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Open standards and interoperability within the automotive domain and smart cities

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Abstract

Vehicle signals are today in highly heterogeneous formats which leads to difficulties for third-party developers to access, understand and integrate with these signals. Thus, the automotive domain needs to find a way to describe its vehicle signals to the outside world. At the same time, smart city initiatives are started all over the world to be able to govern digital sources. Through a case study, this thesis aims to find a way to interconnect and achieve interoperability between the automotive- and urban IoT domains by applying open standards. The study was conducted using a Proof of Concept and the use case was based on finding connections between electric vehicles and charging stations. Furthermore, a knowledge graph was used to visualize the interconnectivity between the two domains. To evaluate the knowledge graph and the Proof of Concept criteria unstructured interviews were used. The result of the study showed that open standards can be applied to improve interoperability in this use case. Lastly, three building blocks for interoperability were identified and discussed.

Keywords: *Automotive domain, smart cities, urban IoT, interoperability, open standards, knowledge graphs*

Foreword

We would like to express our gratitude to our case company Volvo Cars for giving us this exciting thesis opportunity. We would like to thank our supervisors Fredrik Landqvist, Peter Winzell, Fabien Batejat, and John Seneger for providing us with invaluable feedback and support. We would also like to express appreciation and a special thanks to Alan Carlson, our academic supervisor who has tirelessly guided and provided feedback and support.

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1 Introduction

This section presents an introduction to the topic of smart cities and the challenges within the automotive domain. It also presents the purpose of the study and its research question. Lastly, the thesis disposition is presented.

1.1 Background

The effects of digital technologies are witnessed in several contexts across the world, not the least in the automotive industry. Digitalization is changing the way markets and businesses operate and its disruptive effects are changing the way that the industry operates in general. One of the factors causing this change is globalization, which allows manufacturers to expand and enter new markets. Another factor is the increased diversity of consumers and products which will reduce the lifecycle of products as the demand for new and innovative products arise. For instance, manufacturers have recently reduced the lifecycle of a car from eight to three years (Llopis-Albert et al., 2020). Previously the industry was mostly focused on design, manufacturing, and developing electronics and mechanics. Nowadays software is becoming the key component in the industry's value proposition (Glaser et al., 2020). Software and digital technologies are now equivalent to approximately 50% of the vehicle's total value (Llopis-Albert et al., 2020).

The automotive domain is today facing several challenges. One big challenge is that the modern vehicle produces tons of data from various sensors connected throughout the vehicle network. Understanding every individual signal and its uses is a constant challenge and limited to certain experts within the domain. Developers must manage thousands of signals that are in heterogeneous formats, and which come from different car architectures. As it is difficult to access and understand these signals for people outside of the domain, integration issues for vendors or third-party suppliers are becoming a reality. To ensure interoperability, a common ground for understanding these signals need to be established. Open standards can be used to

accomplish semantic enrichment of automotive data which could be a part of a solution to the interoperability challenges in the automotive domain (Klotz et al., 2018a).

To enable current and future innovation within the automotive domain, interconnectivity amongst different systems is crucial. Systems in this case refer to the vehicle, infrastructure back-ends, and external data sources. Klotz et al. (2018a) state that to be able to interconnect these vehicle-related systems, they need a way to communicate, understand and share knowledge with each other. To overcome these obstacles, many domains including the automotive domain, are now looking to integrate with the Internet of Things (IoT) ecosystem. Smart city initiatives are started by public administrations all over the world to try to enable interaction between different IoT devices. Even though these efforts are made, they are still quite new, and the communication does not work seamlessly. The problem is that all kinds of IoT devices use their own set of standards which are not able to communicate with each other (Karpenko et al., 2018a). Klotz et al. (2018a) and Karpenko et al. (2018a) both conclude that there are considerable interoperability challenges within these domains, the core element of the problem is that manufacturers use internal standards to describe their products. Which indicates a knowledge gap in how to apply open standards to improve interoperability. This advocates the theoretical relevance of our study.

Scrocca et al. (2021) explains that there have been many suggestions on how to frame the IoT ecosystems within smart cities to be able to share and access data among different devices, service providers, and authorities to co-create value for both consumers and businesses. The main objective of implementing smart cities is to ensure horizontal and vertical interoperability. According to the Organisation for Economic Co-operation and Development (OECD, 2021), horizontal interoperability refers to the ability of digital services to communicate with different stakeholders, such as rival services. This communication would for example allow direct communication between users even though, for example, not having to use the same messaging application. OECD further states that “Vertical interoperability refers to the ability of digital services to incorporate data, content or functionality from an upstream provider.” (OECD, 2021, p.12). Today the data is mainly vertically-oriented. Another objective is to guarantee semantic interoperability which means, shared vocabularies, ontologies, and definitions that facilitate a common understanding of information (Scrocca et al., 2021; Karpenko et al., 2018a).

1.2 Purpose and research question

Manufacturers within the automotive domain need to find a way to describe a vehicle in a standardized way, not only to the outside world but also for its occupants and immediate surroundings. It is argued that standardizing communication will reduce complexity for third-party developers, suppliers, and other actors interacting with the vehicle. The reduced complexity could enable value creation for both users and businesses. This study is conducted in collaboration with our case company Volvo Cars to gain valuable insights from experts within the automotive domain. According to the literature several domains are today facing interconnectivity and communication challenges. Thus, there is currently a knowledge gap in how to apply open standards to improve interoperability (Klotz et al., 2018a; Karpenko et al., 2018a). The purpose of this case study is to find out if we can apply open standards to improve interoperability between the automotive domain and smart cities. We will investigate the research question by defining a use case within electric vehicle charging. We will further examine if it is feasible to create a knowledge graph, which is an explicit knowledge representation of a domain, using open standards. The knowledge graph is supposed to represent two sets of signals, one from the vehicle and the other from charging stations with applied open standards. We will explore if it is possible to interconnect the two data sets and investigate if they can achieve interoperability. The case study is viewed from a Swedish Volvo Cars perspective and will be conducted as a Proof of Concept (PoC). This means that instead of investigating the problem as a whole, we will select a relevant and extendable use case that could be a part of the solution to the problem. The result will i.e., only reflect a part of the solution but should also be applicable in a wider context.

The research question is proposed as:

How can we apply open standards to improve interoperability in electric vehicle charging using a knowledge graph and what would such a knowledge graph look like?

1.2 Disposition

Section 2 presents related research associated with the study's main domains, smart cities, and electric vehicles. Section 3 presents the theoretical part, for further understanding of useful terms and concepts. Furthermore, motivation of methodology and data collection is presented in section 4. Section 5 presents the result of the study. A result analysis, discussion and further research is presented in section 6. The thesis ends with a conclusion to answer the research question and a method evaluation.

2 Related research

In this section, we will look at previous research that has been done investigating how open standards enable software development in the automotive domain and smart cities. We will also look at how open standards enable communication between actors from different domains to share and access data.

2.1 Smart cities & open data

According to UNDESA (2018), in 2018, 55% of the world's population was living in urban areas and the number is estimated to increase to 68% by 2050. Cities are today facing several challenges to govern over digital sources. One challenge is to manage large amounts of heterogeneous data in technological infrastructure. Another challenge is to provide beneficial services and solutions to the citizens of the society. An example is the growth of mobility habits where several competing mobility suppliers design their own technological infrastructure with internal data formats and standards. This makes it hard to exchange data between different actors which inhibits interoperability. For the problem to be solved, an open standard with a common language is necessary (Scrocca et al., 2021). Scrocca et al., (2021) has constructed a module of ontologies for urban IoT devices. The ontologies target sharing mobility and electric mobility, electric mobility refers to an electric vehicle charging infrastructure.

Urban IoT and open standards are one of the building blocks in smart city initiatives. A smart city is defined by the European Union (EU, 2022) as “A place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business.” The smart city ecosystem consists of numerous actors from different domains, such as users, service providers, buildings and so on. As stated in the introduction, one of the main goals is to facilitate horizontal communication and interoperability. Which in practice means communication between actors that belong to different domains. The communication between applications is today mainly vertically-siloed. Which means applications can only interact with other applications within the same domain, service provider or system. This occurs because of the constrained resources and heterogeneous characteristics

of the applications. Karpenko et al. (2018b) suggests that to reach the smart city concepts full potential, information and data would need to be organized in open systems that are horizontally-oriented. These systems should be easy to interconnect with and exchange data.

Neves et al., (2020) also makes a point out of exchanging data horizontally. The phenomenon is usually described with the term open data. The term is defined by the Open data handbook (n.d, episode “What is Open?”) as “*Open data is data that can be freely used, re-used and redistributed by anyone - subject only, at most, to the requirement to attribute and sharealike.*”. Open data can be used and shared by all actors in the smart city ecosystem, which means new and unexpected uses of the data can arise. Using the data freely can facilitate value co-creation between all actors, such as the citizens, entrepreneurs, researchers and policymakers, which can facilitate urban innovation and economic growth. In this sense, open data is one of the key aspects of a smart city and has a great impact on the interoperability achieved (Neves et al., 2020).

