and capacity, the manufacturers have solved this problem by actively heating or insulating the batteries. During cold temperature both the battery capacity and the amount of currents allowed is lowered. Thus the BEB range during winter can be expected to decrease. Further, the function of regenerative braking is lowered because the batteries do not withstand high charging current when below freezing. (Bullis, 2011)

Lithium cobalt oxide (LCO)

This battery technology is very common in consumer electronics, mobiles, laptops or cameras. It has a high energy density of 150-200Wh/kg, 500-1000 cycles and should be charged with maximum 1C. Lithium cobalt oxide batteries are prone to thermal runaway (may catch on fire) if exposed to temperatures above 150 degrees Celsius or overcharged. (Buchmann, 2016*d*)

Lithium manganese oxide (LMO)

Lithium manganese batteries are a lower energy density, 100-150Wh/kg, but can be charged with up to 3C with a cycle life of 300-700 cycles. These batteries are used in small electric vehicles and medical devices. The thermal runaway occurs at approximately 250 degrees Celsius or if overcharged. (Buchmann, 2016*d*)

Lithium nickel manganese cobalt oxide (NMC)

These batteries have a somewhat higher energy density, 150-220Wh/kg, and can endure 1000-2000 cycles. Charging above 1C shortens battery life, thermal runaway occurs at 210 degrees Celsius or if subjected to high currents. Used in EVs, e-bikes and medical devices. (Buchmann, 2016*d*)

Lithium iron phosphate (LFP)

This battery technology is considered as a safe technology. The energy density is low, 90-120Wh/kg, and accepts a charging current of 1C. The thermal runaway is 270 degrees Celsius and still safe if fully charged. Used in both portable and stationary applications, popular amongst electric buses with large battery-packs and over-night charging. The cycle life is 1000-2000 cycles, although bus manufacturers claim 4000-8000 cycles, depending on current withdrawal strain, charged and discharged voltage. (Buchmann, 2016*d*)

Lithium nickel cobalt aluminum oxide (NCA)

A battery technology with high energy density, 200-260Wh/kg, typically charged with 3C. Cycle life is 500 cycles, dependent on DOD and temperature. At high charge considered as prone to thermal runaway, also at 150 degrees Celsius. Used in medical devices, EVs (Tesla). (Buchmann, 2016*d*)

Lithium-titanate oxide (LTO)

The Lithium-titanate technology has an advantage of withstanding higher charging (5-6C) and discharging currents, but having low energy density, 70-80Wh/kg. A distinct characteristic is the ability to charge at degrees below zero. The cycle life is 3000-7000, bus manufacturers claim 20000 cycles. Used in EVs (Mitsubishi i-MiEV, Honda Fit EV). Due to high charging currents possible it need active cooling at high C-rates. (Buchmann, 2016*d*)

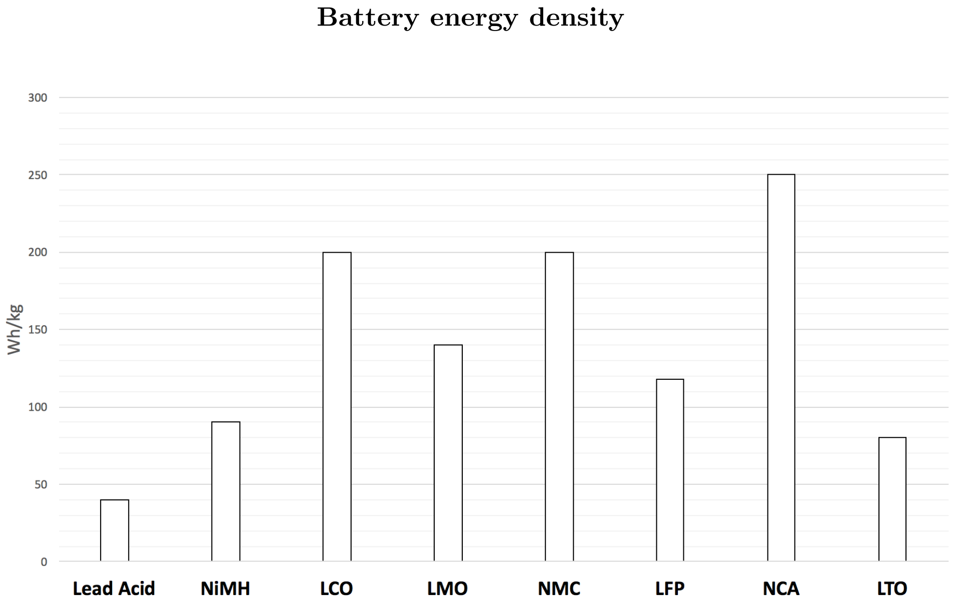


Figure 4.3: Comparison of energy density of different battery technologies, source: Buchmann (2016*d*)

BEB charging

There are several types of charging infrastructure regarding electric vehicles, the most common ones is with a charger connected to the electric grid. Chargers and charging techniques vary in current output, how much energy per period of time that can be transferred to the vehicle battery. The higher the charging current the faster the vehicle battery can be charged, the charging can occur when the bus is not in use, so called over-night charging or during use, so called opportunity charging.

Over night chargers are often low output chargers that are cheaper but are allocated by one vehicle for a longer period of time. If applied on a bus fleet, where most of the buses are stationary during night hours, this means one charger per vehicle. These chargers are able to typically output 400V at 63A and are suited for batteries that do not handle high charging currents well. The charging time is long 4-8 hours, making it impractical to charge during the day. The chargers are operated manually, a person has to connect a cable between the charger and the bus. (Doug, 2015) A scenario where this type of charger could be used during the day is when a bus is en route during the morning and evening, during high demand, and is parked at the depot during midday. Then a bus can be partially charged for a couple of hours prior to the afternoon shift.

During opportunity charging, chargers with higher current output are able to charge a battery quicker, in the range of 3-10 minutes. These chargers are designed as charging stations where the charging procedure is automated. The charging can be either conductive or inductive. Conductive chargers supply current through a pantograph on the roof of the bus. Inductive chargers work by inducing current into coils mounted on the bus, which can be mounted either on the roof or underneath the bus. Inductive chargers may be installed beneath the roadway, making an almost invisible charger possible. The opportunity charging process is automated and very high currents can be transferred. Recently several large enterprises, Siemens, ABB and Heliox, agreed on an open interface for opportunity charging, together with European bus manufacturers Irizar, Solaris, VDL and Volvo. (ABB, 2016)

Opportunity chargers can be placed either on end stops of bus routes, where the bus driver often has a break scheduled, making the charging time unobtrusive. The chargers could also be placed closer to the city core where several bus routes cross, one charger could be utilized by several buses, making a more cost effective solution but create longer bus stops.

4.2 Swedish Public Bus Transport

In the following section the Swedish public bus transport sector is presented. The PTAs and PTOs are described followed by todays generation of public transport buses.

Currently the greatest part of the Swedish public transport sector consists of buses driven by combustion engines, mostly operated on diesel, followed by Bio-gas and ethanol. These buses are according to the general public considered as noisy, stinky and not environmentally friendly. As the population in cities grow, and get more densely populated, with increased amount of traffic the regulations and guidelines in the cities strive towards preventing sources of air pollutants and noise. EU has commenced an initiative, ”Horizon 2020”, which constitutes that the public transport should strive to be resource efficient and decrease its impact on the environment, which it's member countries are beginning to embrace. (Commission, 2016)

Since 1st of January 2012 a new law in Sweden was introduced that regulates the public transport. It is based on the EU public transport regulation, which governs how society can assure public transport and its standard, which commercial transport may not offer. The instances responsible in assuring public transport in Sweden are regional PTAs. These can be represented by either a municipality or a county, consisting of several municipalities. (Regeringskansliet, 2010) The public transport traffic is in turn procured from commercial PTOs or operated in-house through municipal companies, the procurement process is rigorous and highly regulated by contracts. Due to the expected lifetime of ICE buses, of 10-12 years, the larger scale procurements are done in 10-12 year intervals.

During a procurement of public transport traffic, there are several aspects/rules/criteria that control the process. Besides the most influential characteristics as price, working conditions etc., according to todays Swedish guidelines procured public traffic services should strive toward being powered by renewable fuels, where the most common are RME, HVO, Bio-ethanol or CNG and electricity only being represented by small pilot projects or by hybrid buses combining electricity with one of the mentioned fuels. The requirements different PTAs determines before the procurement process varies depending on several factors. (Landsting, 2016)

A PTO that has won the procurement process and been chosen to operate traffic in a region/municipality has several deliverables. It has to assure that it is following the schedule, assures customer satisfaction and does not cancel scheduled buses. If any of these measures are unmet or missed, fines are issued by the PTA which can accumulate over a year, it has happened that they have accumulated up to 100 millions SEK. (Bussmagasinet, 2014)

Together with the environmental restrictions, public opinion and technological advancements regarding electric vehicles there has emerged a electric public transport sector. The public is requesting the arrival of silent public transport buses free from pollution and smog, especially in larger cities with high population. Therefore PTAs together with PTO, as mentioned in section 1.1.2 have initiated pilot projects with the intention of exploring the possibilities and the do-ability in commencing a larger transition towards all-electric buses.

4.2.1 Public Transport Operators

There are approximately 800 PTOs in Sweden of various size, where the largest 20 companies are representing 80% of total public bus transport kilometers. Each day they transport hundreds of thousands of passengers in Sweden. (The Swedish Bus and Coach Federation, 2016*b*)

According to the interviewees, depending on the PTA the PTOs either own their own buses or are charged with operating buses provided by the PTA. In both cases the PTOs are responsible for servicing and maintaining the bus. To perform maintenance of parking buses depots are used, these are either provided by the PTAs or need to be acquired by the PTOs. The PTOs employ own mechanics at their sites, who maintain and service the buses. The share of public bus traffic in a city or municipality a PTO is responsible for varies a lot. Some municipalities tend to procure services for all public transport services as one package, resulting in one PTO in a whole municipality. Other PTAs procure the public transport in segments with overlapping periods, resulting in smaller packages. There are also occurrences of PTAs owning their PTO.

4.2.2 Public Transport Buses

The interviewed PTOs mentioned that public transport buses are mostly comprised of subsystems developed and manufactured by other companies. Thus each of the main systems on a bus is working independently from each other. Many of the bus brands on the market share the same manufacturer of brake systems, air suspension, chairs, wheel hubs, heaters, air conditioners etc. The interior of a bus, specifically the accessibility, is regulated by the PTAs during procurement. Various dimensions such as length between seats or width of the isle is predefined. Due to PTAs sometimes having separate requirements regarding interior-specific characteristics, e.g. amount of wheel-chair enabled seats and various seat configurations, time has to be allocated for new buses to be configured. The most common course of action for PTOs is to procure new buses after each new public transport procurement, except when the buses are owned by the PTA.

The manufacturers of buses are often primarily manufacturers of heavy trucks where the volume of manufactured trucks is smaller than the volume of trucks. 307,000 heavy vehicles were produced year 2014. About 20% of the heavy vehicles comprised of buses, making it a relatively small share compared to trucks. (International council on clean transportation, 2014) The most common buses used in the Swedish public transport are made by Volvo, Mercedes-Benz, Scania, MAN, Setra, Solaris and VDL. Of those Volvo, Mercedes-Benz, Scania, MAN and Setra are truck manufacturers or are subsidiaries to one.

An occurrence with buses is that they break down, either due to a collision or due to a component failure. These occurrences are expensive, a back-up bus and driver must be put-in, an occurred delay may result in fines and towing of heavy vehicles is expensive. The reason for buses breaking down and needing to be repaired is mainly due to faulty accessories that the bus is equipped with or driveline. Accessories such as ticket machines or the entrance doors are often seen as the culprit, much more so than the driveline, according to the interviewed PTOs.

Buses currently utilized are buses with diesel engines, but fueled with fossil-free fuels. According to the interviewees the diesel engine technology is old, well proven and the competence in their construction is widespread. When diesel buses were fueled with diesel they were very reliable, one engine could last the whole bus life-time (10-12 years). Due to the usage of fossil-free fuels, which can power diesel engines with minor modification, the life-time decreased. Nowadays, according to a interviewed PTO, it is not unusual that public transport operators include an engine replacement when setting a budget.

There are several aspects regarding the cost of bus ownership. There are initial costs for procuring a bus, which for electric buses are higher than combustion engine buses. This is highly dependent on required infrastructure, the infrastructure for ICE buses is already in place or inexpensive to set up. The variable cost, fuel costs and maintenance, is highly dependent on the driver behavior and vehicle servicing. A driver can affect the fuel consumption by 20-40% depending on the driving behavior. (Rohani, 2012) The average fuel consumption for diesel powered buses is around 3-5 liters per 10 km, corresponding to about 36-60 SEK per 10 km (depending on volume-specific prices, 11SEK/L used here). The average consumption of electric buses is 8-12kWh per 10 km which corresponds to about 8-12 SEK per 10 km (if calculating with the price 1SEK/kWh).

