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On API Design and Usage in the Connected Car Ecosystem

Bachelor of Science Thesis in the Software Engineering and Management

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ABSTRACT — Connected Cars (CC) represent one of the most important trends in the automotive industry. Providers and consumers in the CC ecosystem have their own goals, objectives, and expectations. The CC initiative also brings new challenges to both providers and consumers. As the CC bubble continues to inflate, it is the speculative and multidisciplinary nature of the ecosystem that makes the study of connected vehicles timely and important. In this regard, this work considers what is known as API (Application Programming Interface) value chain to build a better understanding of the CC ecosystem in terms of opportunities and challenges. As research strategy, we utilise a qualitative case study where empirical evidence was gathered by semi-structured interviews of major stakeholders in the CC ecosystem. The results show that no common characterisation of the CC ecosystem exists and that different API design and usage trade-offs exist depending on the stakeholder role within the API value chain.

KEYWORDS: connected car, connected car ecosystem, API value chain.

1. INTRODUCTION

Connected Cars (CC) represent an important evolutionary step for automotive Original Equipment Manufacturers (OEMs), mobile operators and consumers, turning traditional automotive products into services and packaging them together as complete integrated solutions. Many car manufacturers are betting big on the CC technology hoping that it brings both new exciting experience to consumers[1] and new economic opportunities for solution providers[2]. Beyond its technical aspects, connectivity allows integration of new kinds of business partners to the traditional automotive ecosystem. For example, many emerging businesses are developing new kinds of infotainment solutions to deliver richer content to vehicles [3].

Developing software solution stack for a connected car, however, involves a number of technical challenges. In fact, the rich variety of solutions, and solution providers, within the CC ecosystem is also a source of weaknesses. Different systems need to communicate with one another [1]. In order to achieve such communication software components and services have to be developed to allow interoperability and synchronisation of information from one solution part to another [1, 6]. This requires considerable upfront analysis and planning before actual development [5].

It has been argued that the use of Application Programming Interface(APIs)[1,2] opens the possibility for companies to deliver content and services through well-defined means and channels, which would allow for smoother integration of different technology offerings [3]. Such claim is already established for companies who provide

online content to its customers as well as companies which provide platforms to develop custom applications to end users [1, 2].

It has also been acknowledged that if properly designed and used APIs could become the center of a value chain that includes different kinds of stakeholders. As example API value chain, consider the case of AccuWeather company which provides APIs to access weather data. Application developers use the APIs to build weather apps that display weather statistics and predictions. The apps are then consumed by other applications, other businesses or end users.

Nevertheless, the use of APIs as a technological tool to orchestrate solution development in complex software ecosystems, as the case of the CC ecosystem, needs more empirical evidence and more conceptual elaboration [2, 4]. In fact, the AccuWeather example reported above is often reported as a small typical fragment of a wider and more complex CC ecosystem [1]. The wider picture is much more complex.

Assessing the role that APIs might play in orchestrating software development in the CC ecosystem requires a deep understanding of the ecosystem itself [5, 6]. In this regard, the value chain of API lends itself as an attractive approach to identify and decouple between the various elements and relationships in the ecosystem [1]. Further, exploring the opportunities as well as the challenges of APIs and bringing them to the attention of interested parties in the ecosystem might facilitate the development of comprehensive technological solution for connected vehicles [2, 4, 10].

To our knowledge, no comprehensive research work has been conducted on API design and usage in complex software ecosystems such as the CC case. This study aims to fill this gap of research by conducting an empirical study involving a sample of ecosystem actors. Our contribution can be considered as two-fold: First, we build a better understanding of the CC ecosystem from API value chain perspective. Second, we report on the significance of APIs in managing the technical, organisational, and business challenges of developing software solutions for connected vehicles [1, 12].

The remainder of this paper is structured as follows. Section 2 explains the purpose of the study as well as the research questions. Sections 3 presents background and related work that is relevant to our research questions. Section 4 covers the case company descriptions. Section 5 describes the research methodology we have employed. Sections 6 presents our research results, which are then discussed in Section 7. Finally, Section 8 summaries and concludes the work.

2. THE PURPOSE OF THE STUDY

2.1.AIMS AND OBJECTIVES

The overall purpose of this work is to study the significance of APIs in the development and running of the connected car ecosystem [1, 5, 11]. In particular, we focus on the following objectives: (1) to build a conceptual representation of the CC ecosystem from the perspective of API value chain; (2) to assess the relevance of APIs to different stakeholders in the CC ecosystem; (3) to examine the activities around API design and usage by different ecosystem actors; and, (4) to build an understanding of the constraints and opportunities of APIs in complex ecosystems such as the case of connected cars.

2.2.RESEARCH QUESTIONS

In this research we address the following questions:

RQ1. What actors and relationships exist in the connect car ecosystem?

RQ2. What is the role of API's in building products and services in the connected car ecosystem?

RQ3. What opportunities and challenges are experienced in API design and usage in the connected car ecosystem?

3. BACKGROUND AND RELATED WORK

In this section, we discuss concepts central to this research work and we give a brief statement of existing related studies.

3.1.SOFTWARE ECOSYSTEM

A Software Ecosystem (SECO) has been defined as a set of businesses functioning as a unit and interacting with a shared market for software and services, together with relationships among them. These relationships are frequently underpinned by a common technological platform and operate through the exchange of information, resources, and artifacts [22]. During the last few years, several researchers have conducted in-depth studies to explain ties between firms in emerging software ecosystems (SECOs) [6]. It was suggested that SECOs have become an effective way to build substantial and innovative applications and services on top of common software platforms by including components developed by different players within the ecosystem [4, 5]. This resulted in increasing numbers of integrated product and service offerings [6].

Nowadays, SECOs span diverse applications domains and involve stakeholders of different types and backgrounds. To be able to analyse a SECO within a specific domain, it is necessary to build a clear characterisation of that ecosystem in terms of its elements and relationships [5].

The diverse actors within a SECO form a social network around the technological platform, which is often structured to allow different players to contribute and generate value based on symbiotic relationships between the actors [4, 5]. The SECO movement has made many of the main players in the software industry revise their operating practices and open their platforms to external entities, to reach their business goals and keep up with time-to-market [6].

A popular example of SECO is the Android smartphone ecosystem where Google manages the Android platform while external developers create applications that are then distributed to Android consumers through Google PlayStore [7]. It has been argued that Google's collaboration with external developers has led to improved Android's value to customers, accelerated innovation, increased attractiveness and reduced cost [7].