2.2 Automotive open standards

In a study Klotz et al. (2018a) investigated how the combination of different open standards could create enrichment of automotive data to make it possible for developers to integrate, access, and understand vehicle signals. As mentioned in the problem statement, it is difficult to obtain data from vehicle signals. Also, it is a challenge to understand every signal and its use. This makes it difficult for actors outside the automotive domain to integrate with these signals. To solve the problem, researchers have been trying to define ontologies and common languages for the vehicle signals. Klotz et al. further states that many ontology representations previously made, suffer from the lack of represented signals, sensors, and actuators. The ontologies only use a defined set of signals connected to a fragment of the vehicle, which makes it hard for third parties to develop applications, but also to acknowledge any information about the signals that are not represented in the current ontology. Therefore, the study focused on creating an ontology using multiple relevant specifications and descriptions. The aim of the Vehicle Signal Specification ontology (VSSo) was to create a semantically rich ontology that could describe the whole vehicle (Klotz et al., 2018a).

The VSSo is based on Vehicle Service Specification (VSS), Semantic Sensor Network (SSN) and Sensor, Observation, Sample, and Actuator (SOSA) ontologies through a Web of Things (WoT) interaction to describe the vehicle as a whole (Klotz et al., 2018a). These different open standards will be explained in more detail in the theory section. The study focused mostly on making use of WoT patterns to define vehicle data and connect it to external sources. The study did for instance look at a use case describing the speed and trajectory of a vehicle (i.e., a moving vehicle). The use case was constructed to find a way of describing the evolution of signal value of the vehicle through SOSA/SSN and WoT. The use case was meant to prove that the ontology was applicable and useful for the vehicle (Klotz et al., 2018a).

The previous studies take an important role in our own research on how to combine different open standards in the automotive domain and which benefits it provides.

3 Theory

This section presents the theoretical part of the study to retrieve a better understanding of essential terms and concepts. The first part of the theory will present a more detailed description of interoperability, the second part will describe the term ontology. Further, different open standards will be discussed to create an understanding of standardized ontologies. Finally, data models and knowledge graphs will be introduced.

3.1 Interoperability

Interoperability enables unlimited sharing and exchange of data and resources between different systems. Subsequently, it also refers to making use of the data that has been exchanged. There are two types of interoperability: Syntactic Interoperability and Semantic Interoperability. Syntactic interoperability refers to the facilitation of at least two systems to communicate and exchange data. It also makes it possible for diverse software components to cooperate even though the programming language may differ (techopedia, 2022). This is possible because of the use of common data formats and protocols. Syntactic interoperability is essential for semantic interoperability to function (HEAVY:AI, 2022).

Semantic interoperability stands for the capability of exchanging valuable data between at least two systems where the systems understand each other and where the receiving system can translate and produce meaningful results for the end-users (techopedia, 2022). Semantic interoperability creates metadata, data about data, which makes it possible to connect data elements to a mutual and shared vocabulary which in turn is connected to an ontology. In short, an ontology is a data model within a domain which represents relationships between a set of concepts (HEAVY:AI, 2022). Semantic is a term of the computer science domain that is often used in the context of semantic enrichment. Which refers to a process of adding metadata content to understand and create meaningful information about the data and their connections (Clarke & Harley, 2014).

To summarize, to achieve interoperability it is necessary that data sent from the addresser collected by the receiver or receivers have to fully understand the data (HEAVY:AI, 2022).

3.2 Ontologies

An ontology is a form of domain model that is used to describe knowledge within a domain. Models can be used for multiple purposes, for example when creating a database. An ontology represents knowledge as a set of concepts and the relations between them (Ontotext, n.d). Neo4j Field engineer Jesús Barrasa (2020) suggests that three characteristics differ ontologies from other types of domain models.

The first characteristic is that it needs to be a formal representation. Which in practice means that it needs to be machine readable. That is one of the main points of ontologies. They need to have a structured form (Barrasa, 2020).

The second characteristic of an ontology is that it needs to be an explicit description of a domain to ensure a common understanding of information. Jesús Barrasa further states that:

It's not like a natural language text description, it has to be an enumeration of the entities that belong to these domains and how they relate to each other. I'm talking about entities connected to other entities. That sounds a lot like a graph, doesn't it? Most of the modeling languages used for ontologies, are based on RDF which is actually a graph model. The description being explicit is very important (Barrasa, 2020, episode "What is Ontology?").

The third characteristic of an ontology is that it is consensuated knowledge. Simply put, the knowledge is accepted and used amongst people, typically in a community. It is a shared vocabulary (Barrasa, 2020).

3.3 Open standards

Open standards are standards that are made for the public to use and implement, which can be developed and supported by different actors. Open standards improve interoperability and exchange of data through different actors and third parties and their use of products and services (International Telecommunication Union [ITU], 2005). To be allowed to call a specification an open standard, it needs to meet a few requirements (Walli et al., n.d). Described below are the most relevant ones concerning our case study.

- Availability: It needs to be available for everyone to read and implement.
- Maximize end-user choice: It needs to create a fair, competitive market for everyone who chooses to use the standard. It should not lock end-users to certain vendors or groups.
- No-royalty: It should be free for anyone to implement and use. No royalty or fee should be charged.
- No Discrimination: The open standard itself and the organization who administer it should not benefit one implementor over the other (Walli et al., n.d).

Four open standards will be presented and described below, these are Vehicle Signal Specification (VSS) / Vehicle Signal Specification Ontology (VSSo), Semantic Sensor Network (SSN) / Sensor, Observation, Sample and Actuator (SOSA), Electric Vehicle Supply Equipment (EVSE) and Web of Things (WoT).

3.3.1 Vehicle Signal Specification (VSS) / Vehicle Signal Specification Ontology (VSSo)

Vehicle Signal Specification (VSS) is an open standard within the automotive domain that is used to describe signal data within the vehicle. The purpose of the standard is to create a common language that facilitates understanding of the vehicle signals which in turn allows developers and third parties to make use of standardized vehicle data. Making use of this standard creates a semantic understanding among several domains (COVESA, 2021).

Vehicle Signal Specification Ontology (VSSo) is an ontology that was created to facilitate the current challenges between the automotive domain and the non-automotive domains. The

ontology is based on the automotive standards VSS which defines the vehicle branches, attributes, and signals. The term attribute used in VSSo refers to, for example, ‘model’ and ‘year’. The term branch refers to different parts of the vehicle, for example ‘the engine’. The vehicle can have different branches and even branches that are divided from a tree into sub-branches that derive from a larger branch (World Wide Web Consortium [W3C], 2020a). A modeling pattern of VSSo according to the description of branches, attributes, and signals makes it possible to analyze and trace data and their relationships. VSSo is also based on the open standards SOSA and SSN through a WoT pattern. SOSA and SSN are used to represent observations of signals in the vehicle (Klotz et al., 2018b). WoT is a standard that aims to create common protocols and formats for IoT systems and services (World Wide Web Consortium [W3C], 2020b).

VSSo facilitates the combination of data from heterogeneous landscapes and is therefore improving interoperability (Klotz et al., 2018b).

3.3.2 Semantic Sensor Network (SSN) / Sensor, Observation, Sample and Actuator (SOSA)

To observe vehicle signals it is possible to make use of Semantic Sensor Network (SSN) and Sensor, Observation, Sample, and Actuator (SOSA) ontologies. SSN and SOSA are ontologies for observation, actuation, sensors, and actuators (World Wide Web Consortium [W3C], 2017). The model pattern can be used for defining the domain signals in an ontology. To clarify, there are both static and dynamic data in the vehicle signal network. The static data refers to the vehicle attributes such as model or year. The dynamic data refers to the data that is dependent on time and space. Generation of dynamic signal data from embedded sensors and actuators is only possible if the signals are known in a static vehicle description (Klotz et al., 2018a).

3.3.3 Electric Vehicle Supply Equipment ontology (EVSE)

This thesis will make use of the Electric Vehicle Supply Equipment ontology (EVSE) which is included in the module of Urban IoT ontologies (Scrocca et.al.,2021). The ontology defines

classes and properties that are under the domain of electric vehicle charging, and more specific charging stations (Comune di Milano, n.d).

EVSE ontologies make use of open standards such as SOSA and SNN patterns to describe sensors and observations in the ontology. The purpose of the ontology is to facilitate the exchange of data between municipalities and service providers to achieve interoperability (Scrocca et.al.,2021). The ontology was created by Milano municipality and is an open standard that can be used in any city since the ontologies are universal (Comune di Milano, n.d).