4.3 Fleet management systems

Due to the large amount of buses the PTOs are in possession of, for the larger public operators ranging from about 50 buses to 2500 (The Swedish Bus and Coach Federation, 2016*b*), it has been vital to incorporate and use fleet management systems, according to the questionnaire 80% of the PTOs utilize FMS-services. Fleet management systems serve as an IT aid, processing large amount of data with the purpose of facilitating the operation, planning and control of large fleets of vehicles. The first fleet management systems fulfilled only basic functionality that replaced tables on paper that was handled manually. As the development of IT services and electronic hardware went on the systems acquired more functionality. There is a variety of functionality these systems fulfill, the functionality that is of primary concern in this thesis are systems covering and analyzing how the buses are being operated when in traffic. That are logging and telematically reporting information to the transport operators, which with real-time data can make quick and informed decisions, both during acute incidents and for long term planning. The FMS-support services aid the operator in the daily operations of the vehicles, e.g. supply geographical position, communicate with drivers, catch Alco-lock alerts, catch critical engine diagnostic trouble codes (DTC) etc.

4.3.1 FMS-support systems

Public transport operators utilizing FMS-support systems have telematic units (TU) installed in each vehicle. Common TUs on the market are equipped with positioning electronics, mobile networking, vehicle specific network interfaces and several inputs and outputs. In a reference TU installation the TU is connected to the bus power supply, and connected to the vehicle network (Controller Area Network, CAN, this report does not cover the technical details specific to a vehicle network), in which most of the modules present in a vehicle communicate with each other. By connecting to the vehicle network the TU can listen to messages broad-casted by several modules and on-board computers with only one connection, e.g. the engine module for DTCs, the instrument cluster module for the mileage data or the wheel speed sensors for the vehicle speed. The additional inputs and outputs a TU can be equipped with can be connected to auxiliary after-market accessories operators equip the buses with, e.g. Alco-lock, ticket-systems, passenger counters, auxiliary heaters or temperature sensors. The TU can also be connected to a screen that can be mounted in front of the driver on the dashboard, showing driver specific information, e.g. Eco-driving performance or broad-casted messages from the depot. This enables real-time feedback to the driver without him having to let his hands off the wheel.

In the following sections is a brief overview of the different aspects concerning a FMS-support service and various common functionalities that may be implemented and are available on the market.

Platform independent

Larger bus manufacturers offer to supply their own fleet management systems, often originating from their heavy trucks department, that may be integrated in the vehicle systems in various degrees. These systems are tailor-made to the specific vehicle model. These systems are often extensive with a lot of functionality due to the ability to handle proprietary information (messages that only the manufacturer can interpret) from the network. Public transport operators divide their vehicle purchasing from several manufacturers, due to risk and dependability reduction. A subscription and purchase of a FMS-support system from each manufacturer that is represented in a public transport operators fleet would become very expensive and difficult to manage. Therefore most PTOs purchase third-party solutions that are independent of the vehicle manufacturer, thus having a uniform system across the whole fleet with only one interface to their in-house FMS. The advantage of this is that it brings costs down, you only have one supplier of the system and only need one system to manage. But this might also have a lock-in effect where you are dependent on your FMS-support supplier hardware and software.

The largest truck and bus manufacturers in Europe have come up with a standard that regulates access to the information contained on the network in the vehicle, called the FMS-standard. It stipulates the identifiers and messages present on the bus that should be made available to third-parties and the physical properties of the connector. Not all manufacturers supply a FMS-gateway, but there are third-party gateways that can read the networks of various manufacturers and pass that information along. The purpose of a FMS-gateway is to only pass through predefined messages, as defined in the FMS-standard. Another function is that it is isolated from the electrical wiring of the network, therefore it is not possible to send messages on the bus network, thus possibly manipulating the bus, which could be potentially fatal. Therefore FMS-gateways should be used according to the manufacturers installation recommendations, to not void any warranties.

Eco-driving

From an economical point of view there are several benefits of Eco-driving, less vehicle wear, lower energy consumption and higher passenger comfort. Drivers usually participate in mandatory courses teaching correct driving techniques when employed. Studies have shown that the Eco-driving technique courses show a decrease in fuel consumption for heavy vehicles, although the effect decays after some months, resulting in no long term effects. The effects from Eco-driving training can be maintained by regularly occurring training courses or feedback to drivers. The drivers are represented by various individuals, simplified by those who want to be bus drivers and those who do not, with the whole spectrum in between. (Kujala and Lundberg, 2013)

The bus drivers who are proud of their profession, happy with their job and enjoy being bus drivers, are often very interested in developing their driving skills. This group often appreciates the guidance and feedback from Eco-driving courses and are pushing themselves in improving their skill and perfecting the customer comfort.

Then there are drivers not as interested in Eco-driving or customer comfort. This group not showing interest in improving their driving skill has shown to be a culprit in the strive for less wear, lower energy consumption and customer satisfaction.

Transport operators with interest in solving the varying effort amongst the drivers, have implemented various bonus systems. The drivers Eco-driving performance is monitored and evaluated and depending on the results, the drivers are given a monetary bonus added to the salary. Monetary incentive is a widespread instrument to increase performance, effectively affecting those, who lack interest.

The TUs installed in the vehicles monitor the driver behavior, according to several performance indexes, and feedbacks this information directly to the driver via a screen. With the direct feedback a driver can himself or herself learn how to improve, by spot behavior that is affecting the performance negatively and positively. The performance is also relayed to the back-offices collecting the statistics for processing. The common technique of driving Eco-friendly with vehicles equipped with combustible engines is to plan the journey and to have foresight, avoid having to make hard brake-ins and constantly conserve kinematic energy. (International council on clean transportation, 2015) The technique is the same for electric vehicles. The higher the acceleration of a electric vehicle the higher the currents and energy consumed, leading to heat losses in the drive-line, and wear on the battery. Due to the batteries wearing of high current draw a slow acceleration to desired velocity is preferable. In theory the acceleration should be as low as possible, although a driver should mind near traffic, keep the traffic rhythm, due to not slowing down other traffic. Although there is regenerative braking only part of the kinetic energy is recuperated, about 80%, thus it is more energy effective to let the vehicle coast for as long distances as possible.

Safety alarm

For the safety of the drivers the operators equip the buses with personal alarms. Drivers are able to notify their support personnel or security personnel if a hostile situation occurs.

Tachograph data

When a fleet becomes large a lot of planning/scheduling of maintenance is necessary. Vehicles are often put into servicing on a mileage basis, therefore it is of interest to be able to remotely download driven distance data to facilitate scheduling maintenance of vehicles and their components.

Positioning

Public transport operators have staff that is monitoring traffic around the clock, actively rectifying unforeseen delays or disruptions. To be able to detect delays or to re-route traffic positioning of vehicles is used.

Comfort temperature

During winter periods the buses need to be heated before the start of a shift. Both for passenger comfort, but also due to bus driver working environment, which is regulated by law. The exact inner bus temperature may not be below 5 degrees Celsius at the start of a shift, or else the driver should not drive. This has led to the inner temperature being monitored so that workers can start the auxiliary heater, which may also be done remotely through a TU.

Alco-lock

Installed Alco-locks in vehicles are often required by the public bus authorities. The Alco-lock prevent drivers to drive off in buses under influence. To early discover incidents where drivers attempt to drive under influence or possible delay due to unplanned driver change it is of interest for support staff to receive these messages telematically.

Remote-diagnostics

The bus drivers drive several different buses during a shift. They do not have the opportunity of getting to know and learn their vehicle, how it sounds or how it behaves on the road. Thus they cannot identify emerging faults that risk growing and resulting in more expensive damages. Also due to the often stressful shifts, it is easy for a driver to overlook that a dial is not within a correct interval or that a small red light, cramped next to several other, is lit indicating a possible major breakdown. Each unplanned stop leads to high fines, and expensive towing. With an automated system monitoring service it is possible to detect arosen DTCs and by other means alert the driver, etc. by phone of a problem, to quickly be able to mitigate the issue.

4.4 Summary

This section has provided a brief overview of the earlier research within electric vehicles. It has further given a basic introduction to a BEB and the state of the art of the key technologies used. The Swedish public transport sector and its interfaces has been explained to be able to assess and identify barriers of this technological shift and how those influence the PTOs and their FMS-service suppliers. In the next chapter identified barriers are presented and discussed from the perspective of our chosen framework.

Chapter 5

Barriers against adoption of Battery electric buses

The purpose of this chapter is to identify the perceived barriers among the industry actors and link these to the theoretical framework. It serves as a good base for PTOs to understand what the technological transition implies for them. It will answer research question one: "What barriers among public transport operators hinder the technological transition towards a battery electric bus?". This is done by first giving a short overview of attitudes among the questionnaire respondents in section 5.1. Second, by summarizing the barriers in section 5.2 and describing them in detail in section 5.3 and 5.4. Third, in section 5.5, by discussing the status of the market and by looking deeper into the barriers we have identified three reverse salients. The analysis is continued in chapter 6, where the second research question is answered and the opportunities for FMS-services to facilitate the barriers are discussed.

5.1 Attitudes towards BEBs among the questionnaire respondents

The results from the questionnaire shows that it is currently a wide spectrum of attitudes towards BEBs. Different PTOs have varying experiences of buses, although, most of them have plans to buy a BEB in the future. The questionnaire had a response rate of 50% (10 out of 20 respondents answered). Among these, five where owning BEBs today and planned to buy more, four did not own any today, but were planning to buy. One did not own today and did not plan to buy it the in future. The PTOs that responded to the questionnaire together own 7696 buses (which equals to 59% of total 13,105 commercial buses in Sweden in 2015 (The Swedish Bus and Coach Federation, 2016*b*)). Noticeable is also that all PTOs BEBs today aim at buying additional electric buses in the future. Out of the nine respondents aiming at buying BEBs, four aim at buying more within less than two years time, three within two to four years and two within four to eight years. No one selected more than eight years. The variation in attitude has also been apparent in the interviews conducted with the PTOs.

Among the BEB owners, all stated lower environmental impact, quieter operation and higher energy efficiency as advantages compared to other power-trains. Moreover, 80% chose goodwill among PTAs and customers, 60% rated that less maintenance was an advantage. Finally, 40% stated that passenger comfort was an advantage compared to other power-trains. In addition to this, one respondent mentioned that the depreciation time should be longer as an effect of the technology used in the buses. The same respondent linked BEBs to possible similarities with trams, which have an depreciation time of 25-35 years, compared to todays 10-12 years. Another respondent mentioned the possibility of better and more efficient interior-planning in the BEBs, as an effect of not using the ICE power-train.

Among the respondents not owning BEBs, all stated that goodwill, lower environmental impact and more quiet operations were seen as advantages compared to other power-trains. 80% considered energy efficiency as an advantage and 60% picked less maintenance and passenger comfort. Lower TCO was seen as an advantage among 40% of the respondents not owning BEBs.

5.2 Summarized mapping of perceived barriers

The context of the market and current situation is complex, as described in chapter 4. In this report, the transport industry and more specifically the public transport bus sector is studied. Its done by viewing the sector as an LTS and socio-technical system, where many socio-technical factors are included and the interplay between society and technology is investigated. This has previously been made many times within the academic literature (Kaijser, 2005; Hillman and Sandén, 2008; Sandén and Hillman, 2011; Geels, 2005; Nykvist and Nilsson, 2015*b*; Wikström et al., 2014). In the previous chapter 4.2, the components and artifacts were discussed. Here, the BEB has been viewed as an innovation trying to become a system within a LTS, the transportation regime.

The data in this chapter is the result from the questionnaire sent out to the PTOs, the interviews and also secondary data such as reports from pilot-projects, observations, academic papers, research papers and websites. The perceived barriers have been identified by looking at the system goal of transporting people in a manner that is environmentally friendly, sustainable and economically efficient. The framework in chapter 2.7 is used to categorize the barriers into the three levels in the MLP-theory; landscape level, regime level and niche level. This in order to understand their relationships, which corresponds to the names of the rows in table 5.1. Since many barriers appear on more than one level, they are divided whether they are component related (section 5.3) or linked to managerial aspects of the BEBs (section 5.4), hence the name of the columns in table 5.1. In the section 5.3 and 5.4, every perceived barrier is discussed more in-depth.

