The technical pull towards open innovation in the development of ITS networks for autonomous vehicles

The relative strength of open innovation drivers

Master's Thesis in the Master's Program
Entrepreneurship and Business Design

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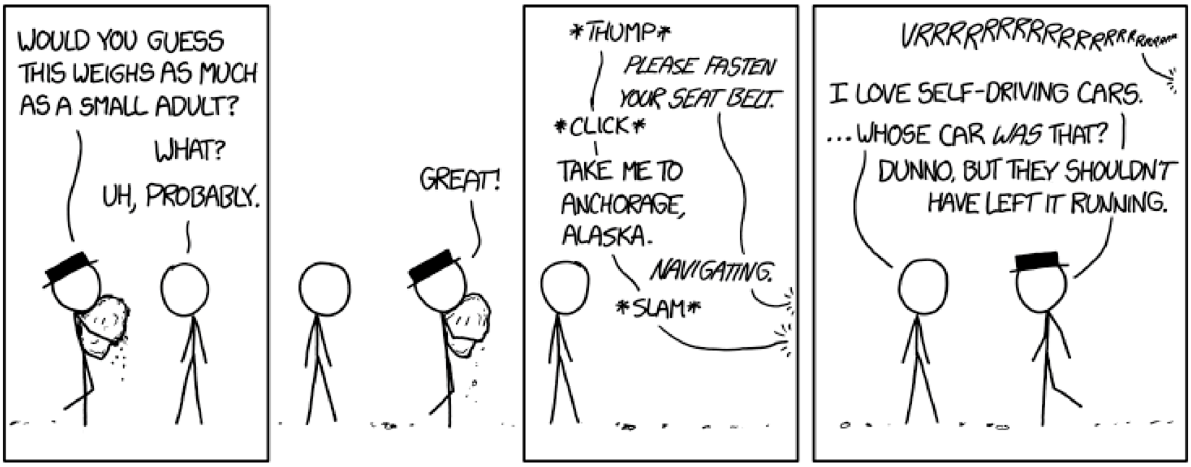

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Foreword

This thesis was written during the spring of 2016 as the final part of a master education in Intellectual Capital Management. Its creation represents the author's attempt to understand how to anchor the ethereal subject of open innovation in the more tangible field of technology. In this process the people surrounding me have been indispensable.

Thank you Erik for allowing me to explore and build whilst always making sure my trajectory pointed towards something relevant.

Thank you Bo for adding perspective and much needed chill to a racing mind.

Thank you Sanne. This exists because of your support.

Erik Wintzell,
Chalmers University of Technology
Gothenburg, Sweden
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Abstract

Use

With products becoming increasingly complex and expensive to develop open innovation initiatives are increasing in relevance. Understanding where such initiatives are more likely to be pursued and can create more value can help actors focus their efforts and foresee the development of new market structures.

Purpose

The purpose of the thesis is to create a framework for analyzing where open innovation initiatives are, for technical reasons, more likely to be initiated in the development of ITS networks.

Method

The thesis was written at a major automotive manufacturer to study factors affecting the direction of autonomous vehicle development. It was written from an external viewpoint and no information regarding the manufacturer's technologies, systems, or assessments was disclosed to the author to ensure impartiality. On request from the company no technical experts were consulted. The thesis is thus based only on public sources. No choices, views, or statements represent the standpoints of the manufacturer. The ITS network structure is based on combining CVRIA, nITSa, and in-vehicle autonomous drive systems. This ITS network structure was delimited to only include systems directly interacting with the vehicle, and these systems were then grouped to reflect a plausible structure as estimated based on a literary review. The synthesized ITS network was then evaluated according to the interoperability effort assessment framework and the systems with the highest scores identified. Within each of these systems a key technology was identified, and which companies held capabilities within each technology mapped using patent information. Finally, existing open innovation initiatives within the field was evaluated against the created maps.

Theoretical framework

The theoretical possibility to evaluate the likeliness of open innovation to be pursued is based on the work of Chesbrough, Teece, and Vanhaverbeke. A combination of two reference architectures describing a future finalized ITS network combined with an in-vehicle system network is analyzed. Patent mapping of key technology is used to evaluate technical capabilities of actors. A framework derived from the system engineering effort evaluation framework COSYSMO is used to evaluate interoperability needs between systems. The resulting maps are compared to examples of existing open innovation initiatives.

Results and implications

The framework produce interoperability maps which highlighted systems correspond with the scope of analyzed open innovation initiatives. The profile of actors engaged in the initiatives is consistent with the capability map and expected results for initiatives working with system development, but not for the development of general standards.

Innehållsförteckning

1 Introduction

This first part will explain the background for the study and the relevance of the thesis. Then the purpose of the thesis and connected problem formulations are presented, followed by delimitations.