3.3.4 Web of Things (WoT)

Nowadays several projects and platforms are based on the use of Internet of Things (IoT). Currently, IoT has made it possible for different devices such as mobile phones, home applications, and even smart cars to share data and communicate over the internet (Zeng et al., 2011). The IoT systems and services are often used for specific cases, which means they follow closed protocols and are not able to communicate horizontally. This makes it hard for developers and third parties to understand the heterogeneous technology landscape from different actors' IoT systems and services (W3C, 2020b). Some research suggests that Web of Things (WoT) is one possible open standard to solve the IoT challenges (Zeng et al., 2011). WoT standards aims to create common protocols and formats that could be used to interact with heterogeneous systems. These IoT systems and services are integrated into the web which can support data sharing and increase interoperability and flexibility (Klotz et al., 2018a; W3C, 2020b). WoT can counteract the fragmentation of IoT by using and developing standardized web technologies (Klotz et al., 2018a).

3.4 Data models & Knowledge graphs

Data models are a way of describing and creating a visual representation of a database. It defines the structure and the relationships between different points in the database. The data models describe data types and how the data is stored and retrieved in a system (IBM, 2020). There are different types of data models, and in this section graph data models will be prioritized and explained. Graph data models are both human- and machine friendly, the graph can describe and represent complicated and indirect relationships, which is one of the

advantages of a graph data model. There are two types of graph data models, these are Property Graphs and Knowledge Graphs (Barrasa et.al., 2021). In this thesis, knowledge graphs will be used and will therefore be explained further. “A knowledge graph, also known as a semantic network, represents a network of real-world entities- i.e., objects, events, situations, or concepts - and illustrates the relationships between them” (IBM, 2021a, episode Knowledge Graph).

A knowledge graph is often explained as “whiteboard friendly” (Neo4j, 2022a, episode Graph Modeling Guidelines) because the data is stored in a database that is visualized and structured as a graph. Which is the opposite to relational databases where data is structured in tables of columns and rows and it makes use of primary keys (IBM, 2019; IBM, 2021a). Further, a knowledge graph is structured with nodes that are connected by different relationships (edges). These relationships are meant to create an explicit representation of a certain domain i.e., defined in an ontology. A knowledge graph tries to represent how things are connected and give a contextualized understanding of the area (AllegroGraph, 2022). In this thesis, a knowledge graph will be created using the graph database management system Neo4j.

To retrieve data from a graph using a Neo4j database, a language called Cypher query language is used and is inspired from the relational database language called Structured query language (SQL). Cypher makes it possible to match patterns and relationships and visualize them as a graph (Neo4j, 2022b). A knowledge graph, which belongs to the umbrella term NoSQL database, is to prefer when handling large amounts of data and supports flexible data models (IBM, 2021b)

4 Method

This section presents the chosen methodology, use case and data collection method. We have chosen a qualitative approach to collect data through a literature review, modeling, and unstructured interviews. We have also chosen to conduct the study using a Proof of Concept to further investigate and seek answers to our research question.

4.1 Case Study

In this study we conducted a qualitative case study. A case study is most commonly used when researching a group such as an organization or a situation (Patel & Davidson, 2019). Which was very suitable in our case since we pursued the study at an organization where we looked at a specific situation in their business and studied it in depth. According to Bell & Waters (2020) a case study is usually performed as a project where you study a change within an organization. You look at the relation between different attributes within the studied phenomenon and try to find out how they impact the situation or organization. Some argue that there are disadvantages to case studies due to a lack of credibility and generalization. The criticism towards case studies is based on difficulties in verifying information and data, which may lead to misleading results (Bell & Waters, 2020).

4.2 Use Case

To solve the interoperability challenges presented in previous sections, Volvo Cars need to find a way to describe their car to the outside world. As mentioned in the problem statement we can use open standards to achieve semantic enrichment of dynamic automotive data to improve interoperability in the automotive industry. There are thousands of signals within the vehicle, which means we had to focus on a few selected signals, related to a specific scenario. We decided to focus on signals related to electric vehicle charging and more specifically, an electric vehicle on an ongoing route where the driver would like to find a charging station. This use

case was chosen because of the current lack of research, the relevance, and the ongoing evolution of electric vehicle charging.

The use case is presented in greater detail as follows:

We will look at a use case of an electric vehicle from the perspective of a driver's ongoing route. We will look at a state where the driver has a low battery (low battery level alerts at \leq 20 percent displayed to the driver) and would like to find the most suitable charging station. In this state we will analyze different signals from the vehicle and charging stations separately, we will then look at various relevant signals to examine if interconnectivity between the two is possible. The signals we will take into regard are the following: The positioning of the vehicle and the nearest charging stations when the vehicle alerts for low battery. Accessibility of charging stations when the vehicle alerts for low battery. The accessibility refers to: if the charging stations are available or not available. If not available, what is the remaining time until available according to the charging station? The accessibility also refers to the compatibility between vehicles and charging stations. The compatibility depends on matching characteristics between the two such as compatible plug types. By combining these signals, we could find the most suitable charging station for the vehicle.

The use case is presented as a sequence diagram for further understanding:

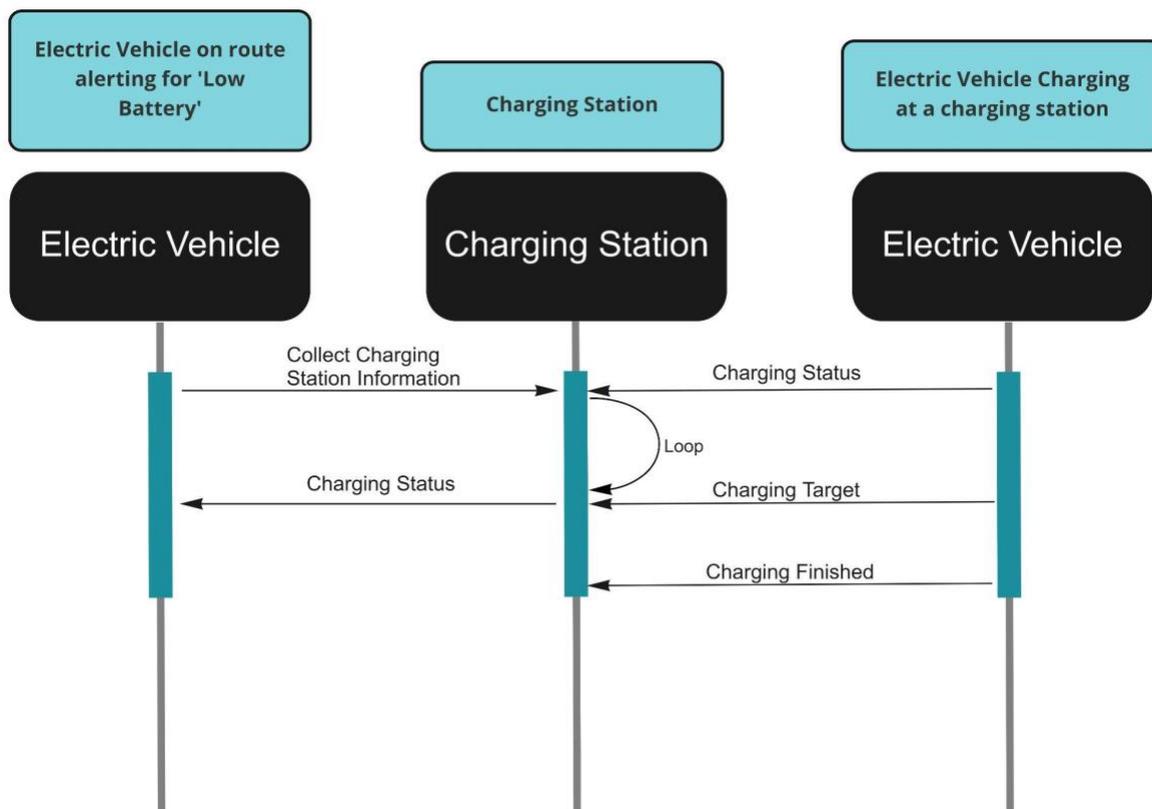


Figure 4.1: Sequence diagram of vehicles and charging station

Figure 4.1 is a sequence diagram describing signals between vehicles on route and the charging station, followed by the vehicle currently charging. The black boxes represent the objects: Electric Vehicle on route, Charging Station and Electric Vehicle currently charging. The arrows represent the signals and their direction. The loop describes the scenario when the charging station is available and does not retrieve any information from a charging vehicle.