Barriers mapped to the theoretical framework

	Component barriers	**Managerial barriers**
Landscape	None	Lack of knowledge and experience Behavioral change Economy Ownership of infrastructure and buses Business models Varying requirements from PTAs
Regime	Variation in solutions and lack of technical standards Unknown functionality in cold climate Reliability Durability	Lack of knowledge and experience Behavioral change Economy Maintenance Ownership of infrastructure and buses Business models Varying requirements from PTAs
Niche	Variation in solutions and lack of technical standards Charging infrastructure Shorter range or decreased load capacity Unknown functionality in cold climate Reliability Durability	Lack of knowledge and experience Economy Maintenance

Table 5.1: Barriers mapped to the theoretical framework

5.3 Component barriers

In this section, the perceived barriers linked to the components of a BEB will be described. Further in section 5.4, the barriers linked to the managerial aspects of the BEB will be covered. The barriers in this section relate to the components and technical limitations of the hardware, software and various technical design issues. The barriers covered in this section are: Variation in solutions and lack of technical standards (5.3.1), Charging infrastructure (5.3.2), Shorter range or decreased load capacity (5.3.3), Unknown functionality in cold climate (5.3.4), Reliability (5.3.5) and Durability (5.3.6).

5.3.1 Variation in solutions and lack of technical standards

Currently there are several variations of electric technologies aspiring to change the transportation paradigm, as mentioned previous in this report. This includes variations among different powertrains and also variations of the same powertrain. Which also entails variations in the BEB solutions. For BEBs the main concern is the battery technology and charging infrastructure, as mentioned in chapter 4 Electric vehicle technology & Swedish public bus transport. The current solutions that exist are overnight charging (slow charge) or opportunity charging (with charging stations along the route or at the end stations). Both solutions involve different charging and battery solutions and there is an ongoing discussion among the actors in the market in which solution to embrace. In the questionnaire, among the PTOs not owning a BEB, the lack of technical standards has the lowest frequency when they rated disadvantages of BEBs compared to other powertrains, only 20% considered it a disadvantage. However, among the PTOs owning a BEB, 60% saw the lack of technical standards as a disadvantage. This problem is also frequently mentioned in our interviews with both PTOs, the PTA, Bauner and Annerberg. During the interview, the senior business developer at the bus manufacturer Hybricon mentioned that infrastructure companies such as ABB and Siemens are working on this issue and that standards for an open charging interface for opportunity charging is coming this fall (also mentioned in chapter 4 and in Maasing (2016)). When the questionnaire respondents where given a chance to answer the question whether they think there are big differences among the bus manufacturers, six out of ten respondents answered "Yes", three answered "No", "Don't know" or "Both". One respondent specifically mentioned that the big difference is regarding which charging solution to use.

There are a few BEBs on the market today, thus the market is still very young, as mentioned in chapter 4. In the interview with the development manager at the PTA UL, the lack of commercial articulated BEBs has stopped them from investing in BEBs before, and they are now instead prepared to consider to engage in pilot projects since they want to get involved in the development of electric buses. This has also been mentioned by the PTOs, where some have focused on conducting pilot projects to gain more experience, while others have taken a passive role in observing the market development. The pilot-projects have mostly been conducted together as joint projects with PTOs, educational institutions, municipalities and BEB manufacturers.

There is also a lack of technical standards, more specifically considering the message definitions in the BEB vehicle networks related to EV-technology. This was realized during the BYD education day in Stockholm, the interviews at Hybricon and after contact with the Society of Automotive Engineers (SAE) standard institute regarding their standard SAE J1939. The communication between the charger and the bus, charging voltage levels and the charging interface were also mentioned during the interviews at Hybricon.

The variation in solutions and lack of standards form barriers at two levels of the MLP framework, regime and niche. At regime level, the barrier is the co-operation among the regime actors, the need to define new standards in order to choose viable technical product which satisfies the market demands without the risk of manufacturer lock-in that currently distances some of the PTOs and PTAs. At niche level, the technological maturity of the products needs to be increased and meet the agreed standards.

5.3.2 Charging infrastructure

The charging infrastructure topic has an important role for the future of BEBs, as it involves many different possible modes of operation. Charging at night only, or on end stations or along the route, thus is seen as a technological barrier. It could be argued though, that the battery would have the same characteristics, however we argue, that the different battery technologies only consider different materials and the battery-size the BEB should be equipped with. The charging infrastructure barrier originates from the choice of battery technology and the uncertainty regarding charging solutions, which is an important question to answer for an increased BEB adoption.

The charging infrastructure in the depots is according to 50% of the questionnaire respondents a large investment that is needed. Among all respondents, 60% see the charging infrastructure as a disadvantage compared to other powertrains.

The uncertainty regarding the charging infrastructure configuration is mainly apparent on a niche level. The lack of standards today together with the variety of solutions create an uncertainty and hesitation amongst the market actors. However, the process of standardization is ongoing, as mentioned in section 4.1.3. In order to be a fully viable option, further testing is needed on the component level. In section 5.4.5 the charging infrastructure will be elaborated more around uncertainty over ownership. This will cover how the charging infrastructure in this way show up on more levels in the theoretical framework.

5.3.3 Shorter range or decreased load capacity

There is a term commonly called "range anxiety", often mentioned as a problem with BEV utilization. Lundström has covered this problem in detail for BEVs and mentioned during the interview that it is closely linked to what the research community calls "the guess-o-meter". The difficulty in estimating the available distance left. According to Lundström, the range anxiety is higher among drivers not used to EVs, as they get experienced in driving the vehicle, they tend to worry less about it. He links it to a lack of experience of how the driving style affects the energy consumption. Moreover, there is a trade-off between range, speed, use of air conditioning and driving style. This trade-off is evident in BEVs since there is a lack of range over-capacity, which is not as apparent in ICEVs. With ICEVs most drivers seldom drive the car with less than half tank fuel, according to Lundström. Regarding BEBs, Bauner explained that this issue gains in importance regarding payload, the compromise of range versus passenger capacity, which the PTOs have to consider. By oversizing the battery, energy consumption and price increases, and passenger capacity decreases. The trade-off is further implicated by the importance of trying to increase the relative battery cycle-life, by utilizing a smaller SOC range of the battery. E.g Lundström mentioned that Volvo recommends their buses to stay within 60% and 40% of SOC in order to preserve battery life. An advantage of using larger batteries when charging is the lower temperature variation, as larger batteries heat up less and have a larger thermal area for conductivity, compared to small batteries.

So, even though the bus-driver are not affected by the trouble of "range anxiety" directly, this is currently an issue for the PTOs and PTAs in the design-phase and dimensioning of bus routes. Due to the rather low experience of electric buses, the PTOs use the BEBs on distances shorter than specified by the manufacturers (battery overcapacity). However, there is an example where a PTO in Copenhagen during a demo found out that they could drive a longer distance than they first had prepared for (The Swedish Bus and Coach Federation and BIL Sweden, 2014). With the increase of experience on how the different external factors affect the energy consumption, the routes could be more optimized with less safety margin. Worth to mention, is that there always has to be a capacity margin to be able to handle unexpected situations such as e.g. traffic jams (The Swedish Bus and Coach Federation and BIL Sweden, 2013) and that not operating the BEB on SOC from 100 down to 0 % every charge cycle is beneficial for the battery health.

In the questionnaire, the shorter range of BEBs was most frequently chosen as a disadvantage compared to other powertrains. All of the respondents considered this a disadvantage. The operator that currently do not plan to buy BEBs in the future, responded that shorter range was one of four major factors influencing them not to buy BEBs.

BEBs are heavier than conventional ICEV buses (The Swedish Bus and Coach Federation and BIL Sweden, 2013) and among companies considering other solutions this is often mentioned as one of the major disadvantages of the BEB (The Swedish Bus and Coach Federation and BIL Sweden, 2014). A project website about road-electrification state that one of two big issues with BEVs is the low energy density of current battery technology (Elways, 2011).

These issues form barriers at the niche level in the MLP framework. The problem regarding shorter range can be directly linked to the battery. The barrier is formed as an effect of the current development of the energy capacity and price of this component.

5.3.4 Unknown functionality in cold climate

In the Nordic countries, the issue with operations in cold climate has risen as an important topic. As mentioned in chapter 4, pilot- and research-projects have investigated the topic in more detail. Lundström mentioned in the interview that it is important not to forget about the winter climate and refers to the doctoral thesis by Wikström (2015), where the operation of BEVs in winter climate affected the range drastically. In her thesis she quote a project called Rekkevidde that state that EV energy consumption goes up by as much as 50% during winter conditions, unfortunately, we have not been able to find this reference afterwards. The capacity of batteries decreases at low temperatures (The Swedish Bus and Coach Federation and BIL Sweden, 2013), which affects the range of the BEV. The range decrease has also been documented in other studies (energy and transport, 2012). As mentioned in chapter 4 Electric vehicle technology & Swedish public bus transport, the functionality of charging in low temperature, functionality of a pantograph covered in snow, and heating of BEBs might need more investigation. However, among the questionnaire respondents owning BEBs, only one respondent viewed it as an disadvantage compared to other powertrains. Interestingly, among the respondents not owning a BEB, 40% rated it as a disadvantage. This trend has been similar during the interviews with the PTOs, where the ones with more BEB experience, have less uncertainty regarding operation in cold climate.

These problems relate to the regime and niche levels in the MLP framework. On the regime level there is a need for more knowledge and experience in utilizing the BEBs in cold climate. At niche level, there will be gained experience and continued development, as new bus manufacturers enter and learn to develop products prepared for cold climate.

5.3.5 Reliability

The nature of the current status in the bus industry with many ongoing pilot projects, prototype products and rather low experience of BEBs raised the question about reliability of the BEB. As mentioned in chapter 4, the electric motor has been around for more than a century and is extensively researched and tested. However, in the context of a new system it raises some questions especially connected to the electric powertrain. This view is shared with the PTOs and bus manufacturers interviewed. When asked about reliability and operation faults, they state that there are very rare faults related to the electric powertrain alone. Faults are more often related to accessories, such as door-malfunctions or ticket-systems. However, since the BEBs as a system has been around for a rather short time the knowledge regarding the reliability for a BEB is still rather low. This is also expressed among the responses in the questionnaire, where 40% of the respondents (40% for both owners and non BEB owners each) count reliability as a disadvantage compared to other powertrains. This might show the lack of trust for the technology, even though the technology as such is old. The questions seem to circle around how to handle situations such as traffic jams, heating in cold climate or air conditioning systems linked to the capacity of the battery (The Swedish Bus and Coach Federation and BIL Sweden, 2013). Another issue raised in one of the interviews with a public transport operator is the increased risks for battery leakage and risks involved with working with high voltages.

The problems mentioned in this section link to the acceptance and knowledge of how to handle the new product, which therefore constiututes a barrier on regime level. The problems also form a barrier at niche level in the MLP theory, since there are some "prototype errors" that need to be sorted out, relating to specific components within the new BEBs.

5.3.6 Durability

There are conflicting opinions on the life expectancy of a BEB. One questionnaire respondent stated that the advantage of the BEBs compared to other powertrains was a longer estimated depreciation time, compared to other vehicle types. According to this respondent, BEBs could be compared to electric trams with up to 25 to 35 years of depreciation time. However, 60% of the BEB-owners and 60% of non-BEB-owners (second largest among both) see the BEB durability as a disadvantage compared to other powertrains. As mentioned in chapter 4 and the previous barrier section, the electric powertrain itself is a well tested technique and has the same or less amount of moving parts. Less parts in the transmission that could potentially break, as mentioned in the interview with the service manager at Transdev. Some BEBs also use hub-motors, which theoretically further eleminate this risk. The unsecurity is more frequently linked to the life expectancy of the batteries, as discussed in chapter 4. There is a trade-off in how much capacity (and weight) that should be carried around at the cost of passenger space and range, in order to be able to charge the battery at sufficiently low power levels. This, in order to maintain the best battery health possible relative to the number of charge cycles without a too big decrease in battery capacity. Furthermore, there is currently a uncertainty regarding how many cycles the batteries can handle.

This barrier could potentially open up for new opportunities for market actors, where bus manufacturers offer PTOs to lease the batteries, thus minimize risk for PTOs, while manufacturers take full responsibility for the battery service throughout the BEB life cycle. This has been up for discussion before, e.g. in a battery-swap-project for electric cars called "Better place" in the 90s as mentioned in the interview with by Bauner. However, this project was not successful and went bankrupt in 2013 (Reed, 2013).

The problem with uncertainty and durability form a barrier at the niche level in the MLP framework. It is specifically linked to the battery and the uncertainty of life expectancy of that specific component.

5.4 Managerial barriers

In this section, the perceived barriers linked to the managerial aspect of the BEB will be described. The barriers covered in this section are linked to the division of responsibility, operations/ownership and how to handle the new situations due tot the technological shift, for the industry actors. In section 5.3, the barriers linked to the components of the BEB are covered. The barriers covered in this section are; Lack of knowledge and experience (5.4.1), Behavioral change (5.4.2), Economy (5.4.3), Maintenance (5.4.4), Ownership of infrastructure and buses (5.4.5), Business models (5.4.6) and Varying requirements from PTAs (5.4.7).