ACTORS AND RELATIONSHIPS

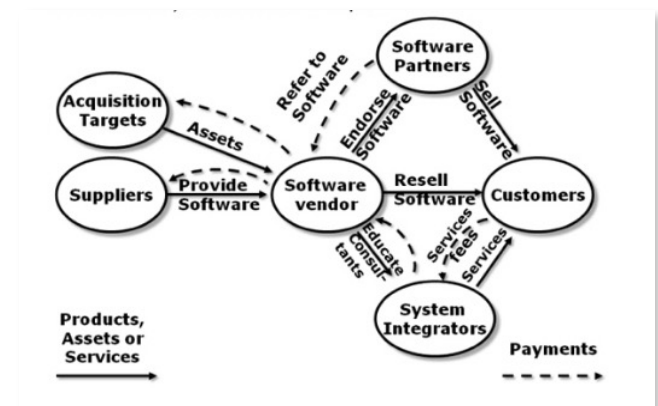


Figure 1. Players and their roles in the ecosystem [4].

Figure 1 depicts typical actors, marked with oval shapes, and activities, marked with continuous black arrows, within a SECO [4]. Six kinds of actors are identified. Suppliers and Acquisition Targets provide Software Vendors with software and assets respectively. Software Vendors in turn resell software to Customers. Vendors may also endorse software used by Software Partners and provide consulting services to System Integrators. Customers may also get software and services from Software Partners and System Integrators. The dashed arrows depict compensation for product and service acquisition.

Another classification of actors within a SECO has been given around the roles of Orchestrator (or Keystone), Niche, External actor, Vendor, and Customer [6]. Orchestrator is typically a provider of a platform technology. A Niche actor uses the platform to create business value. External actors are developers providing indirect value to the ecosystem. Vendor actors make profit from selling the products of the SECO to customers, end users, or other

vendors. Finally, Customers are entities that purchase or obtain a product of the ecosystem.

Using the Android example above, Google can be considered as the ecosystem “orchestrator”, partners such as Samsung can be considered as Niche player while app developers can be seen as external actors. The Android company, which provides an Android app store can be considered as Vendor. Example Customers include end users playing mobile games. Each actor plays a vital role in the ecosystem to maintain its stability and sustainability.

The technological platform underpinning a SECO plays a vital role in determining and maintaining the interactions between the various ecosystem actors. It is often represented by an extensible software platform where extensions can be developed against a set of well-defined APIs (Application Programming Interfaces). It has been suggested that actor interactions and relationships can be studied along three viewpoints: software, organisational, and business related structures [7]. This is depicted in Figure 2. It has been debated that those structures are critical when studying the static and dynamic aspects of SECOs.

Software structures contain actor and software elements that are related to the construction of applications in the ecosystem. Example software elements include source code units, software components and deployment nodes. Organisational structures contain actor and software elements that are related to the governance of the interaction and organisation of the elements in the ecosystem. Examples of such structures include knowledge flows and information sharing channels. Business structures contain actor and software elements that are related to how actors create, deliver, and capture value. These include business models and partner contracts.

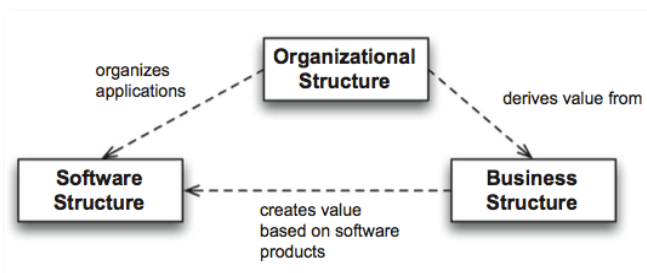


Figure 2. A three Viewpoint Model for SECOs [7].

3.2. CONNECTED CAR

The idea of Connected Car (CC) has grown significantly in the past few years following the evolution steps of mobile ecosystems [11, 12]. An essential part in realising connected vehicles is to comprehend how applications can be delivered to the vehicle seamlessly as the case of smartphones in the mobile sector [10]. The strategy of automakers is to evolve a frequently competitive car environment that

relies on the ability to integrate new in-vehicle features that uses different kinds of connectivity solutions [11]. An example would be to provide the car with in-vehicle infotainment system (IVI) offering a richer user experience [4, 11]. The trendy CC concept is recognised as one of the most exciting and innovation-driven industry; it leverages connectivity to vehicles offering incredible opportunities for both automotive and mobile industry as well as consumers [15, 16].

CONNECTED CAR ECOSYSTEM

The CC concept is evolving into a rich ecosystem of services providers and consumers, creating and developing product and service offering based on each other’s solutions. Not long ago, the CC ecosystem was a restricted environment where everything has been managed by automotive Original Equipment Manufacturers (OEMs) [5]. However, the collaboration today has opened to new partners including vehicle manufacturers, telecom companies, app and service providers and diverse automotive suppliers. For instance, the BMW ConnectedDrive system [16] represents a joint effort to provide consumers with a complete integration solution [16, 17] and to access a wide variety of different applications and programs [16].

As the CC ecosystem is rapidly growing in the software industry, the traditional ecosystem is shifting towards a more open ecosystem [5], enabling an increasing range of services [7, 10, 11, 13, 14]. In fact, the CC innovation platform has lately become a hub for non-automotive vehicle to join the automotive business sector. It is expected by 2020 [15] that the entire automotive ecosystem will completely transform to be connected to the Internet according to Telefónica [16].

The ecosystem of CC can be categorised into many different segments such as infotainment system or vehicle interaction. However, we have not mentioned all of them in this paper. An example CC model is given in Figure 3 showing five main focus areas within the ecosystem [19].

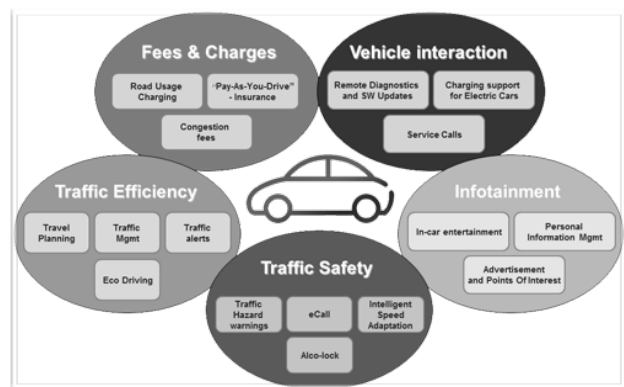


Figure 3. Connected Car Ecosystem [19]

Each segment in Figure 3 represents a subset of the ecosystem that have different stockholders involved in the innovation of CC. As we mentioned earlier, those stakeholders have different roles and engage in diverse collaborations to create assets to reach target users [5, 11]. The current reality is that the CC ecosystem is constantly evolving to become a seamlessly connected universe of different computing devices such as wearable, tablets, laptops, smartphones, and internet of thing (IoT) sensors; which is often connected through big data inside the vehicle to support prediction services[14, 19].

One of the applications of Traffic Efficiency given in Figure 3 is traffic alerts that can directly interact with vehicles to prepare for driving situations up ahead [19]. For example, the vehicle senses the road condition and then shares its information with others cars to inform them about traffic congestion or heavy rain. This kind of interaction called vehicle-to-vehicle (V2V) communication helps achieve smooth and safe continuing flow of traffic data [11, 14]. There is also a vehicle-to-X (V2X) communication which enables an exchange of information among cars and, of course between cars and the traffic infrastructure [11, 15].