4.3 Proof of Concept

The case will be studied using a Proof of Concept (PoC) to find out if the concept of using open standards to improve interoperability in electric vehicle charging has potential. A PoC is generally the first step of proving that a vision or an idea is practically feasible and can be used as both a method and delivery format (Prototyp, n.d.). The PoC is the theoretical representation

of the idea and can be conducted by doing a study or creating a prototype. The purpose is to show that the concept is viable (INKA interactive, n.d.). Before conducting the study an overarching objective and a few evaluation criteria need to be identified. These will help evaluate the result and success of the PoC. The objective needs to be identified to know what the outcome of the PoC is supposed to be and what organizational purpose it is supposed to serve. The evaluation criteria are supposed to be tangible, measurable, and meaningful targets. The evaluation criteria defines where our main focus should lie and will lead the project in a certain direction (Kantify, n.d.).

The objective of this study is based on our research question and aims to investigate if we can apply open standards to improve interoperability in electric vehicle charging using a knowledge graph.

Evaluation criteria for the PoC: The case related evaluation criteria for the PoC will be identified during the interviews and will be presented as a result.

There are general evaluation criteria for assessing models which we will additionally use to evaluate the knowledge graphs.

Model criteria	Description
Completeness	Completeness refers to the case where a model captures all desirable aspects of a certain context (Zowghi, D & Gervasi, 2003).
Consistency	Consistency means that there are no internal contradictions within the model or specification. It can also refer to a desirable consistency within the model's terminology. I.e., the model should be consistent, without contradictions, as well as the terms and words should have the same meaning throughout the model (Zowghi, D & Gervasi, 2003).

Table 4.1: The table presents the model evaluation criteria.

4.5 Data collection

The data collection of this study was built on a literature review, the open standard models, and the unstructured interviews. We searched and used documents related to the subjects: smart cities, interoperability, open standards, electric vehicle charging, and urban IoT. The search was done using Google Scholar and Göteborgs universitetsbibliotek to collect relevant scientific articles. Our supervisors also provided us with scientific articles that were related to

similar previous studies using open standards in the automotive domain. Relevant websites were also used to complement and strengthen the information from the articles. We also used e-books to collect data. When using a literature review it is according to Bell & Waters (2020) important to have a search strategy to find the most relevant and suitable sources (Bell & Waters, 2020). At the beginning of the literature review, we used keywords in our search such as *automotive domain* and *smart cities*, extensive words that gave us many search results that were beyond our scope. Therefore, we started to define our search with narrowed and specific keywords which is according to Bell & Waters (2020) a preferable approach to find relevant sources. Some of the keywords that were used are: *Urban IoT*, *Internet of Things*, *Web of Things*, *interoperability*, *open standards*, *ontology*. These keywords were combined with words such as *connected cars*, *smart vehicles* and *electric mobility* to further narrow down the search and retrieve as relevant results as possible.

Apart from the collected data mentioned above, we also had to retrieve data related to the vehicles and charging stations to observe their signals according to our use case. Since we have been working with Volvo Cars the most optimal alternative would have been to retrieve live data from their own cars to get a realistic outcome. Because of the privacy policy, live data from the vehicles was not an option in our study. Our ambition was to collect live data related to the charging stations. We found an open dataset from ‘Södertälje kommun’ which we thought was going to be useful but later on turned out to be inadequate since a lot of relevant signals were missing and therefore did not fit into our standards. Instead, we used simulation data in both our vehicle- and charging station datasets (the implementation of those datasets is described in section 4.7).

Lastly, data was also retrieved from two open standard datasets. The data was collected through observation of the datasets that were visualized as knowledge graphs. The data was originally represented as a turtle file (TTL-file), which is a data serialization of RDF data. We decided to implement the TTL-files into a knowledge graph to gain more insights about the standards structure. The datasets that we used in this method are the following two: Vehicle Specification Signal ontology (VSSo) and Electric Vehicle Supply Equipment (EVSE). The two datasets were selected because of their relevance towards our use case and the research question. The observations and the information that we collected from the datasets was important for us to be able to create our own datasets based on those open standards (this will be explained in section 4.5.1 and 4.5.2). VSSo and EVSE are open source and are available for the public to use but

are not suitable to implement in Neo4j structured as a knowledge graph. This caused some deficiencies in the graph that we had to take into consideration when observing the knowledge graphs. Below is a clarifying explanation of the data collected from the open standard datasets separately.

4.5.1 VSS-ontology dataset

We retrieved an ontology dataset from Vehicle Specification Signal ontology (VSSo) to observe the relationships between signals across the vehicle. The dataset was retrieved from a TTL-file and later on implemented into Neo4j. We collected data from VSSo by examining the knowledge graph and studying the nodes, relationships, and labels in the ontology. By gaining deeper knowledge and insights from the graph we could accurately implement the VSSo when creating our own Vehicle dataset.

4.5.2 Electric Vehicle Supply Equipment ontology dataset

We retrieved an ontology dataset from Electric Vehicle Supply Equipment (EVSE) to observe the relationships between signals across charging stations. The dataset was retrieved from a TTL-file and later on implemented into Neo4j. We collected data from EVSE by examining the knowledge graph and studying the nodes, relationships, and labels in the ontology. By gaining deeper knowledge and insights from the graph we could accurately implement the EVSE ontology when creating our own Charging Station dataset.

4.6 Unstructured interviews

An additional data collection method that we used was unstructured interviews. The unstructured interviews were necessary in our study to find guidelines for the project and gain information to examine our results. The respondents were our supervisors at Volvo Cars who are seen as experts on the topic. They were also the receivers of our project. We had project updates scheduled once a week for the whole thesis project and each session lasted for 30 minutes. When needed, these meetings were used to conduct interviews with our supervisors

to gain necessary information. Unstructured interviews are according to Bell & Waters (2020) not structured with questionnaires or checklists, instead there is an open dialog between the interviewers and the respondents. However, the interview should be structured with selected themes that shall appear during the interview. The interviewers should ask a few questions connected to the themes but leave room for the respondents to reflect and develop their answers (Bell & Waters, 2020). Therefore, we chose to specify themes and a few open questions before every interview to retrieve the information that we needed. The interviews were firstly made to identify the evaluation criteria of the PoC and secondly, to evaluate the identified criteria and lastly, the model criteria. The answers were collected with a few notes through the interview process. According to Bell & Waters (2020) the notes should be brief and to the point but good enough to make use of. After collecting the answers through notes, we summarized the information we retrieved to support our result.

4.7 Implementation of knowledge graph database

This section presents the creation and implementation of the datasets into the knowledge graph database. We also present the mind maps that were created to identify the relevant signals and were then added to a simulation dataset for each domain.

4.7.1 Vehicle dataset

We created a mind map to define which signals that we would like to observe in this use case for vehicles. The signals in the mind map are structured in the same way as the VSSo. When finishing the mind map simulation data of 10 vehicles were created. The simulation data was created with an Excel-file and then converted into a CSV-format file to meet the requirements for importing datasets into Neo4j. We created a Cypher query in Neo4j to create nodes, relationships, properties, and labels for our Vehicle dataset to represent a knowledge graph. The knowledge graph was structured, as mentioned above, as the VSSo standard.

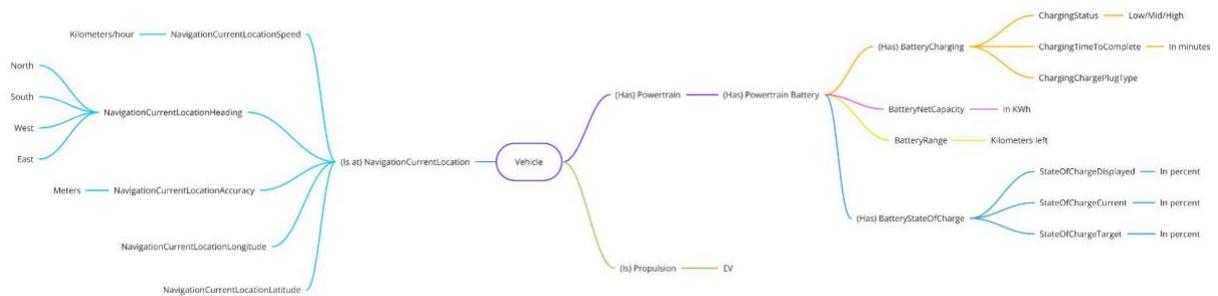


Figure 4.2: Mind map of vehicle signals used in our study. The mind map is representing the relationships between different attributes.

4.7.2 Charging Station dataset

We created a mind map to define which signals that we would like to observe in this use case for charging stations. The signals in the mind map are structured in the same way as the EVSE ontology. When finishing the mind map simulation data of 10 charging stations were created. The simulation data was created with an Excel-file and then converted into a CSV-format file to meet the requirements for importing datasets into Neo4j. We created a Cypher query in Neo4j to create nodes, relationships, properties, and labels for our Charging Station dataset to represent a knowledge graph. The knowledge graph was structured, as mentioned above, as the EVSE ontology standard.