5.4.1 Lack of knowledge and experience

Since BEBs are new on the Swedish market the experience and knowledge about them is still rather sparse and isolated among some manufacturers. The operators are still learning how to handle the vehicles and are starting to create an understanding of what to expect. PTOs were in the questionnaire specifically asked whether the lack of knowledge was preventing them from using BEBs or preventing them of using them to a larger extent. Seven out of ten respondents answered the question with "No" and two answered "Yes". One responded that they are in a "state of learning", with a knowledge threshold that is needed to be overcome among workshop personnel, bus drivers and other personnel. One respondent also added that according to them, the knowledge is available although the experience is lacking.

When purchasing BEBs, the need to educate the workshop personnel on the new systems is also explained more in detail in the interviews with PTOs. The eduction regards knowledge about high voltage circuits in the powertrain, new components and the different motors. How this is done varies among the PTOs interviewed. Either the bus manufacturer takes the full responsibility for maintenance of the bus, hence no need for education of in-house staff. However, some PTOs prefer to perform most of the maintenance themselves, especially to gain knowledge about the new technology. 60% of the non owners of BEBs of the questionnaire respondents saw the lack of knowledge as a disadvantage of BEBs compared to other powertrains.

Among the PTOs interviewed, most have a dedicated pool of bus drivers that are educated in driving the BEBs. Which certainly generates inflexibility in driver-scheduling as mentioned by one of the PTOs. The same goes for the workshop personnel where a the beginning only few of the mechanics receive education of new buses.

This barrier relates to all levels in the MLP framework. The knowledge and experience is greatly affected by developments and actions at European level, among many different actors within the bus sector. It is affected by long slow processes that need to change, it involves both actors and the public in order to arrive at a standardized version of what the future transport paradigm should look like. The lack of knowledge and experience form a barrier apparent at the landscape level. The actual co-operation between the regime actors such as manufacturers and PTOs needs to contribute with experience in order to make standardization possible, in order to overcome the current barrier at regime level. At niche level, components needs to be further developed into finalized products, to be able to meet the needs of the actors at regime level. This can be done either by continuing with conducting pilot projects or investing in more testing at the manufacturing companies.

5.4.2 Behavioral change

This barrier relates to many different actors, to those who plan the bus routes, the drivers and the procurement staff purchasing the buses.

When planning bus routes, the main change relates to the limitation in range and the time it takes to charge the batteries, whenever the plan is to do it. This includes the consideration if the BEB is planned to charge at a station mid-route, the longer duration of the stop, increases both travel time and increases the risk of traffic congestion (when waiting for the buses to charge). When linked to what is thought of in the current transport paradigm, this implies changes which at the beginning may cause planning to be less flexible. As mentioned in the range barrier, the "range anxiety" might also in the beginning affect the route planers.

For bus drivers the main difference in driving behavior is linked to regenerative braking and to the smaller margins in range, which is more affected by driving style. According to Lundström there is some confusion among new drivers of BEVs of how to interpret regenerative braking. The driver must not think that they gain energy by braking, it is still better to freewheel, than brake with regeneration enabled. This might be further confusing due to bus manufacturers implementing the regenerative braking in different manner, as mentioned in chapter 4. Furthermore, for some models this implies a change driving behavior, when the braking effect of regeneration might cause the bus to skid on slippery roads. The driving style has a larger influence on consumption, as mentioned by Lundström, implies a change in behavior and larger consideration about how to drive the bus.

For procurement officers, the procurement of BEBs would need tighter communication with the route planners in order to really understand their need, as they can not demand ”the same as usual”. Lundström says that one of the conclusions from the project ”BrukaELbil” was that getting used to, and accepting the BEVs, is as much about evaluation of one’s own needs as it is regarding a new technology. Annerberg arranged a trip to Hamburg with several participants and several employees at companies soon in position to be able to buy BEBs. He believed it had brought some new ideas and visualized how a PTA could act during BEB procurement.

In addition to this, a transition to BEBs also implies some changes for the bus passenger. The most commonly mentioned characteristic is the silent operation. This characteristic is often linked to EVs in general, where the silent operation might pose a risk for pedestrians not hearing the bus coming. Moreover, the silent operations allows other sounds from the bus parts to appear, which might be an unusual and annoying experience for the passengers (The Swedish Bus and Coach Federation and BIL Sweden, 2013). The silence might also not allow for private conversations due to everyone in the bus hearing.

The need to view public bus transport from a new perspective and maybe re-define what one expects from a transportation system, creates barriers at both landscape and regime level in the MLP framework. At landscape level, the public acceptance of what transportation is, and what to expect from it may be altered as the importance of densification of the cities raise new needs for cleaner and silenter buses able to drive in city centers and residential areas. At regime level, both the PTOs and the bus drivers need to adopt to the use of the new technology, according to new ways of planing routes, Eco-driving or maintenance.

5.4.3 Economy

The price of a product is an increasingly important aspect as the product enters the majority market (Moore, 2014*b*). The Total cost of ownership (TCO) has been a highly debated both in the academia and also among the interviewed PTOs. Rezvani et al. (2015) writes in their literature review about EV research that the high initial cost is often found as a barrier to adoption whereas *”the lower operational costs encourage EV adoption”* in comparison to ICE cars. In an evaluation of the TCO for a BEB, Pihlatie et al. (2014) concludes that as long as vehicle, charging infrastructure and new operating concepts are taken into consideration, electric buses can compete with a lower TCO compared to conventional traffic systems. However, Pihlatie et al. (2014) also add that their calculation assumes that the labor costs is the same, hence the number of buses and bus drivers in the fleet is not increased. If the number of buses and bus drivers would need to be increased, it would *”...kill the economy for the fully electric bus case.”* (Pihlatie et al., 2014, p. 4).

As with the interviewed PTOs, there seems to be an uncertainty regarding the input parameters when calculating the TCO of a BEB. This could be linked to the uncertainty in battery life, maintenance intervals and Reliability of the bus. One of the interviewed operators even mentioned that they would not be ready to place an order on 50 BEBs right now, due to these uncertainties.

Among the PTOs answering the questionnaire, 40% of the BEB owners and 40% of the non-BEB owners saw economics as a disadvantage (third most frequently picked among both groups) for the BEB compared to other powertrains. Only one respondent specifically mentioned the economy as an advantage for BEBs compared to other powertrains. Moreover, the respondent that where not planning to buy a BEB in the future stated that the economy of the BEBs was one out of four reasons for it.

Annerberg mentioned in the interview that there is an uncertainty in how the price of batteries will develop. He also refers to a pilot project under the name Greencharge at Blekinge tekniska högskola in Sweden where they calculated a lower TCO for a BEB compared to a bus powered by Bio-gas.

Bauner mentioned the importance of the second hand value and how it affects the current truck market. He investigated the topic as a part of his doctoral thesis and told that the truck has four ”life-cycles” where it first starts with the original owner and then is sold further in several iterations and ends up on a totally different market, with another purpose. On example he tells is that a truck might start in service as a distribution vehicle in Åmål, Sweden and ends up as a tanker in Abidjan on the Ivory coast. If the needs of the second hand market are not covered, it would affect the second hand value of the vehicle and in this manner also the initial value as it is based on an expected return on a second hand value. He knows this life-cycle considers also mini-buses and expect it to be the same for large buses.

Lundström mentioned in the interview that the barrier related to bus price, compared to only the costs directly linked to cars, is closely related to the reliability and risk of getting fines when the buses stops working, as discussed in chapter 4.

In the magazine eBus (two issues, one in 2013 and on in 2014, issued by the Swedish bus and coach federation), this debate has been widely covered. The advantages of BEBs mentioned have been; Low investments compared to electrified rail-bound traffic (such as trams), lower TCO compared to other solutions, lower maintenance costs and fuel costs generate lower operational costs, lower taxes (country specific), although, for a higher investment cost compared to other non-rail-bound traffic (The Swedish Bus and Coach Federation and BIL Sweden, 2013). One interviewed technician at Karlstadbuss specifically mentioned that the higher initial investment was made up by lower operational costs (The Swedish Bus and Coach Federation and BIL Sweden, 2014). There is also a discussion about how the economies of scale will affect BEBs. The discussions point at the recent decisions made by larger European cities, for example London, Paris, Hamburg and whole regions in the Netherlands where the have agreed to have either a fully fossil-free bus fleet to 2020 or that the whole bus fleet should be converted to electric buses by 2025 (The Swedish Bus and Coach Federation and BIL Sweden, 2014). These actions both raise the awareness about the BEB and might lower the price as an effect of increased production volumes, mentioned by Umberto Guida (project manager for the European project ZeEUS, Zero emission Urban Bus System) (The Swedish Bus and Coach Federation and BIL Sweden, 2014).

This barrier could be linked to all the levels in the MLP-theory. As mentioned in the beginning of this paragraph, the discussion about the uncertainty of the "business case" and TCO for the BEB is highly apparent among the PTOs at regime level. How the economy is influenced and dependent on both demand from the public, and their opinion. The public opinion is largely affected by shifts at landscape level, since it affects the requirements set by the PTAs. The shifts involves what to consider in calculations of BEB TCO, e.g. putting a price tag on environmental costs and noise levels? How well this technology is received by the public might affect of the price development of specific niche components, such as the battery.

5.4.4 Maintenance

As with the price, the maintenance of the product is an aspect that is important when moving from an early market towards a majority market (Moore, 2014*b*). In the interviews with the PTOs, there are currently different solutions, where the bus manufacturer take full responsibility for all maintenance and monitoring of bus health, to solutions where the PTOs let the bus manufacturer educate their own workshop personnel in order to perform that in-house. It is not unusual that maintenance is performed in different ways for different buses within the same company. All of the interviewed PTOs emphasize the goal to keep as much of the maintenance in-house as possible, in order to maintain the knowledge. However, this is met to various degrees as an effect of the different situations in the cities. As mentioned in The Swedish Bus and Coach Federation and BIL Sweden (2013), the change of the current transport paradigm is a system issue. The new components involved raise a question about who will conduct maintenance when high voltage levels are involved and risk for battery leakage gets more apparent than before. Here the PTOs have met the issue in different ways, some have educated all their workshop personnel and some a selected few that will focus on the new areas.

There is an ongoing process where the final form of maintenance starts to emerge. The maintenance barrier is comprised of two components, both the uncertainty about who will conduct the maintenance and the ongoing accumulation of knowledge in how maintenance should be performed for the different components involved. It is clear that it is a process of learning, which could be seen in the questionnaire. Among the respondents not owning a BEB, 40% mentioned the lower maintenance possibilities as an disadvantage compared to other powertrains. Whereas among the respondents owning a BEB none saw it as a disadvantage. When asked about if the expansion of maintenance networks for BEBs affects the respondents in choice of BEB manufacturer, 50% of the respondents answered that it did, 40% that it did not and 10% did not know. One of the respondents also added explicitly that they wanted the bus manufacturers to educate them to be able to perform maintenance themselves.

The two components of the maintenance barrier show on both niche and regime level in the MLP framework. Niche level as there is uncertainty regarding how the specific components should be maintained and on regime level as there are still questions regarding expectations on how the maintenance network will be formed.

5.4.5 Ownership of infrastructure and buses

The question regarding how the ownership structure will be formed is apparent for many different parts of the new transport solution, that needs to emerge in order for the BEB to be widely adopted. The first question is regarding who will own the new BEBs, as mentioned by the PTOs there are examples of PTAs and municipalities purchasing buses in pilot projects conducted in Sweden and in one occasion where the PTO has purchased buses themselves. So far, the municipalities and PTAs have been taking a lead position in investments in BEBs, absorbing some of the risks involved with an early technology. However, in the future when taking the step from pilot projects into full size contracts this situation will probably change.

The second large ownership question circles around who should take responsibility for and own the charging infrastructure. In The Swedish Bus and Coach Federation and BIL Sweden (2013) the uncertainty about the responsibility for charging infrastructure highlighted. Annerberg lifts this issue as the main bottle neck in the transition towards BEBs that need to be solved in order to gain a widespread adoption. He emphasizes that it is a question regarding who will own the charging stations and who owns the ground it stands on, which are not the same parties. As an example, he mentions that the charging stations would probably be owned by the PTA in Stockholm whereas the ground is owned by the municipality. He raises the question *"How should they manage their deal?"*. Moreover, he states that it should not be the PTOs that would need to by the infrastructure. This view is shared with Bojander at the Uppsala PTA (which in this individual case also represents the municipality). He also mentions that *"the PTA needs to consider the full picture of the traveler"* and raised the question about how the operators should be billed for the electricity needed; *"...should the energy companies place a electricity meter on each charging station?"*. These two ownership issues get further complicated if the buses are bound to work only in a specific type of infrastructure, as mentioned by one of the PTOs. Since it would not make sense to *"...be responsible for buses that you cannot use anywhere else"*.

When the PTOs were asked about their view on charging infrastructure investments needed in the questionnaire, one respondent added that the location of the depot in relation to the electric grid will be increasingly important for the TCO of a public bus transport system. Another respondent added that the uncertainty regarding the charging infrastructure is the main problem with BEBs. The respondent not planing to buy BEBs in the future also added the charging infrastructure as one out of four reasons for not purchasing. 60% of the respondents think that there is a need for large infrastructure investments in the depots and 40% answered that they did not think it would need large investments.