Another example of traffic safety service offering called Automatic Emergency Call (eCall) is built to transmit the vehicle's location at the time of accidents. The eCall services ensure a safe automatic message emergency call centers, just in case of a car system crash on the road [11,15]. All these service offerings require connectivity points.

3.3.API VALUE CHAIN

This section discusses APIs and their value chain that enables developers in SECOS such as the CC ecosystem to create applications using the APIs, which are then used by software consumers. A typical API value chain is presented in Figure 4.

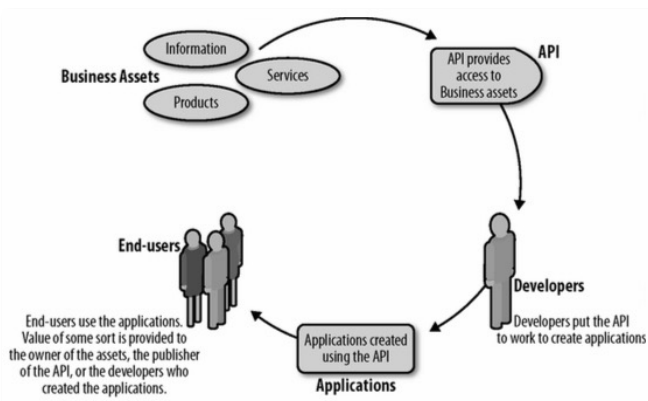


Figure 4. API Value Chain [1].

The API value chain illustrates the process of transforming business assets into value for end users through a number of steps. Each step adds value to certain actors in the ecosystem and connects to the next step in the value chain [3]. However, the nature

of business determines the value proposition, which depend on the type of APIs in the value chain. The following steps are:

3.3.1.BUSINESS ASSETS

Business assets represent value that a provider makes available to other actors in the ecosystem to use it. Business assets can be grouped along different categories including products, information, and services, and each one of these categories has its specific value [1, 3]. It is significant to validate the assets that the providers are exposing through the API and make sure that they provide value to target consumers. Otherwise, the API becomes useless and will not succeed [1].

3.3.2.API PROVIDERS

API provider is an actor who designs and create the API to expose those business assets to the intended API consumers through applications [1, 3]. In some cases the business asset owner is the same as the API provider, which makes the profit flows back to the business owner [1].

3.3.3.DEVELOPERS

Developers, also known as API consumers, are those actors who build application by using and adapting the APIs to their own business context. API consumers refer to people who have an interest in using the API to develop their businesses [1].

3.3.4.APPLICATIONS

Once the applications are created, they are made available to end users through a marketplace mechanism [1] provided by application distributors. The role of distributors is vital in the sales of applications to end users.

3.3.5.END USERS

End-users are the consumers of the applications created by developers. Also known as application consumers, end-users can include external developers, machines, and a human-user [1].

In this paper, we use the API value chain as a conceptual model to identify the various elements and relationships within the CC ecosystem.

3.4.RELATED WORK

There is little research work done on studying APIs in the context of the CC ecosystem. Most of the studies that we have come across discuss the various aspects that an automotive vehicle provides as part of the CC initiative [1, 3]. However, the works do not discuss how APIs are designed and used and what impact they have on the ecosystem [2, 6].

However, the CC ecosystem has also emerged as one of the most challenging technologies associated with both the business model of an organisation and IT innovation for APIs to solve [1, 3].Through these solutions, automotive manufacturers are now able to connect cars through these APIs, delivering a variety

of innovative business products and services such as infotainment systems, retail, and mobile devices, along with a wide variety of other business opportunities [2, 12]. In this way, consumers can also play a role by taking into account this new technology, thus creating opportunities to drive innovative new services to the CC [11, 12].

In defining and measuring the elements of the API value chain, an initiative has established a useful methodology to identify the level of in-vehicle connectivity at each step of the development process of the CC ecosystem [3, 6]. Regularly organisations in an ecosystem are arranged along value chains, where each of the steps of the value chain adds value to the services and makes them available to the next step of the value chain [1, 5].

In order to gain insight into the nature of APIs in the CC ecosystem, one must understand its value chain first [5]. The API value chain is crucial to accelerating value, improving business performance and, of course, extending business services to reach the widest possible audience [1, 3]. It, therefore, opens new channels for the automotive market and its customers [1]. It also improves customer loyalty and brand recognition; APIs can achieve all those advantages while keeping control over the data stream.

Nevertheless, many developers, both internal and external, do not know exactly what the APIs capabilities are or even what it is used for. The aim of this report is to fill the gap of existing studies, capture new knowledge and build a deeper level of understanding of the API value chain in the CC ecosystem by conducting an empirical study supported by reliable explanations [1, 3]. The latter is a vital area that has to be addressed today, not only due to the need of new businesses to engage in the connected car, but also to help traditional car manufacturers turn connectivity into core competency [11, 12].

An example CC ecosystem has been reported in the work of Cronin, M. J. [17]. The study explains how Ford has transformed their traditional system to an innovation-driven connected car concept. For the purpose, Ford has built an open platform where third-party mobile applications are developed and used. In the end, Ford has strived towards a CC ecosystem and adjusted their business model accordingly. However, Ford did not mention which exact APIs they were using to make the development process succeed [17].

4. CASE COMPANY DESCRIPTION

We have conducted our case study [9] in collaboration with different companies that are involved in CC ecosystem. Companies wanted to be anonymous due to data sensitivity and partners agreements. Therefore, we label selected companies in alphabetical order as in the following:

4.1.COMPANY A

A large Swedish premium automobile manufacturer company and has many branches all over the world. The company's headquarter is in Gothenburg, Sweden. The company delivers autonomous vehicles products and services. About two years ago, they have announced their Swedish Pilot Project of self-driving cars on the public roads on daily basis. Currently, there is ongoing development and delivery of the autonomous vehicle — Connected Car.

4.2.COMPANY B

A large Swedish multinational provider of services and communications technology. It is located in Gothenburg, Sweden, and is today headquartered in Stockholm. The company's offerings include services, software, and infrastructure in information and communications technology (ICT) for telecom operators and other software industry. It also provides the connected car services such as Cloud-Based Platform, and that will provide infotainment, communications services, applications in-vehicle. It has announced recently, collaboration with a number of partners in an EU-funded research project, called the internet of things initiative (IoT)

4.3.COMPANY C

A medium Swedish research institute located in the west of Sweden, Gothenburg City. The company C works to produce studies and developments related information technology (IT) in collaboration with different fields such as the industry, the public sector, and, of course, academia. It aims to help Swedish automotive and transportation produce substantial development and growth. Company C has collaborated with a global truck manufacturer in Gothenburg City to create innovation for IT-services, based on the platforms Automotive Grade Android (AGA), for transport. AGS platform based on Android operating system (OS), which allows access to vehicle signals in Fleet Management System (FMS) in the connected vehicle.