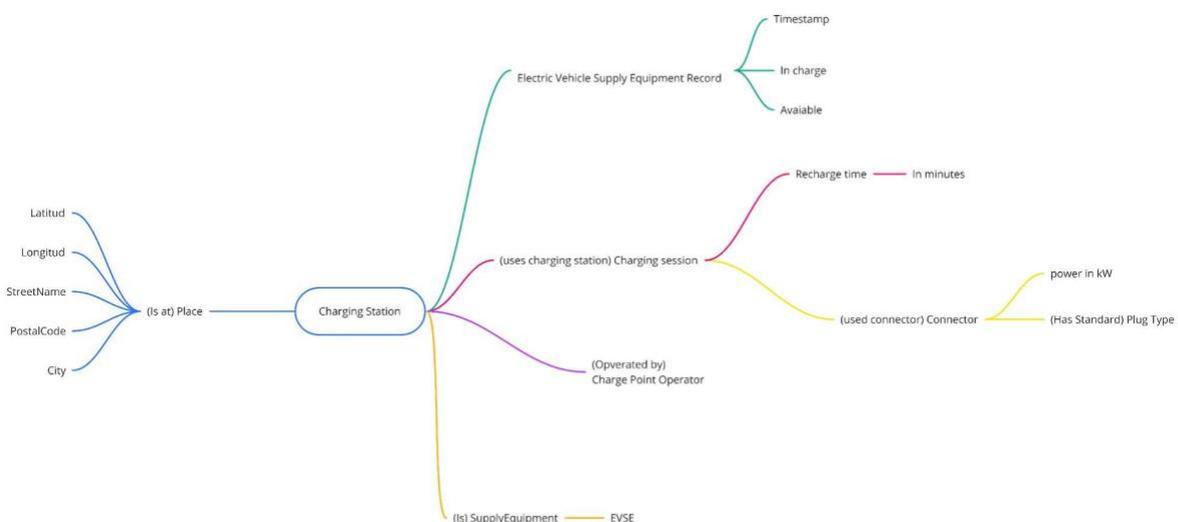


Figure 4.3: Mind map of charging station signals used in our study. The mind map is representing the relationships between different attributes.

After the simulation datasets for vehicles and charging stations were implemented into Neo4j creating two separate knowledge graphs in the database. We began to explore whether the two knowledge graphs, with applied open standards, could interconnect with each other. As mentioned in the use case we would like to find the most suitable charging station for a vehicle on an ongoing route. We used Neo4j as a tool to ask queries between the vehicle and the charging station. The queries were based on finding similarities and matching characteristics between the vehicle- and charging station signals to find the most suitable charging station. We tried different solutions to interconnect the automotive standards and investigated what level of interoperability we could achieve.

5 Result

The result section will give account for the findings from the unstructured interviews conducted with our supervisors at Volvo Cars and the findings from our knowledge graphs. The first part of the result will give account for the Proof of Concept evaluation criteria retrieved from the interviews. The second part of the result will present an evaluation of the identified criteria along with evaluation of the model criteria presented in the method section. We will also give account for the findings in our knowledge graphs which will help evaluate some of the criteria.

5.1 Identifying and defining the evaluation criteria

In this part of the result, we will present the Proof of Concept evaluation criteria. We used unstructured interviews with our supervisors at Volvo Cars to identify and define the evaluation criteria. The evaluation criteria are presented in a table presented below.

Evaluation criteria	Description	Target
Criteria 1	It is possible to apply Vehicle - Urban IoT - open standards to describe vehicles and charging stations	See sub-questions
Criteria 1.1	Same as criteria 1	The open standard models fit the Electronic Control Unit (ECU) signals in the Volvo vehicle
Criteria 1.2	Same as criteria 1	The open standard models fit relevant open datasets for charging stations
Criteria 1.3	Same as criteria 1	The open standard models include all necessary signals and fit our use case
Criteria 2	Achieve interoperability between two domains: Automotive domain and Urban IoT	Find matches between vehicle and charging station dataset with applied open standards
Criteria 3	Achieve interoperability from a realistic, relevant, and extendable use case	The use case is realistic, extendable and of relevance
Criteria 4	Use new technologies to store data related to vehicle signals	Such as use of Neo4j and Cypher instead of a relational database

Table 5.1: A table of all identified evaluation criteria.

5.2 Evaluation of criteria

In this section we will attempt to answer our research question by evaluating our proof of concept and knowledge graph from the identified criteria.

Criteria 1: It is possible to apply Vehicle - Urban IoT - open standards to describe vehicles and the charging stations.

Will be evaluated in its sub-questions.

Criteria 1.1:

The open standard ontologies fit the Electronic Control Unit (ECU) signals in the Volvo vehicle.

Because of privacy obstacles we did not have access to the ECU signals in the Volvo vehicle. The live data containing these ECU signals could contain sensitive data about the driver such as their identity and whereabouts. Access to this kind of data is a process that takes a very long time and was not suitable given our time frame. As a result of these obstacles, we were not able to examine if the standards fit the ECU signals in the Volvo vehicle.

Criteria 1.2:

The open standard ontologies fit relevant open datasets for charging stations.

The open datasets from the Swedish data portal were uploaded in various formats such as XML, Json and CSV. Since Neo4J is highly compatible with the CSV format, that was the desired format. Also, the access to datasets containing relevant information about charging stations were sparse. As mentioned in the method section a dataset from Södertälje kommun was found and retrieved. The dataset mostly contained information about the location of the charging station and was missing other important parts such as availability status and charging plug. We, therefore, decided not to use an already existing dataset since the formats were diverse and represented signals were sparse. To summarize, the open standards did not fit the open datasets that were found.

Criteria 1.3:

The open standard ontologies include all necessary signals and fit our use case.

The VSS ontology and EVSE ontology both had adequate representation for all the signals desired for our use case. Thus, the result of this sub-question is that the open standards fit our use case.

Criteria 2: Achieve interoperability between two domains: The automotive domain and Urban IoT.

Find matches between vehicle and charging station datasets with applied open standards.

By structuring our vehicle dataset and our charging station dataset according to the VSSo and EVSE standards it was possible to find interconnections between the two datasets. Matching the relevant data signals, such as location and plug type, made it possible to find connections between the two domains. The matches were made from Neo4j Cypher queries to find out whether the vehicle could interconnect with the charging stations according to the defined use case. The result of the queries and matches of the datasets in Neo4j was according to Volvo Cars supervisors, an achievement of interoperability.

A clarification of interoperability between the two domains will be described below. It will also be visualized in tables and knowledge graphs according to the defined use case.

Vehicle	v_PlugType	v_Latitude	v_Longitude	ChargingStationID	ChargingStationName	cs_PlugType	cs_Latitude	cs_Longitude	Distance	Available
2	AC	57.730998086563964	12.056735540781654	2	Lindholmen Science Park	Type 2(AC)	57.70762318906369	11.938346617974174	7504	120
5	DC	57.712152064556335	11.935233540780969	1	Lindholmen Science Park	CCS(DC)	57.70762318906369	11.938346617974174	537	0
7	AC	57.824474393492274	12.004174727293366	10	BILAB Kungälv	Type 2(AC)	57.876885882659636	11.983183464814879	5965	120
8	DC	57.64218556595914	11.932236540778415	6	Cicle K Mölndal Söderleden	CCS(DC)	57.64607006999608	11.98472105616634	3157	0
10	DC	57.67581040156721	11.92785191379633	1	Lindholmen Science Park	CCS(DC)	57.70762318906369	11.938346617974174	3596	0

Table 5.2: Table of all vehicles alerting for low battery matched with suitable charging stations

Table 5.2 presents the outcome of the match query that was performed in Neo4j. The match query is intended to take several signals into account to find connections between the most fitting vehicle and charging station.

The matching query attempts to find all vehicles alerting for low battery and the most suitable charging station based on several different signals such as distance and plug type. The match query firstly filters out all vehicles that do not have an alert for low battery. Secondly, it takes into consideration the distance between the vehicle and the charging station and finds a connection between the nearest ones. This is performed by measuring the distance between the vehicle and charging station (in meters) from the geo positions latitude and longitude for both objects. Thirdly, the corresponding plug type of the vehicles and charging stations is taken into consideration.

For a better understanding of table 5.2, the matching can be described as follows:

Table 5.2 shows that all vehicles and charging stations have a unique ID that is connected to a charging station name to facilitate user-friendliness. Every unique vehicle matches a unique charging station by ID. The first row of the table represents the closest suitable charging station with the corresponding plug type. The table displays the most suitable charging station's state in the column available, where the value zero means that the charging station's state is available. If the charging station is occupied the time left (in minutes) is shown in the column available.



Figure 5.1: Knowledge graph of all vehicles alerting for low battery connected to suitable charging stations.