This barrier relates to two levels in the MLP framework, the regime and the landscape levels. The current transport regime and ownership structure need to be transformed in order to handle the new infrastructure. As the current transport regime is working, there is a need for tighter relations between PTOs, PTAs and municipalities in order to be able to build new infrastructure. At landscape level, this involves expectations on what the different roles for the different actors involved are and e.g. the role of electric suppliers might be similar to the constellation in the railway sector today.

5.4.6 Business models

This barrier is closely related to the ownership barrier. Linked to the ownership, there are two questions about how financing should be made and on how the new modes of operation and ownership would generate revenue for the actors. The researchers Tongur and Engwall (2014) has started to investigate the topic of how important a successful business model is in order to survive a technological shift. They based the article on a longitudinal case study of the automotive industry with focus on electric road systems for trucks. The topic is mentioned in the magazine The Swedish Bus and Coach Federation and BIL Sweden (2013) as an uncertainty regarding business models.

The first part of this barrier is about who will finance the different parts of the transition. As discussed in the previous barrier, the municipalities and PTAs have taken a lead role in the pilot projects in Sweden so far, to trigger the transition. They have supported the PTOs by absorbing all or parts of the financial risk involved, although this will probably not be possible if the BEB should gain traction in more than just pilot projects. Annerberg emphasizes the importance of tight co-operation between the actors in order to solve the ownership and responsibility of the charging infrastructure. This is something that should be solved between the municipality and the PTA. The new manufacturers of charging infrastructure, for example Siemens and ABB together with the electric distribution companies, for example Vattenfall and as Annerberg says, they use to state on conferences that *"We helped in the electrification of the railways at the start of the century and now its time for the road transports"*. However, as Bauner described, financing might be a large risk. He linked back to a battery-swap-project in the 1990s for electric cars called Better Place, that later went bankrupt in 2013 (Reed, 2013).

The second part of the barrier is the new situation with charging infrastructure and power distributors, that bring in new actors with new business models into the market. This brings up new questions such as; Should the infrastructure be offered together with the bus from the same company? Who should be the one deciding which solution to aim for? How will the new co-operations among the actors look like? Annerberg mentioned in the interview that in this new situation, the public bus transport sector transition, responsibilities have to be re-assigned. Until today, the common behavior has been to fill the tank, drive and then re-fuel when the fuel reaches a certain level. In a new electrified BEB regime, the system needs to be more optimized in order to not carry around to much extra load, since the same margins, as the PTOs previously have been used to, will be gone. The payload gets even more important than before. As mentioned under the previous barrier, Bojander raised the question regarding how the billing of electricity will be conducted, it might for example be made by mounting an electric meter on each charging station. However, he does not see the infrastructure investment with for example two end station chargers as a barrier, since it is a rather small investment compared to a complete system with several buses.

Moreover, Bojander mentions the focus of the different actors on the markets. The focus of the PTA is on being able to lower the price for the passenger and shorten the travel time as much as possible in order to attract more customers. Therefore they have to set monetary incentives for the PTOs that enhance these aspects. How to work with these issues change now when changing the buses to BEBs.

These issues mentioned form barriers on the landscape and regime level in the MLP-framework. It is apparent at landscape level as the change towards a BEB regime involves a change in how and what passengers and other actors use to include in the view of transportation. At regime level, new ownership structures and relationships need to be formed in order to be able to reach a successful BEB regime.

5.4.7 Varying requirements from PTAs

The structure of the road transport sector in Sweden is rather complex with variations among the regions, as discussed in chapter 4 the PTAs come in many different forms and set varying requirements. This could be seen in the questionnaire where one respondent specifically mentioned requirements from PTA as a reason for purchasing BEBs and the respondents that are not planing to buy BEBs stated the lack of this requirement as a reason for not purchasing. In the interviews with the PTA and the PTOs, the importance of the requirements in the contracts was mentioned, which is the most efficient way create incitements for PTOs to purchase BEBs. Hence, the lack of and variation of the requirements from the PTAs act as a barrier in the adoption of BEBs. One respondent specifically mentioned in the comment section of the questionnaire that:

> ”It is important that the PTAs do not set specific requirements and manage the means and instead focus on the goals in the tender documents, as it prevents both introduction of and possibilites for different bus sizes and fuel types, such as electricity.”

This was also mentioned during the interview with one of the PTOs, that the different situations for the PTAs and their earlier specific requirements on for example Bio-gas, has led to lock-ins. This has today resulted in a lot of capital bound to infrastructure for Bio-gas, which could have been used for electricity. Annerberg also emphasized during the interview that many of the larger regional procurements have been done in recent years, resulting in rather few large new regional procurements the coming years. There is also an ongoing discussion regarding a financial incentive system for electric buses, which was up for suggestion in the government budget. He added that it is important that this financial incentive system work on contracts already in effect, in order to gain best possible effect. The Swedish bus and coach federation together wrote a comment letter about these risks as a response to the proposed incentive system (The Swedish Bus and Coach Federation, 2016*a*).

The contracts span for rather long periods of time and are expensive to modify, as mentioned by Bojander. He added that it is a Catch-22, where the contracts affect the market for a long period time and might need modifications if new things emerge or if there is a need to shift to more environmentally friendly solutions.

During one of the interviews with a PTO, the interviewee mentioned that it is hard to know what is going to influence the requirements in the contracts in future. Especially with consideration to the large variations between different PTAs. Some PTAs own large parts of the bus fleet and depots, whereas some place the requirements on the PTOs to handle themselves. The PTAs owning buses or depots that have made large investments on certain types of fuel infrastructures are less flexible in changing to new fuel types since they have responsibility for old buses or infrastructure along the route or in the depots. For example, a PTA owning large parts of a infrastructure made for bio-gas, it is harder to switch to a fully elextric vehicle fleet since they are bound a lot of capital to the current infrastructure. On the other hand, there are examples of PTAs owning their own bus fleet, which make them more flexible. If the PTOs own the buses its harder for them to adapt to a contract that demands them to change their entire vehicle fleet.

Bojander also adds that the easiest way for a PTA to affect the market is through the contracts with the PTOs. Moreover, one important aspect that he mentioned was that one conclusion during the project called Utopia[1] (Urban Transport: options for Propulsion systems and instruments for analysis) was that buses are easiest to apply new technologies on and also the most visually appealing, hence a efficient way for municipalities to gain goodwill by investing in environmentally friendly technology. In an interview in the magazine The Swedish Bus and Coach Federation and BIL Sweden (2014), Umberto Guida (project manager for the European project ZeEUS, Zero emission Urban Bus System) stated that *"...everyone in the industry is learning day by day, but there is a also a need for education on political and agency level"*.

These issues form barriers at both landscape and regime level in the MLP framework. The ongoing change at the regime level demands new requirements in contracts issued by PTAs. Which, in turn are greatly affected by the environmental movement and influenced by regulations at European level (see section 4.2).

5.5 State of the market

After covering the barriers and their relation to the MLP framweork the situation within the industry will now be discussed. First by elaborating around the how the market is entering a state of variation (as described in section 2.5) and second, by discussing the underlying issues that if solved, could help the BEB to gain momentum in this transition.

5.5.1 The market is entering a state of variation

During the interviews with the different actors; PTOs, a PTA, a industry researchers and industry association, they all express that something is happening in the market right now. As one PTO mentioned, that the market is at its verge. There are many ongoing BEB pilot projects, as mentioned in chapter 4, although very few commercial operations. Several manufacturers are announcing that they will deliver BEBs in near future. In the questionnaire, most of the respondents aim at purchasing BEBs in a near future. As could be seen in Figure 5.1, the frequent use of diesel powered buses has been decreasing over the last years, which has allowed for other fuel types to increase in popularity. Some of them due to the simplicity of changing fuel type, by using the same engine (and bus) as before. What the figure indicates however, is that there is a general ongoing change of fuel in the bus sector.

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[1] http://www.transport-research.info/sites/default/files/project/documents/utopia.pdf

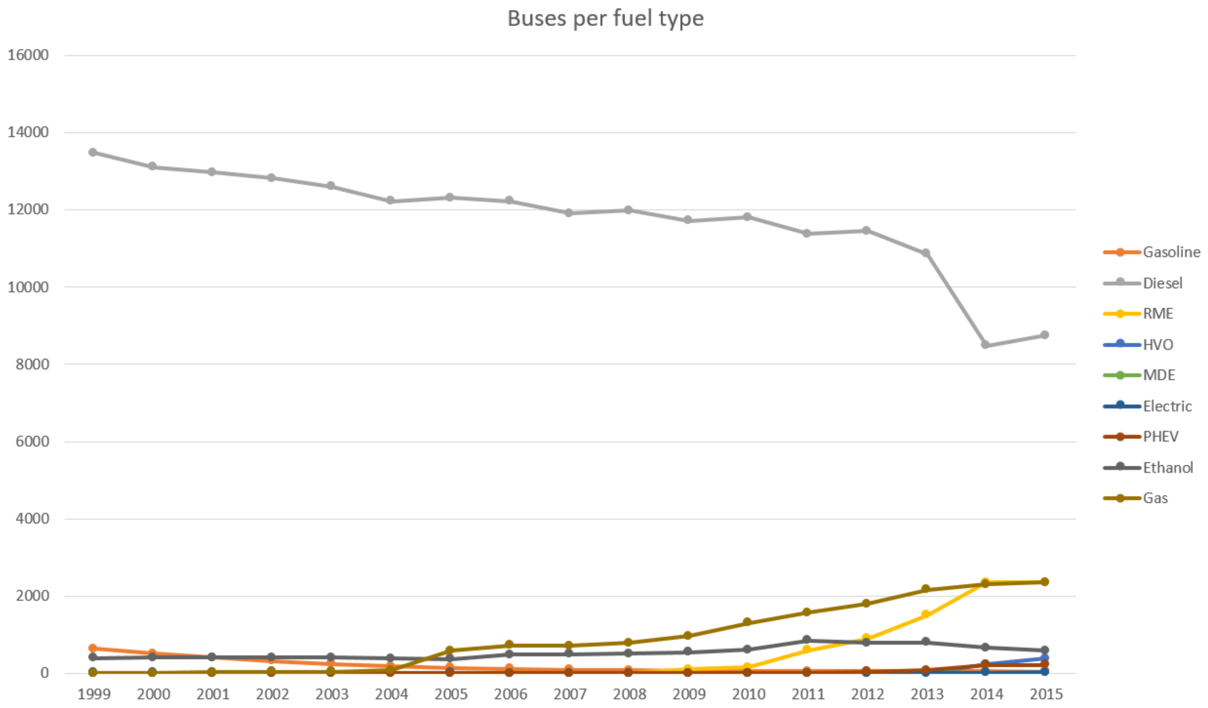

Figure 5.1: Buses per fuel type, data source: The Swedish Bus and Coach Federation (2016*b*)

The indicated change in fuel in combination with the expected upcoming change among the interviewees are according to us arguments for a situation where the current transportation regime is opening up, allowing for new innovations to compete. The market is in a "state of variation" (see section 2.5), where BEBs could be one of the new innovations to enter the transportation regime. When asked about whether the questionaire respondents saw the BEB market as mature, most of them answered that it is not, however four added that it soon will be. Since the current activity with pilot projects, ongoing standardization processes and recent market entries, the BEB could be argued to be at the early market trying to overcome the chasm. For the BEBs to be able to take part of the current transportation regime, they need to be able to satisfy the majority market (Moore, 2014*b*), the PTOs and PTAs. In order to be able to cross the chasm, some specific needs have to be satisfied regarding price of the product 5.4.3 and product functionalities linked to the whole product as mentioned in section 2.6. These functionalities are similar to the barriers such as maintainability 5.4.4 and reliability 5.3.5. If the BEBs could be formed into a whole product and overcome the current issues it would be able to enter the majority market and become a part of the current transportation regime. This was specifically mentioned by the PTA in Uppsala. They are currently waiting for a "final commercial product" (similar to the "whole product") of the BEB and if it would be available they would purchase it directly.

However, we want to remain humble regarding the future predictions, referring to Bauner who pointed out that it is very hard to predict future changes. He mentioned the doctoral thesis by Hans Fogelberg called *Electryfying visions. The Technopolitics of Electric Cars in California and Sweden During the 1990's* that looked in hindsight at how well the future predictions for electric cars in the 1990's were supposed to turned out. With the result that all previous predictions he investigated were wrong (Fogelberg, 2000).

5.5.2 The three identified reverse salients

Before continuing on how the FMS-service providers can aid the PTOs in the transition with the barriers, we are going to discuss the three reverse salients that could be linked to all the barriers in section 2.4. The three reverse salients identified are; the battery technology (and motor), the charging infrastructure and the contracts/ownership. Where each reverse salient is linked to several barriers. As with the barriers, the reverse salients link to several layers in the theoretical framework. The links between the barriers and the three reverse salients could be seen in Figure 5.2.