1.1 Background

The autonomous vehicle, or self-driving car, is coming (Alankus 2012). No matter what perspective is chosen the area is an interesting one. It will impact the auto manufacturers of today, and induce collaborations openness (Wee 2015). And the possible gains from autonomous vehicles are many, ranging from reducing the number of fatalities and injuries by removing the human factor, to improving traffic flow (Weeratunga 2015).

Intelligent Transport System networks, or ITS networks encompasses all systems that are part of delivering the services needed and wanted to enable functions, from autonomous driving safety to in-vehicle entertainment. European Union directive 2010/40/EU defines the term as follows:

"Intelligent Transport Systems (ITS) are advanced applications which without embodying intelligence as such aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks."

The directive further exemplifies what this might include by pointing out how telecommunications, electronics, and information technologies integrates with transport engineering in order to plan, design, operate, maintain and manage transport systems. The network includes such systems as map providers, emergency services, road infrastructure, base stations, and commercial vehicles (PARLIAMENT and UNION 2010), (Picone, Busanelli et al. 2014).

Development are underway in both the in-vehicle systems that does the actual driving, and in the ITS networks that will be needed to supply the vehicles with data input to achieve full automation. A combination of these is needed to reach that goal (Weeratunga 2015).

Combining the plethora of systems and technologies needed to create the autonomous vehicle will be burdensome for firms, and the choices made when it comes to cooperation between firms and technologies might prove strategically important. For actors that are developing systems within this field, focusing the collaboration efforts when developing systems for the network to the situations where it is most relevant could save valuable resources. Similarly, understanding the need other actors has to engage in collaboration efforts can prove to be valuable when trying to anticipate the market.

This thesis is written to find a way of addressing the problem of forecasting where cooperation and openness might feature more prominently in the process of creating an autonomous vehicle.

The basis for an answer is sought in analyzes of the technologies involved, and which actors are engaged in their development. This is due to an ambition to formulate a more objective answer. Thus, the thesis needs to understand how technological needs can drive openness first. To assess the identified drivers the appropriate frameworks must thereafter be found, together with a way to test the framework for validity.

The framework and the results created when applying it to the area of ITS networks jointly aims to create a basis for estimation of the relative pull for actors to engage in open innovation initiatives when developing the affected systems. Hopefully, this will help to empower actors to open up and together create the vehicles of tomorrow by dispelling some of the insecurity.

1.2 Thesis summary

To make a vehicle self-driving many systems are needed. The systems must work together to enable the vehicle to drive itself. To make sure the systems fit each other open innovation can be used, as is done for example when joint ventures are created, standards defined, or interfaces opened up.

The reasons to engage in open innovation for an actor are many. If the actor is to develop something that is going to be part of a complex system, then how hard it is to make the system interact well with the other systems is a driver if the actor can't develop all systems by itself.

By looking at how much information is going to be exchanged between systems, how complex the information is, and how many functions in the systems are involved it is possible identify which systems are hard to get to interact with other systems.

By looking at which actors has patent in technology areas important for a systems it is possible to see which actors has the knowledge to develop the interacting systems themselves.

The framework is evaluated by comparing the results of its application to examples of existing open innovation initiatives. The examples looked at all concerned systems which are harder to get to interact with each other. The actors engaging in the initiatives are complementing each other when it comes to their knowledge, except for the case of a general standard setting initiative.

2 Purpose

The purpose of the thesis is to create a framework for analyzing where open innovation initiatives are, for technical reasons, more likely to be initiated in the development of ITS networks.

The aim is to pursue this purpose in a way that enables the delivery of a tool of high relevance for the auto manufacturer for whom it was conducted. This aim of relevance influences decisions of delimitations, scope, and sourcing throughout the thesis.

2.1 Problems

No framework for assessing technical open innovation drivers for systems within an ITS network for autonomous vehicles has been found. To create such a framework the following questions were answered;

1. What technical aspects drives open innovation?

Closely linked to the definition of open innovation, there are many types of drivers for open innovation. Identifying drivers that can be measured more objectively from an external viewpoint is central to ensure that the results of the study has the potential to be valid.

2. How should technical drivers of open innovation be assessed for ITS networks?

The drivers needs to be assessed with tools appropriate for the situation within ITS networks. The tools used are drawn from existing theory within the technology field of ICT, support the inputs chosen, and be possible to validate. As ITS networks are partially developed, and collaborations and standardization initiatives has already been started, the state of the technology today can serve as input in a validation process. First the framework is applied to a representative view of how a future ITS network looks, then these results are compared to the started initiatives, and the validity assessed.