The figure is visualized as a knowledge graph of table 5.2 to describe all vehicles and all charging stations in our datasets. The graph is displayed in nodes and edges. The blue nodes represent the vehicles by ID and the green nodes represent the charging stations by ID. The vehicles are connected with edges to a purple node (EV) which explains that all vehicles are of the type “Electric Vehicle”. The charging station is connected with edges to an orange node (EVSE) which explains that all charging stations are of the type “Electric Vehicle Supply Equipment”. The edges between the vehicles (blue nodes) and charging stations (green nodes) represent the relationship between these two domains. Which means that the blue nodes that are connected with green nodes represent all vehicles that have an alert for low battery level and their nearest suitable charging station. The blue nodes that are not connected to a green node represent other vehicles in the dataset that does not alert for low battery.

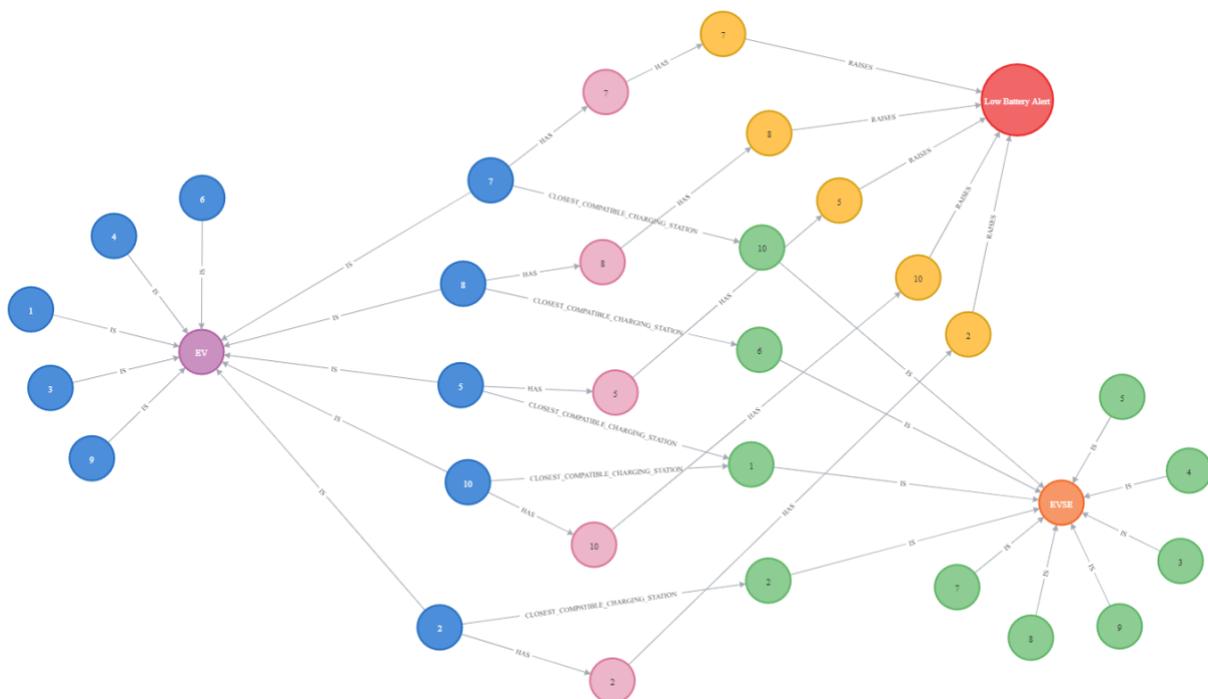


Figure 5.2: Knowledge graph of all vehicles alerting for low battery connected to suitable charging stations and “Low battery alert”

The figure is also a visualization of table 5.2 as a knowledge graph but a more extensive one. This knowledge graph is a more expanded version of figure 5.1 in the terms of nodes and edges but shares the same relationships between vehicles and charging stations. The importance of this figure is to display the vehicles that are alerting for low battery and their connections. The red node represents “Low battery alert” and is connected to all vehicles displaying battery level

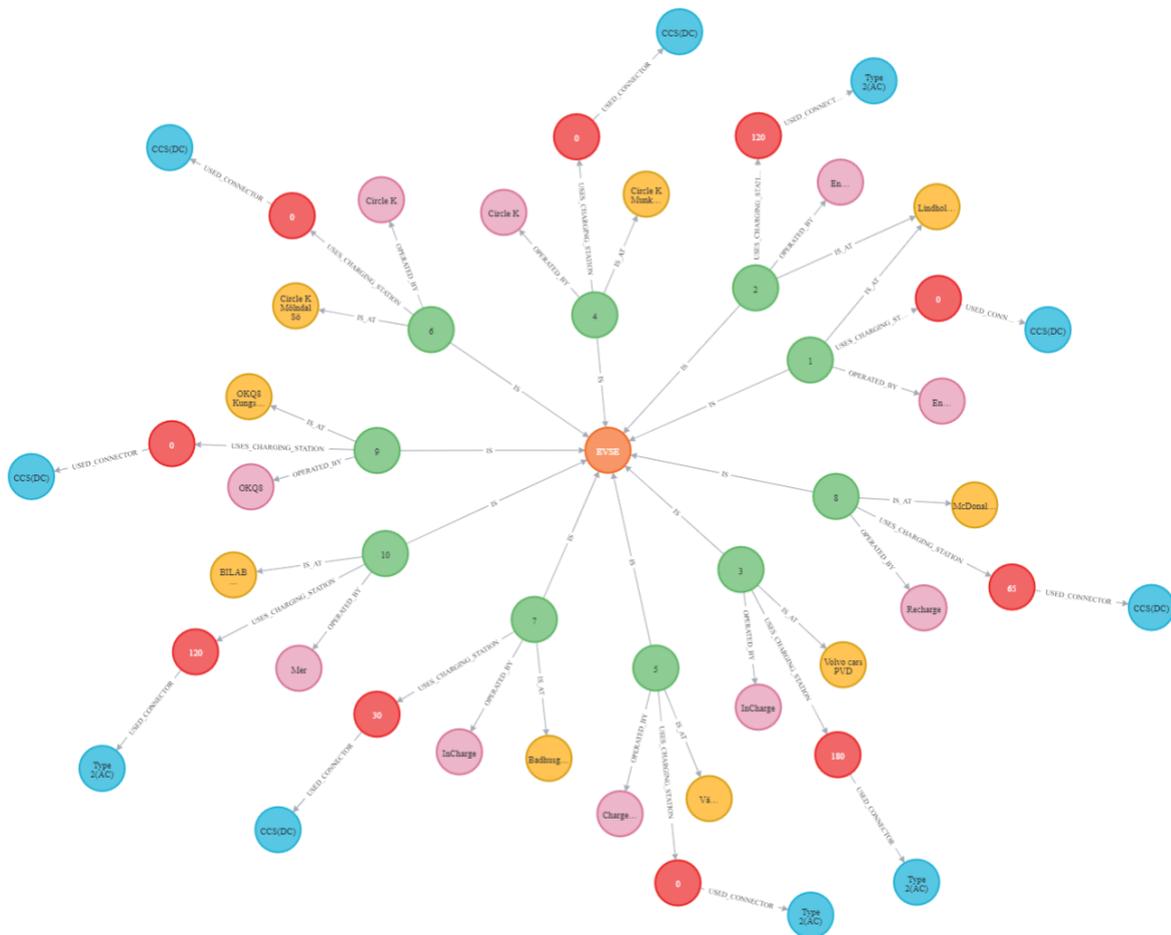


Figure 5.4: Knowledge graph of charging station database

Vehicle	v_PlugType	v_Latitude	v_Longitude	ChargingStationID	ChargingStationName	cs_PlugType	cs_Latitude	cs_Longitude	Distance	Available
5	DC	57.712152064556335	11.935233540780969	1	Lindholmen Science Park	CCS(DC)	57.70762318906369	11.938346617974174	537	0
5	DC	57.712152064556335	11.935233540780969	4	Cicle K Munkeböck	CCS(DC)	57.7240037494214	12.02542936061816	5522	0
5	DC	57.712152064556335	11.935233540780969	6	Circle K Mölndal Söderleden	CCS(DC)	57.64607006999608	11.98472105616634	7923	0
5	DC	57.712152064556335	11.935233540780969	7	Bashusgatan 12	CCS(DC)	57.6578417139538	12.115297840826125	12303	30
5	DC	57.712152064556335	11.935233540780969	8	McDonald's Landvetter	CCS(DC)	57.67942112354107	12.310641176388243	22628	65

Table 5.3: Table of one vehicle alerting for low battery matched with 5 suitable charging stations

The table presents the outcome of the same match query as shown in table 5.2, the difference is that only one specific vehicle (in this example, vehicle with ID 5) is matched against the five nearest suitable charging stations. The structure in this table is the same as in table 5.2.