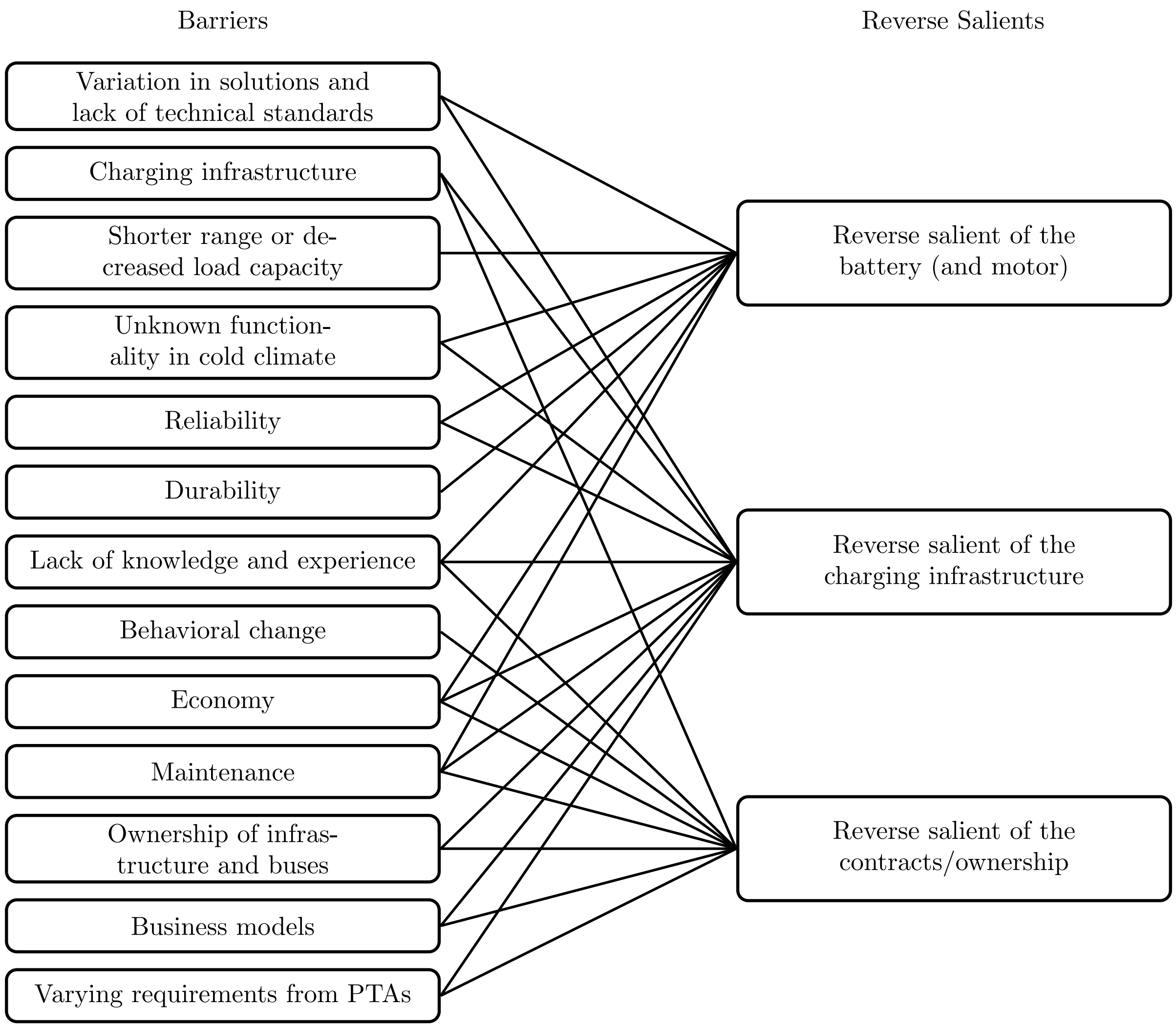

Figure 5.2: Links between the identified barriers and the three reverse salients

Below we present and discuss the three identified reverse salients that can help to categorize the barriers linked to them and further, aid the PTOs, PTAs and other industry actors in their understanding of the oncoming transition.

The reverse salient of battery technology

The battery technology, and to certain degrees also the electric motor, is one of the problems causing uncertainties among regime actors regarding variation in solutions, range, load capacity, winter functionality, reliability and durability. Among the operational barriers, there is a lack of knowledge as to how different battery technologies should be managed and their functionality in the long run. It also includes an uncertainty regarding the economy and maintainability of a BEB.

As presented earlier there are many types of batteries, and one could by interpret the battery, as a system component within a BEB that is lagging behind, thus representing a reverse salient (Hughes, 1992). The battery technologies covered in this thesis have been used widely in the industry, but the experience and knowledge about them in a BEB application is scarce and reserved to bus- and battery-manufacturers.

The two main BEB constellations, high capacity battery banks with slow charging and low capacity battery banks with fast charging, could be seen as two technical systems being being formed, due to economical and practical reasons. The solutions compete to some extent, in applications where the viability of the options is equal, where the difference in cost, performance and practicality is minimal. Regardless of which technical system being more superior there is an uncertainty of where the crossing-point is located. There is no distinct bound of when to use one charging/battery technology or the other. One can argue that there will never be, due to the amount of variations in the bus routes, but as knowledge and experience is expanded, the bounds, albeit diffuse, should be revealed.

This is mostly causing the barriers to appear at niche level since the issues regard specific development of the battery and motor components. The barriers on regime level that link to this reverse salient is more linked in how the regime actors (Hence, PTAs and PTOs) perceive these issues and how they need to adapt to them. At landscape level, this reverse salient is connected to the expectations that exist on the battery technology and how the public and policy relates to it.

The reverse salient of charging infrastructure

The charging infrastructure is a reverse salient and is causing uncertainties regarding technical standards, the charging infrastructure, functionality in cold climate and reliability. Among the operational barriers is the lack of knowledge in how to build the structure which is also affecting economy and maintainability. The ownership issue is an important question regarding the infrastructure, together with the business models and varying requirements barrier.

The charging infrastructure has been a topic covered by the interviewees as mentioned in section 5.3.2 and 5.4.5. There we concluded that the result of it being a barrier on niche level is due to the lack of standards and several technical solutions available with different progress. The charging infrastructure can be perceived as either a subcomponent of a LTS, i.e. the Public bus transport sector, or as a LTS of its own. As stated in section 2.3 Hughes (1987) states that artifacts can be analyzed as a system and as well as a component in an encircling system. The charging infrastructure progress today can be seen as a development of a LTS, where actions of systems builders (manufacturers of different charging solutions (innovations), e.g. Siemens, ABB, Heliox), are forming the system. Moreover, the bus manufacturers, by choosing the supported charging technology, *"...make important decisions aiding in competition and growth."* 2.3, thus further shaping the emerging LTS.

In order for the either of these innovations to prevail, there is another fulfillment, according to Hughes (1987) there is a need for individuals with political knowledge to solve problems regarding growth, expansion and momentum. The need for this has been confirmed by both Nykvist and Nilsson (2015*b*) and Wikström et al. (2014) as well as the interviewees.

Although as the above description seems sequential it is important to note that it is not. Hughes (1987) states that the phases of forming a LTS overlap and backtrack, thus the influence of FMS-service providers is of significance throughout the system development process.

At niche level, there are distinct issues that need to be solved regarding how the charging infrastructure should be designed regarding voltage levels, the interface between charger and bus and how it will be connected to the electricity grid. On regime level this relates to the co-operation that is needed among the regime actors and the standardization process of the interface with other components in the future transportation system. At landscape level, this reverse salient is very similar as to the reverse salient of battery and motor. It relates to how the public, actors in the industry and politicians view the transportation regime and what they see as included in the term "public transportation".

The reverse salient of contracts and ownership structures

The last reverse salient circles around the contracts and the ownership structures for BEBs and the charging infrastructure. As mentioned in both interviews and previously cited literature, there is a large uncertainty surrounding how this new situation should be solved. Even though the electric motor is an old invention there are many uncertainties regarding ownership and responsibility among the regime actors that need to be solved. Due to lack of knowledge and experience with owning large BEB fleets the PTOs are in front of a rough transition. The technological changes, various solutions and uncertainties regarding undertaking and utilization of BEBs, form barriers for PTOs in the approaching transition. For municipalites and PTAs the question lies in whether how ownership ans responsibility should be divided. This also directly relates to what aspects will be included in public trasnport contracts.

There are undoubtedly many actors that will have to be involved in order to solve the barriers linked to this reverse salient. On niche level this reverse salient regards how the contracts should be formed in the future and what future ownership would look like. At regime level these issues raise questions on how the responsibility should be divided among the regime actors. This reverse salient has many links to the landscape level and is at the core of understanding the new transportation industry shaping.

These three reverse salients are the most important areas to focus on especialy for PTOs in order to understand how they might be affected by the transition. Although, it is also interesting for PTAs, manufacturing companies and politicans in order to successfully handle a transition towards a new transportion regime where the BEBs are included.

5.6 Barriers as new business opportunities

It is tempting to focus on solving the reverse salients mentioned in the previous sections directly. In order to asses them, it could be a good idea for PTOs to collaborate with external parties, such as FMS-service providers. As Joerges (1988, p. 14) said *"Indeed, independent inventor-entrepreneurs could be shown to specialize in identifying critical problems and related reverse salients on broad technological fronts."*. FMS-service providers are to various extent acting at the technology-near level, thus the right actors for identifying critical problems resulting from reverse salients at niche level, where we have identified mostly component barriers. As Hughes (1987) said, the development of a large technical system begins and is mainly formed by the action of engineers and entrepreneurs. The FMS-service providers can therefore be seen as engineers and entrepreneurs, system builders, that by invention and development solve critical problems, resulting in innovation.

However, it is important to keep in mind that the reverse salients, through their barriers, are linked to all levels in the theoretical framework. To solve these, more actors need to be involved, not only the FMS service providers. One example might be the need to change the regulations in order to standardize the contracts and requirements from the PTAs, where other actors such as the politicians, PTAs and maybe the public opinion needs to be heard. Since the purpose of this thesis is to specifically look at the role of FMS-service providers in the context of this technological transition, we from now on, omit barrier where other actors are needed and focus on barriers where co-operation between PTOs and FMS-service providers is needed.

What the FMS-service providers can do, is to focus on the perceived barriers apparent at niche level. The perceived barriers can be seen as new business opportunities for companies within the technology industry that, are external to actors in the transportation regime. For FMS-service providers the barriers at niche level could be used in their process of identifying new business opportunities. Then, at a later stage, the usage might indirectly aid in generating knowledge among the regime actors. Which in turn, could be used to solve barriers at regime and landscape levels as well.

So instead of focusing on the reverse salients, in the following chapter 6, we leave the reverse salients behind and continue with how the barriers at niche level form new business opportunities for the FMS-service providers.

5.7 Summary

In this chapter the first research question has been answered. Thirteen perceived barriers among the industry actors have been identified, discussed and mapped to the theoretical framework. The barrriers were classified depending on whether they very linked specificaly to component aspects, or related to managerial aspects. Perceived barriers linked to the components of the BEBs are; Variation in solutions and lack of technical standards, Charging infrastructure, Shorter range or decreased load capacity, Unknown functionality in cold climate, Reliability and Durability. Perceived barriers linked to the managerial aspect of the BEBs are; Lack of knowledge and experience, Behavioral change, Economy, Maintenance, Ownership of infrastructure and buses, Business models and Varying requirements from PTAs.

Then, the market was discussed and concluded to be in a state of variation. Three reverse salients were identified, which if solved, would help the BEB in gaing acceptance among the PTOs, thus gaining momentum in the current transportation regime. The three identified reverse salients were; the battery technology, the charging infrastructure and the contracts/ownership.

The battery technology form the first reverse salient, relating to barriers such as range anxiety and reliability. It is mostly apparent at niche and regime level. At regime level it relates to how the regime actors perceive the components and their expectations on their reliability. The niche level issues are for example the development and reliability of the batteries.

The charging infrastructure is the second reverse salient that is linked to barriers such as standardization, lack of technological development and interface problems between different components in the new transportation system. It forms barriers at all levels in the theoretical framework and links to all actors. At landscape in how the perception of transportation would change. Regime level barriers focus in the co-operation between the regime actors and niche level involves the design of the whole charging system.

The last reverse salient regarding the issues concerning ownership and uncertainty of how the contracts should be formed. This is a present problem for many of the industry actors, at niche level it specifically relates to how to handle maintenance and how to design the contracts. On regime level it treats how responsibility should be divided among the regime actors. On landscape level it links to who should deliver the transportation services.

Finally, it was concluded that the FMS-service providers should not focus on the reverse salients, since they need collaboration among several industry actors. They should instead focus on solving the barriers at niche level in order to aid the PTOs in the technological transition of buses to BEBs.