4.4.COMPANY D

A Swedish start-up company located in Gothenburg, Sweden. Company D has been involved in many different national projects and is currently working together with automotive Original Equipment Manufacturers (OEM) suppliers and other parties to build safe and natural speech-driven solutions. It also sells its product Talkamatic Dialogue Manager (TDM) to the automotive industry, which offers to developers and end-users Free Dialogue, as well as multimodality and rapid development.

5. METHODOLOGY

The research strategy we employed when conducting this qualitative study can be described as a case study [9]. Our research method can be classified by a combination of exploratory and

descriptive study. The selected methodology allows us to study the phenomenon of API value chain in its natural CC ecosystem context [9]. We have excluded design research and action research since we did not aim at finding a solution to an immediate problem facing a business value. We also could not conduct an experiment because we did not have any treatment that we needed to apply or a control factor to observe [8, 9].

An alternative approach that was considered was a survey study, but we found this method not appropriate for our study for at least two reasons. First, we aimed at an in-depth research on a particular subject that we did not know much about. A survey study would have been more appropriate if we wanted to collect wider opinions about data collected from a sample. For example, we had no idea what kind of challenges are faced in the CC ecosystem. It would have been hard to design a survey to cover detailed challenges. The second reason for our selection of case study relates to the size of the population. Our first contact with potential respondents indicated that it would be impossible to involve a large number of actors due to data sensitivity issues.

Further, we were not asking for numerical values; rather we needed descriptive textual data, for example to identify the actors and their relationships in the CC ecosystem.

We have used semi-structured interviews as data collection method gathered from different stakeholder perspectives to understand the API value chain in the CC ecosystem [8]. It is imperative to have the interviews with different people of various roles and organisational units. The use of different sources of data and information enabled better data triangulation. This may strengthen the study and increase research quality [8, 9].

5.1. RESEARCH APPROACH

As we mentioned earlier, we have pursued a qualitative case study to investigate and understand what and how the connected cars ecosystem used the API value chain to produce and deliver business value [1]. This approach was the best way to reach, collect and present the data. We have chosen a particular case company (i.e. Company A), along with other partners, because they have ongoing development in this area.

Company A started an initiative and a pilot project on self-driving cars on public roads. For this reason, we contacted various people involved in the development process of the pilot project. Based on that we have chosen business providers, software consumers, and researchers as the focus group. Those people play a leading role in the autonomous driving initiative which gave us the opportunity to have an open conversation and discussion that helped us to gather data from different perspectives.

5.2. DATA COLLECTION

We started our interviews with specific questions (See Appendix for interview questions), and then the discussion drifted towards more open-ended questions [9]. This technique gave us the opportunity to ask questions based on conversational flow regardless of questions order [8]. The interview also permitted us to improvise and explore points raised during the discussion, in turns it helped us to gather a richer set of data. A total of four interviews were conducted covering companies within different sectors. The total number of participants in the interviews was five. All the interviewees were deemed knowledgeable of the topic under investigation. The interviews themselves lasted roughly one hour and were recorded on a voice recorder. Notes were taken separately during the discussion.

We have prepared a set of interview questions in advance in order to collect relevant data and obtain accurate results. In fact, we had organised our interview questions into four parts. In the beginning of the interview, we presented our objectives and aim behind the interview. Then, we mentioned how the data collected from the interviews will be used. In addition we have asked the participant for their permission to record the interview during the first stage [8, 9].

Second, a set of introductory questions were presented to collect data about the interviewees and their corresponding organisations. Third, a number of questions were used to address the three research questions. This set of interview questions can be classified into four categories: (1) stakeholders and relationships involved in the CC ecosystem (RQ1); (2) role of APIs (RQ2); (3) challenges and opportunities (RQ3); and, (4) wrap-up questions, including open-ended questions [9], in case there is anything relevant to be added to the discussion.

We gathered data from four companies within the connected car domain in order to gain broader perspective of the initiative. The companies are operating in the region of Gothenburg. A qualitative data analysis method, namely, grounded theory approach is employed to explore and understand the issues covered. We followed a linear approach to analysing our data in two steps [8]. We first transcribed the interviews verbatim and then read through all the data to get an in depth impression. Last, we carried out a coding process to organise the text into segments [9].

To extend our data, we have interviewed different people involved in developing the CC ecosystem from the perspectives of API value chain. In order to explore in-depth the role of each element in the API value chain, we planned to interview participants with the following roles: (1) Business asset providers; (2) API providers; (3) Application developers; (4) Application Distributors; and (5) Application consumers.

5.3. PILOT TEST

We performed pilot testing of the interview questions to check that the domain of the interview questions labels the demanded information. We had 12 interview questions and for each one of them we applied various themes rely on the collected data. For instance, we have some questions have one theme while others have multiple themes, due to the diverse views given by the partners [9].

The motivation for choosing our strategy of gathering our data based on how reliable facts we are seeking to increase the confidentiality of our study. This strategy permits comprehensive coverage to promote the immense potential benefits of API design and usage in the CC ecosystem. Finally, the theoretical technique that we have chosen our sample is referred to as a purposeful sample. Because we looked for the most productive sample that answered our research questions.

5.4. DATA ANALYSIS

The approach we conducted to analyse our data was qualitative content analysis [21]. We followed this approach because all the data we collected is analysed accurately stepwise. We began our process to analysis the obtained data by identifying the domain of the interviews. Then we followed inductive reasoning to list our findings based on evidence and observation from our participants perspectives along four major steps:

As a first step, we started with summarising the data by interpreting the context of the interview data and organising it in text format. The goal was to highlight key terms and concepts in different categories. In the second step, we have labelled our categorised data in various coloured highlights, and then specified the connections between them after removing the unnecessary value. We assigned all the answers we collected for each question. Then, we kept the identity of the data throughout the analysis process. For instance, each company has its own identity and source information. To separate between them we labelled the selected companies in alphabetical order.

The third step was to gather some interview questions where the combination of their responses address a particular research question. For example, RQ3 needed to be classified based on the three viewpoints of ecosystem architecture (i.e. technical, business, and organisational structures). Finally, we have analysed all the data. The last step was summarising the answers for each research question.

6. RESULTS

This section describes our findings of four interviews of companies of different sizes (large, medium, and small), all involved in API design and usage in the CC ecosystem. The results are presented along the research questions. We find it important to start our findings with a definition of the CC

ecosystem as reported by our interviewees.

We have managed to interview only five participants out of thirteen planned and contacted. It was rather challenging to get access to companies for two significant reasons (1) the sensitivity of the data we were asking for, and (2) partners agreements.