The tables and figures presented above are visual representations of the interconnection and integration between vehicles and charging stations. The integration depends on which characteristics the driver of the vehicle is looking for when in need of electric vehicle charging. The presented interactions between two domains Vehicle and Charging Stations were shown to the supervisors at Volvo Cars and was considered as an achievement of interoperability between two domains.

Criteria 3: Achieve interoperability from a realistic, relevant, and extendable use case

The use case is realistic, extendable and of relevance.

According to our supervisors at Volvo Cars the use case of finding the nearest charging station for an electric vehicle is highly realistic and relevant. During the interview they further explained that electric vehicles in a smart city context is highly relevant as they both are gaining more popularity around the world. The topic is described as “up and coming” and applicable in a real-world scenario. Since this PoC only had the opportunity to look at a fragment of the problem, another important aspect according to our supervisors, was that the use case was extendable. Other researchers need to be able to do more extensive research related to our research question and use case. According to our supervisors, this criterion is met. For example, Volvo Cars might do a similar project but with real ECU data signals to further investigate the problem. Thus, the investigated use case is regarded as realistic, relevant, and extendable.

Criteria 4: Use new technologies to store data related to vehicle signals.

Such as use of Neo4j and Cypher instead of a relational database.

Neo4j and its query language Cypher were used in this thesis project instead of a traditional relational database and its Structured query language (SQL). According to our supervisors at Volvo Cars, there are some advantages of Neo4j compared to a relational database. They explained that Neo4j is a scalable and schema free (NoSQL) database technique used to observe

and store data. This kind of data storage is becoming more common around the world. Neo4j also has a user-friendly toolset which facilitates the use of it. Furthermore, they compared Neo4j with a relational database. Neo4j is described as a structured and flexible way of storing data. The flexibility of the database refers to the ability to ask several queries where a huge amount of data can travel between different nodes. To ask the same questions in a SQL database with the same amount of data and relationships would end up with unworkable queries. They further argue that this is because relational databases are built out of tables with primary keys.

According to our supervisors, the case that we investigated is a perfect example of when Neo4j is a better option in the selection between a NoSQL database and a SQL database. To explain the thousands of signals of the vehicle and for them to communicate with other domains requires a database that can handle that amount of data and relationships. Even if our project only had time to look at a small dataset with a subset of the signals in the vehicle, using this technology would enable for a more extensive project further on.

Criteria 1.1	Criteria 1.2	Criteria 1.3	Criteria 2	Criteria 3	Criteria 4
Unfulfilled	Unfulfilled	Fulfilled	Fulfilled	Fulfilled	Fulfilled

Table 5.4: Proof of concept evaluation

5.3 Model criteria

In this section we will present the results of the model criteria towards the knowledge graphs. We used unstructured interviews with our supervisors at Volvo Cars to evaluate the model criteria.

5.3.1 Completeness of the models

After interviewing the supervisors at Volvo Cars, it was possible to establish that the created models (knowledge graphs) captured all desirable aspects of the selected context. The models are representing all the signals that we desired to make use of (shown in figure 4.1 and figure

4.2). Further, to retrieve any wanted data from the graphs, queries to ask the database are needed. The queries act in this case as a sort of completeness-condition that determines whether it is possible to gather the requested data from a graph. Which means that if it is possible to gather all the requested data, the condition is met and the model is complete. If the asked queries would miss relevant information, the model would be incomplete. Our complete set of signals made it possible to ask queries to the knowledge graph database to retrieve the data that was requested. Therefore, the models meet the criteria of completeness.

5.3.2 Consistency of the models

After interviewing the supervisors at Volvo Cars, it was possible to establish that the models (knowledge graphs) do not have any internal contradictions. The models are representations of the vehicles and charging stations, structured according to the VSSo and EVSE ontology with nodes, relationships (edges), properties and labels. According to our supervisors, the models created do not have any contradictions since they are following well-established ontologies which do not have any inconsistencies. Neither are there contradictions in the dataset nor its terminology. It was also discussed that models containing these small datasets are not likely to have contradictions. The larger the database, the higher the risk for contradictions and inconsistencies. Therefore, the models meet the criteria of consistency.

6 Discussion

This thesis has through unstructured interviews and by creating a knowledge graph database tried to find an answer to the research question “*How can we apply open standards to improve interoperability in electric vehicle charging using a knowledge graph and what would such a knowledge graph look like?*” To seek answers to the research question we have conducted a Proof of Concept study that provided a knowledge graph. The PoC and knowledge graph has been evaluated based on a few evaluation criteria. By doing this we hope to provide knowledge on how to describe heterogeneous signals using open standards and how they can interconnect. This section will initially present an analysis of our results. Followed by a discussion of our empirical findings in relation to theory and result.

6.1 Open standards suitability

Since we did not have access to real live data from a Volvo vehicle, we were not able to examine whether we could apply the open standards on real vehicle data. Seeking answers to our research question with a knowledge graph built on simulation data may harm the study's validity as the result might differ when using real live data. As stated by Klotz et al. (2018) the real vehicle data signals are often very difficult to understand and highly heterogeneous. Which means that if the study was done with real vehicle signals the complexity of the study would increase and the result might differ completely. Another way to interpret the result is that Volvo Cars does not have a way to share their vehicle signal data without exposing the driver's sensitive information. I.e., their vehicle data is locked. Which in itself is hindering the interoperability since open data is one of the foundational pillars to interoperability.

The open datasets for the charging stations that were found were either in diverse and unsuitable formats or missing crucial information. As stated above, not being able to use a real dataset from a charging station might affect the study's validity negatively. The result indicates that to be able to achieve horizontal interoperability, the data need to be described in a common language (Karpenko et al., 2018a).

6.2 Open standard ontologies

The open standard ontologies that were used had adequate representation of all signals that were relevant in our use case. A study made by Klotz et al. (2018a) defined an ontology to describe a vehicle. A study was also made by Scrocca et al. (2021) that defined the EVSE ontology to describe charging stations. These ontologies were fundamental to the conduct of our study. VSSo offered all needed signals for our project which gave our study an accurate result. However, if the ontologies were missing necessary signals the result may lose validity as we would have to adjust and add the missing signals. Klotz et al. (2018a) explains that if an ontology suffers from lack of represented signals, sensors and actuators, domains will not be able to make use of that ontology. This means that if any signals, sensors, or actuators were missing, it would be hard for other researchers to pursue further research of this study since the datasets would not follow the ontology.

6.3 Interoperability between the automotive domain and urban IoT

The result of the study indicates that open standards can facilitate horizontal interoperability. Horizontal interoperability, as previously mentioned, refers to the ability for digital services to communicate with different stakeholders from various domains (OECD, 2021). Our result showed that it was possible to store two datasets from different domains in a knowledge graph database and find matches between the two. This was possible because of the open standards that were used. The applied open standards semantically enriched the datasets and added meaningful information which could allow for interconnectivity. Which implies that open standards have an important role to play when trying to achieve horizontal interoperability.

6.4 Relevance of use case

As stated in the result, the use case that we chose to work with was considered as highly realistic and relevant to achieve interoperability. A use case to achieve interoperability between vehicles and the electric mobility domain was chosen. According to Scrocca et al. (2021) the growth of

electric mobility is causing difficulties in exchanging data between domains. Furthermore, digital sources have become more significant and beneficial to inhabitants and businesses (UNDESA,2018; European Union, 2022). These statements indicate the electric mobility part of the use case is both relevant and realistic. The second part of our case reflects the automotive domain. According to Klotz et al. (2018a) there have been some difficulties to explain the vehicle signals to their surroundings. However, ontologies for the electric mobility domain and the automotive domain have been presented in related research (Scrocca et al., 2021; Klotz et al., 2018a). There is a lot of ongoing research regarding exchange of data between different domains. The combining of two relevant domains indicates a relevant and realistic use case to achieve interoperability.

6.5 Used technology to store data

According to the result that we got from the interviews, it was concluded that the most suitable technology to use in our study was to use a graph database to represent datasets that were created. According to Neo4j (2022a) a knowledge graph is “whiteboard friendly” because of the visualized structure compared to a relational database. The use of knowledge graphs made it possible to create a result that in a visualized way could describe the signals and their relationships and create a better understanding of it. If we had chosen to use a relational database, the outcome of this study may differ. The result would only be presented in tables which may have caused difficulties in understanding the connections. It would also be more difficult for us to create queries and to consider primary keys when executing the database. As AllegroGraph (2022) described, knowledge graphs have an advantage to represent entities' connections and to give contextualized insights of the area. Furthermore, IBM (2021b) declares that knowledge graphs are also a better option when supporting flexible and great amounts of data. In the interview's, the supervisor informs that a knowledge graph database would be needed in a more extensive project further to manage the stored data.