Chapter 6

Fleet Management System-service opportunities

This chapter discusses the identified opportunities that origin from the Component and Managerial barriers, at niche level, that were identified in Chapter 5. We have chosen to view the barriers for PTOs as opportunities for FMS-service providers. Each niche opportunity is analyzed and discussed regarding to its benefit for PTOs in the public transport sector. The aim is to answer the second research question: "How can fleet management system services assist the public transport operators in this transition?". The feasibility and gain is assessed and insights arisen during the data gathering by the interviewees are accounted for.

The opportunities identified within the technological transition of the Swedish public bus transport sector have been identified as being of importance. We draw the conclusion that in this case, the identification of barriers and activity towards identifying opportunities is required for PTOs in order for them to prepare for increased BEB adoption and retain their competitive advantage. We argue that, the earlier the PTOs assess or prepare for the barriers, induced by the technological shift, the better their competitive advantage.

6.1 Opportunities linked to the Component barriers

The following opportunities linked to the component barriers, are as presented in Section 5.3, related to the technology near level. Where issues regarding hardware and software create complications regarding compatibility or interfacing.

6.1.1 Charging infrastructure

FMS-service providers can through collaboration with PTOs, assess the barrier of charging infrastructure.

There are currently two main technologies of chargers available, the small low-output chargers installed at depots that charge a bus, often overnight, during about 6 hours. And further the high-output opportunity chargers (either conductive or inductive) installed at bus stops, which enable charging en route. The common view amongst the interviewed PTOs is that both are going to be used, depending on the type of traffic. Buses with high traffic load, mostly going in dense cities, with short distances will be utilized by buses equipped with small battery-packs that can handle fast charging. Buses with lower passenger load, often routed between cities or sparse suburbs will probably use buses with large battery-packs that are slow to charge. These two bus/battery configurations seems to as of now be the only cost effective options. Batteries susceptible to high currents and high cycles are too expensive to mount as high capacity battery banks or in high range configurations, as mentioned in Section 4.1.3.

Opportunity charging

PTOs could utilize FMS-services to log the battery charge levels during the shifts, the data could then be aggregated and used as support for new route planning or as a basis for planing of new charger locations. The FMS-service could be used as a tool for collecting real-time data in order to establish a basis for the current charging performance. The balance between the amount of battery stored and distance between the chargers could then, through better knowledge and understanding be more optimized.

Depot charging

During depot charging FMS-service suppliers could develop tools for interacting with the chargers. Due to batteries wearing due to high currents, as concluded earlier, lower charging currents are beneficial. When BEBs are parked at the depot the FMS-service could be designed to retrieve shift info from a PTO database for when the next shift is about to start, and by calculating time left while knowing the battery capacity and current state of charge, send a command to the charger containing the preferred charging current. This would lead to lower battery wear and also have the benefit, if large fleets are charged at the same time, of the peak electricity demand and strain on the electric grid decreasing.

6.1.2 Shorter range or decreased load capacity

The decreased range of the BEBs in comparison with conventional ICE buses is obvious. The utilization is thus significantly affected, increasing the importance of route planning and management. The aid from FMS-service providers can be in the form of data parameter collection, as elaborated above, in order to acquire a base-line of the performance and limitations. The aid can further be in the form of aiding the bus drivers in Eco-driving in order to exchange the range capabilities. With a Eco-driving monitoring system aiding the drivers, their awareness for how the driving behavior affects the range could be increased. Range estimations based on current driver performance could be incorporated into the Eco-driving monitor, thus present direct feedback to the driver regarding how the driver is performing. The difficulty in range estimations, as Lundström has mentioned regarding EVs, is easier due to the fixed routes. If the monitoring system identifies that the current driving behavior might reduce the SOC to levels where there is a risk of standstill before the end of a shift. The range estimations could further be used by alert systems that send alarms to the depot if there is a risk of a bus being stuck, due to low SOC. The assessment of driver behavior influence is a key part in making the BEBs a viable substitute to the current generation of buses.

6.1.3 Unknown functionality in cold climate

The implications of low temperatures for the performance and durability of batteries is an explored subject within battery research as mentioned in Section 4.1.3. The battery capacity being sensitive to temperature is a challenging barrier in both terms of range and durability. Due to the negative effects of charging most lithium batteries in degrees below zero it is essential to heat the batteries when charging, which personal electric vehicle manufacturers have solved with heaters built-in inside the battery-packs. Whether this is assessed by BEB manufacturers, and how, should be investigated both in order to gain knowledge of how the system behaves in cold climate, but also to gain confidence in the the BEB reliability and durability during harsh winter conditions.

Further the decreased battery capacity, due to low temperatures, impacts the PTO calculations for how much battery over-capacity is needed for buses to manage a complete route planned for the day or in-between chargers. Similar as to the earlier barriers the PTOs should investigate the performance with data collection in order to acquire a base-line of the performance and expose limitations. Some sort of alarms or control functions could also be implemented in order to alert if charging outside of safe conditions is attempted. Also if no charging is occurring due to the battery monitoring circuit disabling the charge process alarms would be beneficial in order to prevent a bus from being left with low SOC at the start of a shift.

6.1.4 Reliability & Durability

Due to BEBs sparse usage so far in the Swedish public transport there is not much experience, data or research covering the reliability or durability of battery-electric buses. The progress of the BEB launch in EU is mostly similar, with only pilot projects in larger or smaller scale. Asia is the area with most BEBs in use, however access to performance data is difficult to acquire. Manufacturers tend to not disclose statistics of negative kind, but exaggerate performance and reliability. The maturity and extended experience of electric motors used in other transportation vehicles, such as trains, trams or trolleybuses, are probably applicable to electric buses. Although it is difficult to draw trustworthy conclusions on BEB durability and reliability when introduced in larger scale in the Swedish public transport.

Although the current generation of different lithium battery technologies is reaching maturity, the factors affecting the performance and health of batteries has increased uncertainty and risk in usage. Unlike the lead acid batteries for starting motors, the batteries in electric vehicles are expensive and complex systems. The need for different monitoring circuits and cell management is bigger. The cost, which is highly dependent on the life-time of the batteries, is difficult to estimate. It is difficult to forecast trends in battery health or capacity without large amount of logged data. We argue that this is necessary for owners of large battery-electric fleets to monitor in order to create reliable TCO-forecasts and avoid expensive unforeseen costs. The barrier of reliability, due to lack of information, could be assessed with the equipment and services provided by FMS-service suppliers. Extensive data logging of expensive BEB component characteristics, with monitoring of specific value-trends could be utilized in order to detect anomalies, thus predict imminent expensive failures.

6.2 Opportunities linked to the Managerial barriers

The following opportunities linked to the managerial barriers, are as presented in Section 5.4, related to ownership and operations. The opportunities identified aid the PTOs in their barrier with lack of knowledge and experience, economy and maintenance.

6.2.1 Economy & Maintenance

Uncertainties create risks which are both expensive and lead to unnecessary exposure. In order to mitigate risk and unnecessary cost due to the technological transition the PTOs should, which is a recurring theme, gain more knowledge regarding the new technology. Early risk analysis enables more informed decisions, thus both monetary gains as well as mitigated risk and exposure. The gained knowledge on niche, the more technology-near, level e.g. the practical and actual performance in terms of both durability and reliability of BEBs results in an competitive advantage towards other PTOs. The gained knowledge can be used to create better support for tender preparations and thus a more accurate cost prognosis, thus gaining an edge against competitor tenders.

The gained knowledge could also be used as support during the vehicle procurement process. Data and collected experiences could be used during discussions with bus manufacturers in securing that vital functionality is offered, or as to present relevant and clear requirements. The collection of data can be used as a benchmark as to how the vehicles have performed, whether the claims of dependability, range or reliability by the manufacturers are true. With data collection and benchmarking, identified problem areas could be passed on for better feedback to the manufacturers, both in assuring that problems derived from the manufacturer are mended, but also to identify driver behavior or fleet management routines that might negatively affect the vehicle reliability or dependability, which in the end affects the TCO.

Increased and more substantiated feedback to the manufacturers would lead to synergies in regards to technical development and advancements. With the increased understanding of the vehicles and their usage, PTOs in collaboration with manufacturers together could strive towards vehicles better suited to the daily application and thermal implications.

The batteries, which are a heavy post in the TOC, are now due the risks often by the manufacturers being offered as a service. The batteries can be leased, thus allowing the PTOs to avoid financial risk, although to a high premium. As the public transport sector is competitive, this might not be a viable long term option. Therefore it is in PTOs interest to early improve their competence regarding the batteries and drive-line. Both durability and reliability of the batteries should be investigated, further the impact of driver-behavior should be assessed. As covered in the earlier chapters, the bus drivers have an immediate influence on range and battery durability, where calm and planned driving is preferable. In order to prolong battery life, avoid expensive towing, there should be tools aiding drivers in beneficial driving-behavior as well as mechanisms that assure battery health.

6.3 Summary

In this chapter the opportunities at niche level have been presented and discussed. The opportunities can be used by FMS-service providers in aiding PTOs in assessing the transition to electric buses in the Swedish public transport sector.

The identified opportunities have been chosen at a niche level, because of them being under transformation by technicians or specialists, which MFS-service providers incorporate. The identified opportunities for FMS-service suppliers enable PTOs in acquiring a deeper and more accurate knowledge of the new technology. With the possible new tools the PTOs can gain a thorough and substantiated knowledge of a future fleet of electric buses. Simultaneously by assessing these opportunities, PTOs can perform more detailed and credible analyses of their fleets, resulting in decreased risks and expenditures. This chapter has covered the vital part of knowledge and information and how this knowledge could be used by both PTOs and FMS-service providers in order to stay competitive in a competitive industry.

Chapter 7

Conclusion

In this chapter we summarize the research that has been done and recap the main conclusions made in the report. The identified barriers and opportunities are extracted and their impact assessed. Further areas of improvement and topics of interest for public transport operators and FMS-service providers are presented. Finally a recommendation is elaborated, of allocating resources into expanding the knowledge about the electric bus mechanisms in order to improve the competitive and differential advantage.

The electrification of the public bus transport in Sweden seems to be at its verge. This thesis has provided a brief introduction and background to a large sector present in Sweden, impacting hundreds of thousand of commuters every day. The problematization and purpose has led to formulated research questions that have shown to be vital in assessing, in order for electric public transport buses to become a viable option for PTOs.

A theoretical framework within *industrial dynamics* has been formed in section 2.7 Research framework, based on the theories of *LTS* (Hughes, 1983), *MLP* (Geels, 2002), *Technology adoption life cycle* (Rogers, 1962) and *Salient and reverse salients* (Hughes, 1992). The developed framework has been used to identify the electric public transport bus as an innovation, striving towards becoming part of a LTS, the transportation regime. The components and artifacts mentioned by Hughes (1983) have been identified and categorized in a way as to understand their relationship. The components and artifacts identified as perceived barriers have then been discussed and categorized using the *MLP* concepts, resulting in a table of barriers present at different levels, all linked to three underlying *reverse salients*.

The work has covered what the transition to BEBs would imply for the PTOs by answering research question one:

What barriers among public transport operators hinder the technological transition towards a battery electric bus?

This thesis has illuminated problems obstructing the BEB from crossing the chasm from early adopters over to an early majority and the current transportation regime, with focus on how the PTOs would be affected of the transition. The perceived barriers were categorized into three levels in the theoretical framework and categorized in whether they were component related, or related to managerial aspects.

Perceived barriers linked to the components of the BEB are; Variation in solutions and lack of technical standards, Charging infrastructure, Shorter range or decreased load capacity, Unknown functionality in cold climate, Reliability and Durability.

Perceived barriers linked to the managerial aspect of the BEB are; Lack of knowledge and experience, Behavioral change, Economy, Maintenance, Ownership of infrastructure and buses, Business models and Varying requirements from PTAs.

The State of the market was concluded to be at the front of an upcoming change. Where the BEBs might be able to take part in the new transportation regime. Although first, some issues need to be solved for the PTOs to be able to handle the transition. The thirteen barriers all connect to the three identified *reverse salients*; the battery technology, the charging infrastructure and the contracts/ownership, should be assessed. The identified reverse salients form a resistance against a broader adoption of BEBs, and are not solvable by individual actors in the market alone, collaboration between stakeholders is needed.

Following this, we continued with how the FMS-service providers could assist the PTOs to overcome the arosen barriers due to the approaching introduction of BEBs in the Swedish public bus transport. This was done by answering research question two:

How can fleet management system services assist the public transport operators in this transition?

After identifying the thirteen barriers, we continued on to focus on the barriers FMS-service providers can address. The barriers FMS-service providers can address have shown to primarily be present at niche level due to the technological nature of the services. The PTOs together with FMS-system providers are encouraged to together strive towards gaining deeper knowledge in these new technologies that are emerging. This would support the PTOs in overcoming the barriers of the Charging infrastructure, Shorter range or decreased load capacity, Unknown functionality in cold climate, Reliability, Durability, Economy, Maintenance & Lack of knowledge. The gained knowledge and anticipation of the electric buses will itself act as momentum into entering the early majority market for the BEB.