The study has its limitations due to the fact that the sample we selected cover companies with different sizes in the automotive industry. We shall emphasise that the size of the company has an enormous impact on the results, in particular when it comes to identify the challenges and opportunities (RQ3). The interviewed participants have different priorities related to kinds of challenges and opportunities. Another factor that may have influenced our findings is the fact that companies play different roles in the ecosystem. In many cases it was not clear to what role the challenges and opportunities relate to. Nevertheless, we believe that the setting we described is typical in any software ecosystem

6.1. DEFINING THE CC ECOSYSTEM

The first two interview questions were designed to assess interviewee's perception of connected car and CC ecosystem. Most of the participants have described the two concepts differently. The following definitions were offered during the interview:

- A car is enabling to communicate with outside world, e.g., vehicle-to-vehicle, vehicle-to-infrastructure, or charging a battery in case of electronic vehicle.
- The connected car is wireless network enabled vehicles to interact with other devices both outside and inside the vehicle.

The interviewees also explained the CC ecosystem, meaning, and they shared one definition as follows: it is a car connected environment that is around a set of players collaborating to evolve both internal and external car connectivity. The ecosystem is around two main side of functionality offering: developers and users.

The participants also explained that the CC is a large ecosystem and consists of multiple ecosystems based on the software elements that interacts with different actors. For example, developers involved in CC development may include massive apps developers of different backgrounds. Developers create applications and services and distribute them on marketplaces such as APPStore (IOS), Google Play (Android), or simply third-party markets. The CC ecosystem use developer offerings to increase revenue and customer satisfaction.

Due to this, we eventually recognised from our interviewees that there is no current standard definition of connected car or CC ecosystem. It seems that the software industry has a long way to go

to standardise such concepts. In fact, our data gave us evidence that the definition of CC is still confusing to most audience. The definitions given are not aligned with one another. Instead, each respondent stressed their own perspective and role in the value chain. As suggested by the difference in the definitions given, we conclude that the CC is still an ongoing development effort and may get even more complex as new actors join the ecosystem.

6.2. ACTORS AND THEIR RELATIONSHIPS

The participants were asked to identify actors and their relationships involved in the CC ecosystem from API value chain perspective. All respondents have agreed on the same classification of actors and their relationships. However, they also mentioned that categorising actors in the CC industry by role is challenging because of the rapidly evolving market. One of the participants revealed that there are diverse actors playing multiple roles depending on the business goals they are trying to achieve. Usually, the same stakeholder assumes multiple overlapping roles in the ecosystem.

But, it was still possible to classify broad categories of industry actors. Table 1 shows the roles of each interview participant. For example, Company C is relevant to roles Business Asset Provider, API provider, Application developer, and Application consumer. The company assumes different roles depending on the goal and collaboration with other actors. Company B, which is an example of Application Distributor, engages into distributing applications that are created using APIs through several share-markets to reach their target users.

Table 1. Displays the participants who contributed in the interviews conducted for this research

Role of participant	Companies
Business Asset Provider	A, B, & C
API Provider	B, C, & D
Applications Developer	A, B, C, & D
Application Distributor	A & B
Application Consumer	A, B, C, & D

Then, the participants have explicitly explained the interactions between the components and each actor in the value chain. Moreover, they have also identified the critical players as those providing telecommunication networks and technology platforms on which telematics and infotainment services are delivered, along with suppliers, operating system providers, and automotive manufacturer. In addition, digital provider companies are helping both telecom companies and car manufactures by providing CC software and apps.

Our participants reported the values of each components in the value chain of API as a method to identify the assets' provider and their relationships. Based on our data, we have built a conceptual model for API value chain in the CC ecosystem. This is illustrated in Figure 5. Typical examples of business assets, API providers, API consumers, and application consumers are given.

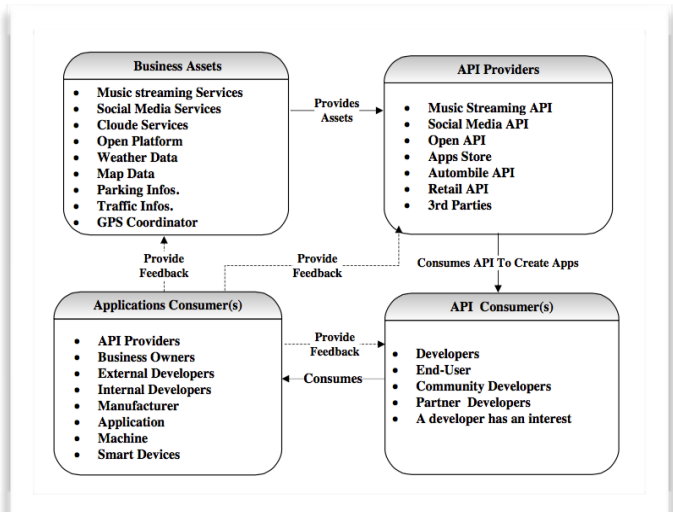


Figure 5. API Value Chain in the CC Ecosystem.

In some cases, the business asset provider is the same as the API provider. This is the example of the National Swedish Radio. In some other setting, the two latter actors are different from each other. This is the case of government providing traffic services offering. In this case, third party companies provide APIs to access such data.

During the interview, our conversation took its own flow to suggest the existing of Open Platform APIs in the CC ecosystem. All the participants agreed on the entire ecosystem of the CC used open APIs to support collaboration among the stockholders. For example, API providers, Telecom companies share some of their functionality with the outside world, Open APIs can generate a wealth of new apps that are created by the same features.

In other words, an Open API creates a smooth cooperation between the actors, to engage with their own users based on their needs. So the Telecom companies offer their platforms-as-a-services (PaaS) to other partners to serve their needs. This leads to building a real value chain among stockholders in the ecosystem. Creating these relationships also build trust in the ecosystem.

Another example provided by Company C and Company D is the use of open source software platform, Automotive Grade Android(AGA) as an in-vehicle solution providing APIs for both internal and external use. The AGA Platform, which is used as a kind of standard in the CC ecosystem, allows API

consumers to integrate Android apps and services into vehicle to access in-vehicle data such as mapping data. This creates for those companies an opportunity for significant competitive advantage as they build stronger relationships with external actors.

In fact this platform offers multiple opportunities to API consumers. We list a few of them in the following as reported by our respondents: (1) provide better interfaces based on driving context; (2) minimise distractions during driving, and (3) allow other connected services to be integrated. Consequently, there are different accessibility levels of APIs that could be used externally and internally depending on the nature of the business they are willing to expose. Depending on the business case, APIs can be public, private, or restricted to certain ecosystem stakeholders only.

According to Company C, there are no typical users of APIs as API consumers could be anyone who has interest in exposing business assets to other stakeholders. It does not matter whether the user is an individual developer, an internal development group, or an external entity. According to Company A, an API user could also be a machine device or a software component that implements or ensures connectivity inside the vehicle.