6.6 Interoperability findings

The study indicates that it is possible to achieve interoperability using open standards. This result is in alignment with Klotz et al. (2018) studies on “A car as a semantic web thing” who suggests that open standards are one of the great enablers of interoperability (Klotz et al., 2018). Besides indicating that open standards can enable interoperability, the result also pinpoints that vehicle manufacturers and charging station providers are still using their own formats and standards to describe their data. This result is also consistent with the reasoning in the study by Scrocca et al. (2021) who stated that several competing mobility suppliers use their own technological infrastructure with internal data and formats. Another finding showed that Volvo Cars does not today have a way to share their vehicle signal data without exposing sensitive information about the driver. Accordingly, to be able to interact and communicate with other domains, Volvo Cars and other automotive manufacturers need to find a way to share and exchange their data without exposing the driver's sensitive information.

By analyzing the result, we contend that the study indicates that there are three main building blocks for interoperability in this specific use case. The first building block is the open standards. To be able to interconnect devices, connected cars and homes they all need to speak a common language to understand each other. The open standard specifications need to provide semantically rich descriptions of the devices or vehicles signals and attributes. As stated by Klotz et al. (2018) many automotive standards are missing descriptions of important parts of the vehicle's signals. An open standard that fails to describe the vehicle as a whole will likely not be adopted by the manufacturers.

The second building block is the open data. To be able to communicate with other actors in a network, for example a smart city, the data needs to be free and accessible for others to use. A smart city consists of both competing and collaborative actors who can make use of each other's data to co-create value (Scrocca et al., 2021). To share and exchange data the providers or manufacturers do not need to share all information about a certain device if it runs the risk of exposing sensitive user data. In our use case information about the driver is not necessary to accomplish communication between the domains.

The third and last identified building block is the actors. The actors within the network all play an important role in creating and keeping the interoperability level high. All actors need to implement suggested standards within their domain. For example, the actors within the automotive domain all need to describe the vehicle in the same way, i.e., they need to use the same standard to describe the same thing. If automotive manufacturers use different standards to describe a vehicle, the level of interoperability will decrease since other actors within the network will need to adapt their own technology to be able to understand multiple automotive standards. This difficulty was also indicated in the study's result, where we could establish that the charging station providers all use different ways to format and describe their data. Which suggests that open data that is not described in a standardized way might not be useful for other actors.

Our study also considers the perspective of how technologies, such as, applying open standards to improve interoperability benefits actors of different organizations and individuals to achieve usability, functionality and sustainability when using a product or device. Achieving horizontal interoperability in our use case could in the aftermath allow for multiple electric charging providers to exist on the same platform (for example like Spotify or Airbnb but for charging stations). This would create value for the driver (user) as they would not have to use several applications to charge their car depending on which provider owns the charging station. Which in turn means that horizontal interoperability improves usability and functionality for the users. We consider this finding to be highly relevant in the discipline of informatics as the interaction between technology and the user is one of the key aspects within the field.

7 Conclusion

The purpose of this study was to find an answer to the research question “*How can we apply open standards to improve interoperability in electric vehicle charging using a knowledge graph and what would such a knowledge graph look like?*” by interconnecting datasets from two domains with applied open standards in a knowledge graph and conducting interviews to find and evaluate the Proof of Concept criteria. According to Klotz et al. (2018a) there are challenges within the automotive domain on how to describe the vehicle signals. To achieve interoperability and facilitate the development of applications from third parties, the vehicle signals need to be described in a standardized way. The study shows that it is possible to use a knowledge graph to interconnect datasets from two domains using open standards. This implies that open standards can be used to improve interoperability in this use case. The result further indicates that there are many aspects to interoperability. Three building blocks for interoperability were identified. The first refers to the open standards. The open standards need to be complete when describing objects and attributes within a domain. Actors within the domain also need to agree on what open standards to implement to be able to facilitate interoperability. The second building block involves open data. To be able to communicate with actors from other domains, actors need to find a way to share and exchange their data openly without exposing sensitive user data. The third identified building block is the actors. To reach the full potential of interoperability, all actors within a network, such as a smart city, need to apply both open standards and open data. It is also important that there is a consensus within each domain on what standard to use to find a common language. Altogether our findings indicate that all three building blocks are essential for the interoperability’s success and that interoperability is beneficial for organizations and individuals. We therefore believe that our study has made a knowledge contribution in the current knowledge gap as well as in the informatics discipline.

7.1 Suggestions for further research

For further research it would be interesting to look at a larger number of signals connected to electric vehicle charging. For example, supplier’s payment information and methods, if the charging station is public or private or even electric mobility parking restrictions etc. It would

also be interesting to look at other parts of the vehicle. It could possibly be focusing on other signal fragments of the vehicle that are relevant to other domains. Which would enable third-party's development of applications when interacting with the vehicle.

We have, as mentioned, not been able to make use of live data. However, we managed to in the use of simulation data prove that the use of open standard can be achieved between two domains. Therefore, the optimal suggestions for further research would be to apply live data to the models. However, that kind of project would require a lot of time and access to live data concerning privacy aspects.

Another element to consider for further research, is the life cycle of interoperability. This means that for every update in an open standard, such as, new signals, new labels or new relationships, the units, for example a vehicle, have to be able to update in regard to the updated standard. If the units appear to not be updated according to the new standard, the interoperability level would decrease. Therefore, it would be interesting to investigate how to maintain interoperability through the unit's and open standards lifetime.

Finally, it would be interesting to investigate how to control the data flow over time on open data portals. An open data portal is a platform where actors can share and exchange data. Further research would have to take into consideration how to store huge amounts of data. Is there any solution to how to store huge amounts of data? How do we know which data is relevant to save or could some data be deleted at a certain point in time? These questions are of importance because the open data portal always has to be updated with relevant data.

7.2 Method Evaluation

In this section an evaluation of the thesis method will be performed and discussed. The method evaluation will start with discussing a few advantages and disadvantages of the chosen method. Secondly, a brief discussion of the collected data influence of the result and finally, a presentation of other possible methodology approaches.

To summarize the method as a whole, we consider the method mostly successful. There were two main advantages of the method. Firstly, one advantage was the use of PoC. PoC made it

possible for us to use a narrowed down scope that fit our time frame. A larger scope would quickly become too complex and would require a larger time frame. Secondly, another advantage was the availability of unstructured interview occasions. Since we had scheduled meetings once a week it was possible for us to decide if we needed to gain more information to evaluate the PoC criteria. However, there were also some disadvantages to take into consideration. There was a steep learning curve to create an understanding of the subject, the automotive industry carries complex concepts and terminology. Furthermore, we had to learn to work in a new landscape, Neo4j, with graph databases which we never had done before. We also had to learn a new language, Cypher, which took some time to learn.

As mentioned in our study, simulation data were used instead of live data from vehicles and charging stations. In a best-case scenario, the study would have used live data to create a more realistic and useful result. The use of live data would have increased the validity of the study, the validity could for example refer to the accuracy of the result. However, such a case would perhaps be too complex and require a time frame of more than 10 weeks.

The method is also evaluated on how the method could look from a different approach. Our method was based on the use of Neo4j representing knowledge graphs as a result. Another methodology approach could have been to only make use of interviews and not to create a visualized result. It could for instance imply to interview actors of other domains that already are making use of open standards and open data. The outcome of that approach could indicate concrete challenges and possibilities within the smart city ecosystem when applying open standards and making use of open data. The challenges and possibilities could be more detailed and complex than what we were able to find in this study. We might also be able to find out more about the effects of interoperability in a smart city, what it leads to and how it affects users and businesses. On the other hand, it could also be possible to interview actors of the automotive domain and urban IoT that are in the process of investigating how to apply open standards to capture some findings. However, the research question would in that case have to be re-formulated to suit the methodology.

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9. Appendix

Themes	Description	Questions
Proof of Concept evaluation criteria	Identify and define evaluation criteria	The interview questions were related to what was important for the project success
Availability of datasets	The availability of open datasets within the automotive and Urban IoT domains	Accessibility of the desired datasets and if they contained all necessary signals
Open standards	The suitability of the open standards	If all desired signals were represented in the standards
Interoperability	How to achieve interoperability using a knowledge graph	How to find matches between two datasets and why does the outcome indicate interoperability
Use Case	The use case relevance and extendability	The use case was discussed from a relevance and extendability perspective. Is the use case relevant and is it possible to conduct an extensive research from it
Technology	The technology suit and is relevant for our use case	Is the chosen technology relevant and suitable for our use case
Completeness	Completeness evaluation of the knowledge graph	What indicates if the knowledge graph is complete and how is it measurable
Consistency	Consistency evaluation of the knowledge graph	What indicates if the knowledge graph is consistent and how do we find contradictions

Table 9.1: The table presents the selected themes for the unstructured interviews and the characteristics of the asked questions.