After answering both research questions, the thesis could fulfill its purpose to:

Investigate the technological transition within the bus industry and how FMS services can be developed to increase the adoption of electric buses within public transportation.

However, despite extensive research and preparation it is difficult to tell how a market will develop. This was very well stated in two quotes by Wells and Nieuwenhuis (2012):

> ”There is a powerful tendency among all social actors concerned with the future trajectory of global industrial and economic structures to identify, isolate and often exaggerate change...”
> (Wells and Nieuwenhuis, 2012, p. 1)

and

> ”We have erred on the side of hopeful and sometimes evangelical expectations...”
> (Wells and Nieuwenhuis, 2012, p. 1)

The empirical contribution has illuminated how the current Swedish public transport sector is set to the emerging technological transition. Which barriers that are common amongst the stakeholders and their interplay. They are unanimously conscious about the transition and believe it is coming soon, *”We can see that the market is bubbling, there will probably several upstarts in the next years”* (Source), said meaning that the activity regarding electric buses is increasing rapidly on all levels of society. They believe that when the transition begins, it is going to escalate rapidly. This further exhibits the degree of importance for all actors on the Swedish public transport sector to prepare for the oncoming transition.

Chapter 8

Future research

The topics this thesis has touched upon have proved to be multi-faceted and complex. The involvement of public procurement, international and national regulations, interplay between PTAs and PTOs together has been challenging to grasp. The addition of technological advancements regarding the vehicles and telematic systems has further added a dimension, which has left us with even more questions and thoughts.

Due to this thesis focusing mainly on the effects of the transition on PTOs and the possibilities on a niche level therein for FMS-service providers, there are several aspects that have been left untouched. The possibilities on all levels would be beneficial for PTOs to investigate. Further the impact of regulations and their current development would be of interest. The technological transition has implications on the current ownership models, where the BEBs rely on compatible charging infrastructure of which the ownership, for opportunity charging, still is undefined.

During the research we have identified several aspects and problem formulations that might be of interest for researcher both within industrial dynamics and researchers within intelligent transportation systems, with the aim of exploring and guiding the currently tentative progress on the Swedish public bus transport sector:

Is the public bus transport sector the best candidate for electrification?

During the research there have come up thoughts about the similarities between the public bus routes and the routes of light trucks used for goods deliveries in the cities. The goods trucks have their routes predefined and are standstill most of the time due to unloading and loading. Maybe the main development should be done at the light truck sector?

How can large fleet owners efficiently control and schedule over-night charging of all-electric vehicles?

As the BEBs gain more momentum and the BEB fleets increase in quantity, at depots with over-night charging buses there will be a need for a lot of electricity, which might require smarter charger management and scheduling.

Big data in public transport from an ownership perspective

As the transition to a new technology demands collection of larger amounts of data, there will be challenges in how to process and analyze it. In order to assess this challenge a investigation of how *Bid Data*, extensively used in other industries, could be incorporated in order to improve fleet analyses and trend predictions.

Eco-driving algorithms on BEBs as support for drivers

Do the technological advancements and data collection abilities create possibilities for more advanced and intuitive Eco-driving aids?

How does the constellation of PTAs owning buses affect the ability to early adopt new vehicle technologies

The research found that there are different ownership constellations regarding the buses in the public bus transport sector. Is the diversity favorable for technology advancement or does it affect technological transitions negatively?

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Appendix A

Questionnaire

Enkät om inställning till Elbussar

* Required

Tack för att du tar dig tid att svara på vår enkät

Vi är två studenter vid Kungliga tekniska högskolan i Stockholm som skriver examensarbete inom Industriell ekonomi vid institutionen för Industriell Dynamik. Examensarbetet försöker kartlägga omställningen till eldrivna bussar i kollektivtrafik i Sverige genom att försöka förstå vilka hinder som finns bland operatörer som bromsar utvecklingen. Utöver detta undersöker vi hur omställningen kan underlättas genom att använda förar- och IT-stöd.

Examensarbetet skrivs i samarbete med Transdev och Fleetech och denna enkät är en del av vår informationsinsamling där syftet är att få en insikt i branschens inställning till denna övergång. Enkäten skickas ut i samarbete med Sveriges Bussföretag. Alla som deltar kommer att få en sammanställning av resultatet när enkäten är genomförd. Alla deltagande samt sammarbetsföretag kommer att ges samma information. Resultatet kommer att anonymiseras samt sammanställas på branschnivå inom institutionen för Industriell Dynamik på KTH innan den återges.

Om det är något ni undrar kan ni alltid kontakta oss på våra mailadresser nedan.

Kontaktuppgifter
Adam Ekström, adameks@kth.se
Robert Regula, regula@kth.se

Skip to "Struktur på enkät."

Grundläggande information

Denna information används endast i syfte att kunna återkoppla i ett senare skede och kommer inte att offentliggöras

1. **Namn på företag** *

   ....

2. **Namn på deltagare** *

   ....

3. **E-mail adress för återkoppling av resultat** *

   ....

4. **Telefonnummer för återkoppling**

   ....

5. **Ort** *

   ....

6. **Totalt antal bussar ni äger idag (i Sverige)** *

....

Skip to question 7.

Struktur på enkät

Enkäten är uppdelad i fyra avsnitt

Grundläggande information

I detta avsnitt frågar vi om information som kräv förs senare kontakt samt för att kunna kategorisera de svar vi samlar in

Frågor om elbussar

I detta avsnitt kommer vi att fråga om vilken er nuvarande status och inställning till elbussar är

Frågor om användning av system för fleet management

I detta avsnitt kommer vi att fråga om er användning av och inställning till system för fleet management. System för fleet management används här som en övergripande term för system för övervakning av bussflottan, bussövervakning, eco-driving, fjärrdiagnostik m.m.

Sammanfattning och övriga kommentarer

I detta avsnitt får ni tillfälle att tillföra extra information eller ställa frågor

Skip to question 1.

Nuvarande status elbussar

Definition av elbuss

Elbuss är i denna enkät definerad som en batteridriven buss (Battery Electric Vehicle)

7. **Äger ni elbussar idag?** *

Mark only one oval.

○ Ja *Skip to question 8.*
○ Nej *Skip to question 13.*

Ägare av elbussar

8. **Hur många elbussar äger ni idag?** *

....

9. **I vilken typ av trafik kör ni elbussar?** *
Check all that apply.

☐ Beställningstrafik
☐ Linjetrafik: Innerstad
☐ Linjetrafik: Förortstrafik
☐ Linjetrafik: Landsorts/glesbygdstrafik
☐ Linjetrafik: Expresstrafik
☐ Other: ______________________

10. **Vilka fördelar ser ni hos elbussar jämfört med andra framdrivningstyper?** *
Check all that apply.

☐ Minskat underhåll
☐ Lägre totalkostnad
☐ Goodwill (Hos kollektivtrafikmyndigheter/trafikhuvudmän och kunder)
☐ Mindre miljöpåverkan
☐ Tystare
☐ Mer energieffektiva
☐ Passagerarkomfort
☐ Other: ______________________

11. **Vilka nackdelar har ni stött på hos elbussar jämfört med andra framdrivningstyper?** *
Check all that apply.

☐ Mindre räckvidd
☐ Ekonomi
☐ Bristande kunskap om elbussar jämfört med andra bussar
☐ Mindre Servicemöjligheter
☐ Oklar funktion vid vinterklimat
☐ Bristande infrastruktur för laddning
☐ Brist på tekniska standarder
☐ Osäkerhet kring tillförlitlighet
☐ Osäkerhet kring livslängd
☐ Other: ______________________

12. **Har ni planer på att köpa in fler elbussar?** *
Mark only one oval.

○ Ja *Skip to question 16.*
○ Nej *Skip to question 18.*

Ej ägare av elbussar

13. **Vilka fördelar upplever ni att det finns för elbussar jämfört med andra framdrivningstyper?** *
Check all that apply.

☐ Minskat underhåll
☐ Lägre totalkostnad
☐ Goodwill (Hos kollektivtrafikmyndigheter/trafikhuvudmän och kunder)
☐ Mindre miljöpåverkan
☐ Tystare
☐ Mer energieffektiva
☐ Passagerarkomfort
☐ Other: ....

14. **Vilka problem upplever ni att det finns för elbussar jämfört med andra framdrivningstyper?** *
Check all that apply.

☐ Mindre räckvidd
☐ Ekonomi
☐ Bristande kunskap om elbussar jämfört med andra bussar
☐ Mindre Servicemöjligheter
☐ Oklar funktion vid vinterklimat
☐ Bristande infrastruktur för laddning
☐ Brist på tekniska standarder
☐ Osäkerhet kring tillförlitlighet
☐ Osäkerhet kring livslängd
☐ Other: ....

15. **Har ni planer på att köpa elbussar?** *
Mark only one oval.

○ Ja *Skip to question 16.*
○ Nej *Skip to question 18.*

Inställning till elbussar

16. **Inom vilken tidsram planerar ni att införskaffa elbussar?** *
Mark only one oval.

○ mindre än 2 år
○ 2 - 4 år
○ 4 - 8 år
○ 8 - 12 år
○ Mer än 12 år

17. **Vilka huvudsakliga faktorer bidrar till att ni överväger att köpa in elbussar?** *
Check all that apply.

- ☐ Minskat underhåll
- ☐ Lägre totalkostnad
- ☐ Goodwill (Hos kollektivtrafikmyndigheter/trafikhuvudmän och kunder)
- ☐ Mindre miljöpåverkan
- ☐ Tystare
- ☐ Mer energieffektiva
- ☐ Passagerarkomfort
- ☐ Other: ....

Skip to question 19.

Inställning till elbussar

18. **Vad är det som huvudsakligen hindrar er från att vilja köpa elbussar?** *
Check all that apply.

- ☐ Mindre räckvidd
- ☐ Ekonomi
- ☐ Bristande kunskap om elbussar jämfört med andra bussar
- ☐ Mindre Servicemöjligheter
- ☐ Oklar funktion vid vinterklimat
- ☐ Bristande infrastruktur för laddning
- ☐ Brist på tekniska standarder
- ☐ Osäkerhet kring tillförlitlighet
- ☐ Osäkerhet kring livslängd
- ☐ Other: ....

Skip to question 19.

Övriga frågor

19. **Är det er uppfattning att det krävs stora investeringar i laddinfrastruktur på depåerna?** *

....

20. **Begränsar kunskapen om elbussar er från att använda elbussar eller använda elbussar i större skala?** *

....

21. **Uppfattar ni elbussmarknaden som mogen?** *

....

22. **Uppfattar ni stora skillnader mellan elbusstillverkarna?** *

....

23. **Avvaktar ni med större inköp av elbussar tills de erbjuds av en svensk tillverkare?** *

....

24. **Påverkar utbredningen av servicenätverk för elbussar er i valet av elbusstillverkare?** *

....

System för fleet management

Användning av system för fleet management i form av övervakning av bussflottan, bussövervakning, eco-driving, fjärrdiagnostik m.m.

25. **Använder ni idag någon form av system för fleet management med fjärruppkoppling (internet/tele)?** *

Mark only one oval.

○ Ja *Skip to question 26.*
○ Nej *Skip to question 28.*

Använder system för fleet management

26. **Vilka är de främsta anledningarna till att ni använder er av system för fleet management?** *

Check all that apply.

☐ Minska bränsleförbrukning
☐ Bättre kontroll av fordonsflottan
☐ Möjlighet till bättre planering av underhåll/minskade underhållskostnader
☐ personalmotivation
☐ ökad komfort
☐ optimering av rutter
☐ Ökad resenärsnöjdhet
☐ ökad tillförlitlighet
☐ Other: ....

27. **Är det viktigt att nuvarande system för fleet management även är kompatibelt med elbussar?** *

Mark only one oval.

○ Ja
○ Nej
○ Delvis

System för fleet management för elbussar

28. **Saknas någon funktionalitet i förarstöden på marknaden som ni känner behövs i en elbuss?**

....

....

....

....

....

Sammanfattning och övriga kommentarer

Ett stort tack!

Ett stort tack för att du tagit dig tid att svara på våra frågor. Vi återkommer så snart som möjligt med sammanställningen av undersökningen på den mailadress du angav i början av enkäten. Glöm inte att trycka på 'Submit' när du läst igenom och är klar med enkäten.

Vill du komma i direkt kontakt med oss kan du antingen ange det som en kommentar nedan eller skicka oss ett mail till en av våra mailadresser.

Kontaktuppgifter
Adam Ekström, adameks@kth.se
Robert Regula, regula@kth.se

29. **Övriga kommentarer eller frågor**

Här kan du lämna övrig information som du tror vi kan ha nytta av eller skriva frågor riktade till oss

....

....

....

....

....