However, all interviewees agreed on the need to include feedback elements to the value chain. Different answers were given about the feedback loops, only one participant mentioned that there should be a Local Feedback Loop. The latter would allow users to innovate and enable them to produce regularly new and better services and products that instantly approach consumer interests. The rest of the interviewees have regarded feedback loops as dependency relationship between different actors, stating for example that application consumers should provide other players with their feedback on their exact needs.

Our data shows that the proposed conceptual model for analysing different types of actors and their relationships involved in the evolving CC ecosystem has been effective. It was considered that the API value chain model is useful for the endeavour, because it suggests players as the basic elements of the CC ecosystem such as business assets, API providers, Developers, Applications, and last but not least, End-user. These elements are among the standardising advocated critical components of CC ecosystem; in addition to a missing element called feedback.

In our opinion, the feedback element represents a critical relationship in the API value chain. This element is of great importance in the software development cycle since it allows ecosystem actors to gauge other stakeholder's expectations and needs.

Observation#1: (1) No standard definition of CC ecosystem, yet. (2) Multiple actors have different roles. (3) Mutual Collaboration among actors. (4) No critical API. (5) Exchange feedback is required in the development process. (6) Not necessarily the API providers \neq business owner.

6.3.THE ROLE OF API IN CC ECOSYSTEM

6.3.1.OBJECTIVE OF APIS

By following the next interview questions, we have asked the participants about the objectives of API usage in the CC ecosystem. Most of the participants emphasised the aspect of reusability. They believed that reusability can improve the productivity of both developers work and delivery time of software products. A developer from our case company A mentioned that APIs continuously increased the number of stakeholders as new customers, partners, and third-party organisations joined the ecosystem when the automotive industry started to adopt in-vehicle connectivity.

From what the participants reported there are two different perspectives of connectivity as one of the participants said; the use of APIs could be internal to the car or external connecting the car to outside environment. Company A has explicitly explained the internal and external aspects, as the following:

As example of internal connectivity, most of the cars in the example company are nowadays built with embedded computers called electronic control units (ECUs) which connect to different sensors for data acquisition. The AUTOSAR [20] approach, which heavily based on defining interfaces, standardise the ECU software architecture, and promotes exchange and reuse of ECU software elements between suppliers and vehicle manufactures. This approach helps mapping the software layer to well-structured coupled components. By defining uniform interfaces points in the system, the use of APIs reduce coupling across internal business channels to transport functions and services in the vehicle.

An external connectivity aspect on the other hand provides the car with links to the outside environment through the access of external data for example. Infotainment services have been stressed as good example of external connectivity. The use of the API in both aspects enabled the developers to seamlessly develop and integrate software components and functionality into vehicles. In this way, the API usage makes the developer's job easier, and brings in new opportunities to the ecosystem. The reuse of different features and components, allowed by the middleware layer in the AUTOSAR [20] technology for example, helped reduce development costs and delivery time for both the company and external developers.

When it comes to API capabilities, Company C mentioned that APIs have increased the innovation capacity of the ecosystem. Further, the use of APIs speeded up the delivery of innovative features in the ecosystem. They also described that APIs generate income for API consumers and gave them more possibilities when creating apps. External developers can build diverse apps and distribute them through different market places. Other actors may benefit from these apps in different ways.

6.3.2. QUALITY ATTRIBUTES

We asked the participants about the quality properties that API's promote in the CC ecosystem. Once again, the developer from Company A has emphasised that high reliability is one of the API's key goals. This is important especially that there are many different technologies that are used to ensure safe communication between various parts of the vehicle system. Company B and Company D on the other hand stated that the two fundamental qualities of APIs are usability and capability. Usability refers to the richer use of the created services and quicker integration possibilities between individual services. Capability in turn refers to broader connectivity among the players in the ecosystem.

Company D mentioned that creativity as an essential attribute that APIs bring to different ecosystem actors. It was emphasised that not all API providers or business asset owners are experts in application development. In this regard, APIs facilitate delegating expert development to other partners in the ecosystem. This in turn strengthens the innovation capacity between partners. Finally, one of the participants explained that one of the key roles of APIs is to enhance flexibility in developing the CC solution. Again it was pointed out that APIs encourage other companies to partner with automotive OEMs, thus expanding the ecosystem. An example that most of the interviewees have mentioned is a music streaming service company which joined an automaker company to integrate their music applications through a platform as a services (PaaS) in-vehicle entertainment system (e.g. Sync AppLink Services[17]).

6.3.3. OFFERING OF APIS FOR CC

All interviewees agreed that APIs offer new opportunities to ecosystem players to different degrees. Both Company A and Company C described APIs as fuel powering application development and integration processes in the CC. The use of APIs has also maximised revenue potential and generated higher business value to different actors.

Another participant from Company B reported that there are different possibilities of what an API can offer to their consumers. It was said that APIs improve customer experience and self-service capabilities, provide real-time insights into API consumers, achieve higher customer volumes, and enable on-demand transactions. Besides, APIs reduce costs across the entire API value chain. In addition

APIs improve the technical architecture of the vehicle because it helps mitigate integration challenges when composing solutions out of individual components. Further, coupling between software modules is significantly loosened.

Given the key role of APIs in the software development process, we believe that a more focused planning and analysis of the API value chain in the CC ecosystem will lead to greater business success. To this end, we anticipate that APIs are becoming a standard way of development.

Observation #2: (1) APIs can improve the internal development process. (2) Reduce internal coupling across line of business. (3) Make it possible to connect across platforms and partners in the ecosystem. (4) API is a pillar of mutual exchange information. (5) APIs are connectivity point between components.

6.4. OPPORTUNITIES AND CHALLENGES

During the interview, the participants have presented their view about challenges and opportunities of using APIs and agreed that the both challenges and opportunities can be classified along the three viewpoints of ecosystem architecture (i.e. technical, business, and organisational structures). They also agreed that APIs represent a key for both an opportunity and a challenge when addressing organisational, business, and technological resistance in the automotive sector. Most interviewees mentioned that the challenges the APIs pose can be mitigated through better collaboration between ecosystem actors.

However, these challenges and opportunities might be different from company to company based on two importance reasons: (1) Different roles played by companies make it difficult to identify which role corresponds to which challenges and opportunities, and (2) Company size. Those two reasons were the major factors in the ordering of challenges and opportunities.

For example, technical and management aspects in large companies are different from the ones in startups. For example companies A, B, and C stressed the significance of collaboration and organisational challenges. This was not a major concern for Company D.

6.4.1. OPPORTUNITIES

The business opportunity enabled by APIs is huge both for mobile operators and car makers. A researcher from our case company anticipated automotive forecasted that business revenues of CC services will increase in the next couple of years as the initiative materialises. It was also said that more customers will be attracted to the ecosystem. Further, Company B has also explained how APIs, as

an architectural and programming model, leads to better structures of software within the CC ecosystem which helps reducing development and integration cost. It was mentioned that APIs help organising the business processes within the ecosystem.

On the technical aspects, the participants argued that the use of APIs helped loosen the coupling between software components and accumulated less technical debt for each part of the functionality built. APIs make it a lot easier to replace components or modules with other alternatives. They also mentioned API opens new channels, thus making the ecosystem expand beyond its traditional borders. Company D has also mentioned that through APIs it is much easier to migrate to new technological solutions.

In addition, the participants discussed at least three major channels related to API offerings, namely distribution, information, and sales channels. An example of a content distribution channel is how music data distributed through Internet connection reaches its consumers. Using APIs as a facilitator to distribute digital content increases customer fidelity in online sales and rises advertising revenue. Accordingly, a developer from our case company A APIs provide simple ways to integrate various software components from suppliers and developers. It was added that from organisational viewpoint, APIs provide a good opportunity to collaborate with other players in the ecosystem. The same respondent mentioned that APIs not do a good job at the business level but also help standardise software development related to development methodology, architecture, and ECU interfaces. We conclude that standardisation of APIs is an important step to make it faster to build products and services for connected vehicles.

It worth noting that our participants gave different ordering of opportunities kinds (see Table 2). Companies A, B, and C reported that APIs bring in mostly business opportunities then technical and organisations ones. In contrast, Company D placed technical opportunities as the main ones, then comes business and organisational opportunities respectively. The reason could be that company D is still a start-up company.

Table 2. API Opportunities in the CC ecosystem

Opportunities	A, B, and C (75%)	D (25%)
Organizational	3	3
Business	1	2
Technical	2	1
*100% ALL the participants have quite high response rate (all agree)		

Table 2. shows company views on opportunities and their level of importance. For example, 100% of the respondents gave less importance to organisational issues. But, when it comes to business and technical opportunities, the priority level has been different among the interviewees. 25% of the respondents assigned high importance to technical matters while the rest considered them as of medium level. 75% of respondents reported that business factors are of high importance while 25% of respondents reported the, as level 2.

Observation #3: (1) Create new lines of business and extending products offerings. (2) Build new channels opportunities. (3) Enabling reusability. (4) API improves brand visibility. (5) Company size is matter.

6.4.2. CHALLENGES

Our case companies reported that APIs pose a number of organisational challenges mainly due the involvement of a large number of actors in the CC ecosystem. They also explained why that could be an issue to the keystone actor in the ecosystem (i.e. car manufacturer). This becomes a serious challenge especially when one of the actors performs changes to existing features, so the challenge here is how to communicate those changes to the rest of the actors and how to avoid possible conflicts. As mentioned earlier, the migration to a new system architecture requires strong collaboration and careful planning between ecosystem players.

From a business perspective, the interviewees reported that APIs brings in new business models, making it hard for some partners to adapt to the new business context. APIs might increase competition between different players which may result in the emergence of new players and the decline of some others. It was reported that new business models are required as APIs become central to development. The ecosystem as a whole should also take care that business value is delivered to different actors in order to maintain the sustainability of the ecosystem.

Our participants were discrete about the technical aspects, due to data sensitivity issues between competitors and partner agreements. However, Company C and Company D emphasised that security and safety aspects exposed by APIs represent real challenges. Company B agrees with Company C that security aspects have been always an issue in the automotive domain and may affect the trust level between actors in the ecosystem. It was also reported that configuration and integration tasks could become time consuming as more effort is spent on conforming to standards.

Another important technical challenge to be considered is the use of APIs as software-as-services (SaaS) to address business needs. This is a serious issue especially when it comes to integrating with legacy software applications as it compromises service delivery time. The integration may also be problematic if the APIs are not well defined. This is why all the participants have emphasised during the interviews that the success of the business process required a well-defined API to overcome integration issues.

Once again the participants have disagreed on the ordering of challenges (see Table 3). Companies A, B, and C reported that organisational challenges are the most dominant, then comes business related challenges and lastly technical challenges. In contrast, company D thought that business challenges are the most significant followed by organisational then technical issues. Similar to the case of opportunities, we think that company D is different since it is a small start-up compared to other participants.

Table 3. API Challenges in the CC ecosystem

Challenges	A, B, and C (75%)	D (25%)
Organizational	1	2
Business	2	1
Technical	3	3
*100% ALL the participants have quite high response rate (all agree)		

Table 3., shows the importance levels of challenges reported by our interviewees. 100% of the respondents assigned low level to technical issues (level 3). But, when it comes to business and organisational issues, the participants have given different ranking. 25% of respondents assigned a high importance level to business issues (level 1) while the rest considered them as level 2. 75% of our respondents regarded organisational concerns a highly important, while 25% of the respondents assigned them to level 2.

Observation #4: (1) Migration of software create challenges. (2) New changes without awareness of actors is a challenge. (3) Unwell-defined APIs arise issues. (4) Security and safety factors have been always an issue. (5) Company size is matter.

7. DISCUSSION

7.1. ANALYSIS OF THE RESULTS

Perhaps the most important point made from our study of API design and usage is that the value chain is complex and perceived differently by different actors. This confirms our observation of the literature being inconsistent when it comes to defining connected vehicles and the CC ecosystem. This however might be an indicator that connectivity in vehicles is indeed a scorching hot topic in the automotive industry. However, the confusion in the terminology and perception might not be the best choice when it comes to consumers. Confusion might negatively influence adoption [10,11].

In fact, what surprised us is that the same people who are involved in evolving the CC initiative are still confused about the term. This becomes even more challenging when APIs are brought in to the discussion. The relationship between connectivity and interfacing has not been always crystal clear. From our perspective, we see that this case study may contribute to standardising the definition of Connected Car Ecosystem across the boundaries of its actors. Furthermore, it also has been very interesting to find out that the automotive industry has missed to clarify that APIs have a positive influence on the connected car software development process. This is probably because APIs have traditionally been discussed in the area of business offering over the Internet and not in the field of embedded systems.

We have observed that the use of API and its value chain in the CC, break the complexity of the ecosystem, and that it opened up new opportunities and challenges. However, these significance level of challenges and opportunities vary from one actor to another. This partly explains why certain challenges remain unresolved, a challenge for an actor might not be the same challenge for another. As a result, such challenge is not resolved at the ecosystem level. Contextual factors such as company size, application domain, and position in the value chain might explain the variance in the way opportunities and challenges are perceived and reported.

The variance in opportunities and challenges posed by APIs is a showcase of how complex is the CC ecosystem. One might expect such complexity to be reduced as the domain matures. However, according to our respondents, the situation might worsen as new actors join the ecosystem. This is why careful planning, extensive collaboration, and increased openness are needed. What makes the situation even more complex is that some actors assume different roles in the value chain. In such situation, the actor needs to consider trade-offs and make compromises since a decision (technical, business, or organisational) might be good from one role perspective but bad from the other role viewpoint. Further, we have learned that our respondents are not necessarily aware of the indirect

channels allowed and brought in through APIs. Most actors still maintain the classical thinking of direct channels.

Our study shows that the API value chain perspective is significant to understanding the elements and relationships within the CC ecosystem. We also observed that the selected topic is very sensitive to the automakers and their partners. Most partners however were discrete when it comes to technical details. This may have influenced the results of this work. Other valuable knowledge might have been missed. The good news is that our discussion with the respondents gave them a new perspective to the CC ecosystem and opened up new points for reflection.

As implication to research, this study has triggered new possibilities for exciting future directions. We foresee interest in exploring the openness level of platform APIs in the CC ecosystem. In fact that every software platform has to have a rank of openness since it seems there is a tradeoff between the number of new third-parties willing to join the ecosystem and the challenges caused by the increased size of the ecosystem. The following area should be investigated as future research challenges or directions with regard to the selected topic:

RQ1: How can openness of API platform impact the success of business structures in the CC ecosystem?

RQ2: How to manage challenges related to Open API platforms in the CC ecosystem?

Related to implication to practice, we recommend actors involved in the CC ecosystem to open up their discussion and engage more students and researchers in the field. That may help in clarifying concepts and terminology which would boost adoption of the new CC technology. New niche businesses could also be initiated by fresh university graduates and researcher, thus consolidating the ecosystem, if community collaboration is stronger.

7.2.VALIDITY THREATS

In this section, presented all the possible limitation that we had during our research topic include a number of validity threats to be considered [8].

7.2.1.CONSTRUCT VALIDITY

A big threat could face us during this study is the use of unclear interview questions and terminology. To minimise this threat, we had applied pilot interview questions [8] to make sure that the domain of the interview questions covers the required information. We chose also Face-to-face (FtF) interview [8] to ensure a common understanding of the terms used in the interview questions that should be exist. Thus, this validity assures that the foundation of the research paper relates to a problem

that stated in the research questions, and that our selected recourses are relevant [9]. Further, the selection of interviewees could be a threat if we chose the wrong people for our interview. To minimise this risk, we need to keep in our mind the purpose of the study.

7.2.2.EXTERNAL VALIDITY

This section concerns how the outcomes of our case study can be generalised. To solve this possible threat of being not limited, the purpose of the qualitative studies is not to generalise the result to the entire population. The purpose is to get an in-depth understanding of the phenomena of this study. However, if several companies identified the same challenges or problems, then this can help in drawing conclusions that may be applicable to similar companies to the ones in this study [9]. Despite of that we identified the amount of interviews in this paper as a threat to validity, since we were only able to conduct four interviews in total this could mean that our results may not be generalised.

In order to mitigate the threat associated with generalising the results reported for each role in the API value chain, our selection of participant companies made it possible to cover the same role multiple times. We took this fact into consideration when reporting on the challenges and opportunities.

7.2.3.INTERNAL VALIDITY

Interviews were our primary data source in this study. This could present a threat to validity since the interviewed participants may be biased. We have identified potential threats before each interview to avoid confirmation of bias and inconsistent questioning. We also realised that only the interviewees themselves could be used to assess the credibility of the results and spot potential inconsistencies. This is why we considered triangulation of the results. Triangulation was achieved by interviewing five different people from four different company sectors. This allowed us to compare the participants from different perspectives based on their different roles and their different level of knowledge and experience. We also were not trying to build consensus among the participants, but rather to understand many ways of seeing the data.

7.2.4.RELIABILITY

The possible threat to validity here is whether the data collected and the analysis made will lead to the same results by other researchers. We mitigated this threat by making sure that the concepts we used in the study (API value chain, the three view model, and connected car ecosystem) were clearly presented to the interviewees. Also, transcriptions may be considered as a reliability threat in case the audio is not clear. This threat has been mitigated through taking notes in parallel to recording the interviews.

8. CONCLUSION

Through this research paper, we have conducted a case study to understand CC ecosystem from API value chain perspective. The latter plays a critical role in how and why a CC evolves in its ecosystem. We perceived that API design and usage varies depending on which actors are considered. We also concluded that currently there is no standard definition for connected vehicles and the CC ecosystem. The continuous and rapid evolution of the field is not helping in this regard. However, considering a particular viewpoint such as the one considered in our study (i.e. API value chain) helps in building a better understanding of the ecosystem.

We had three major research questions that were answered through four interviews. The full data set included respondents from Gothenburg City, Sweden. The interviews were face-to-face (semi-structured) interviews with only five actors, where the interview questions were asked from four different companies. All the interviewed participants, we came across have different roles within their company.

Our first research question was to identify the actors and their relationship involved in the CC ecosystem. We have found that multiple actors play different roles in the ecosystem from API value chain perspective. The companies are different but the same company typically represents different roles. These roles have different responsibilities, which translates to different relationships between the actors.

The second question of this paper was to find out the role of APIs in building products and services in the connected car ecosystem. The result we got can be listed as the following: (1)improving the internal development process;(2)reducing internal coupling across line of business; (3)making it possible to connected across platforms and partners in the ecosystem;(4)establishing a medium for mutual exchange information in the CC ecosystem, and (5) establishing indirect connection channels between actors.

Our final research question was to assess the challenges and opportunities in the CC ecosystem. We provided a prioritisation of those based on a three viewpoint model to ecosystem architecture (technical, business, and organisational). Different respondents gave different orderings based on their dominant role in the ecosystem and of course the company size. Business opportunity seems to be the most significant driver for large and medium organisations, as opposed to technical drivers for smaller business entities.

On the challenges side, organisational matters tend to be the biggest concern of large organisations. This is in contrast to smaller start-ups which view business issues as their main challenge. In a perfect world, all the challenges of all the actors need to be taken into consideration in order to sustain the

ecosystem. In concrete terms compromises have to be considered by all parties to avoid collapse of the ecosystem.

Future research and development should address business, technical, and organisational challenges of the CC ecosystem. Also, a better understanding of the API value chain would be beneficial to all actors.

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APPENDIX

INTERVIEW QUESTIONS:

#	Interview Questions
1	What is your definition of Connected Car?
2	What is your definition of Connected Car ecosystem?
3	Are there different levels of APIs (i.e public, restricted, private) in the Connected Car ecosystem?
4	What business assets (i.e. information, services, and products) are made available in the CC ecosystem?
5	Who provides APIs for accessing the business assets?
6	Who are the typical users (i.e. application developers) of APIs?
7	Who is the consumer of the applications? Are they human users or machines?
8	What is the objective of creating APIs in the CC ecosystem?
9	What quality attributes do API's promote in the ecosystem?
10	What APIs can offer to business asset providers, application developers, and end users?
11	What technical (software related), organizational, and business related opportunities do APIs bring to the CC ecosystem?
12	What technical (software related), organizational, and business related challenges do APIs raise in the CC ecosystem?