3. How are the systems that make up an ITS network configured in relation to open innovation drivers?

Mapping out the state of the open innovation drivers today provides the input for validating the framework against reality. This mapping will be conducted on relevant input data, with an additional aim to pick a representation of an ITS network that is interesting for a wide geographical area.

2.2 Delimitations

All major delimitations will be presented here. The delimitations are also explained within each step of the thesis to better place them in a meaningful narrative.

Delimitations of theoretical scope

- Only reasons actors want to engage in open innovation is considered.
- Only open innovation drivers of technical character are considered.
- Only situations with complex networks of systems are considered.

Delimitations of network used as input

- The subset of systems included in the map is limited to systems that directly exchange dataflows with the vehicle in reference architectures.
- Special vehicles are removed, as are systems detailed in table A4 in Appendix C.

Delimitations to capability assessment

- No relative assessment was made of capabilities between actors. Any number of patent families found in an area is an indication of capabilities to develop that system.
- Only systems with a higher effort needed to achieve interoperability were analyzed

3 Method

In short, the thesis was constructed from the following parts:

First a literature study into the theoretical area of open innovation was conducted of the writings listed in a review article of the most cited works in the area, followed by additional searches of interesting sources cited by these works in turn. This study resulted in identified technical drivers for open innovation.

Secondly, another literature study was conducted to identify theoretical frameworks suitable for assessing the identified drivers. This study was I two parts, one focusing on interoperability assessment frameworks in the area of complex IT-networks, and the other concerning ways of measuring actor capabilities.

Next, an extensive literary study over the area of autonomous vehicles and their network of support-systems were conducted. This study identified the general structure of the networks, and suitable sources to use as input into the identified frameworks.

An iterative pruning and consolidation process was then conducted on the chosen source material to reduce the number of nodes within the described network to an amount possible to handle, yet still highly relevant from an auto-manufacturers view. Extensive cross-referencing with high-value sources identified during the literary review conducted over the technology areas was employed to ensued validity.

The frameworks identified in the aforementioned studies was then validated in relation to the auto-manufacturer by conducting an in-depth qualitative discussion with a field expert at the company, and the evaluation model used was slightly altered to reflects the views expressed.

The newly re-scoped network was then fed into the frameworks and qualitatively evaluated for the two identified drivers.

Then a highly iterative and qualitative process for creating viable patent landscapes for the technology areas chosen was conducted. Validity of the subsequent results of this was elevated by requiring 80% relevance maintained in random samples of the found patents.

The frameworks validity in relation to reality was then tested using a multiple case study method for comparative analysis, where existing open innovation initiatives were compared in scope and actor participation to the results of the framework's application to the ITS network.

The following sections explains in more detail how the study was conducted. It begins with an overview of the study, followed by a general theory concerning research methodology. After that the steps taken are described in detail, and the section concludes with a short discussion on the implications of the method used.

3.1 Nature of the study

This section outlines the nature of the thesis in regard to its approach, epistemology, ontology, and the implications this has for any results created.

According to Bryman and Bell (2003) there are generally two types of scientific studies; inductive and deductive. A deductive approach is what is used to a large extent in this thesis, and is described by Bryman and Bell (2003) as conducting the steps in figure 1.

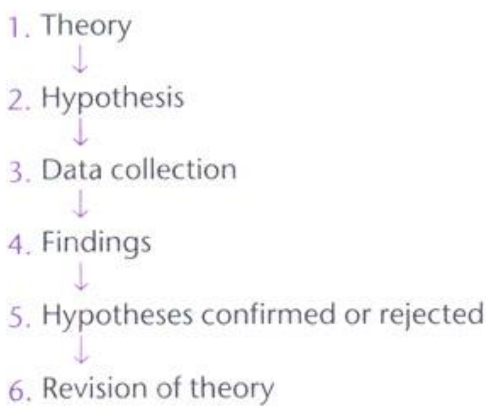

Figure 1, the deductive process.

The thesis adheres to this process quite well (see previous section for quick reference), with an additional initial step of identifying the appropriate theories which to frame the problem in. There is also a lack of revision in the theories used as such, and instead the thesis conclude with identification of which part of the theories was found to be consistent with results, and which was not – a revised theory in itself is not formulated.

In regards to the epistemological and ontological natures of the thesis, an interesting situation materializes. Consider the fact that in essence the thesis is based on qualitative choosing of theories of quantitative nature fed with data generated through a rather qualitative process, the object of assessment being possible future constellation of a large amount of systems not fully developed at the moment. This means, that from an ontological viewpoint the object of study, a future ITS network, is per definition ontologically subjective – we cannot measure the future. And the ultimate object of study being the probable need for collaborative behavior from collections of individuals in relation to this future network, this puts the study in the realm of subjective epistemology – the probabilities of future behaviors is not subject to a public consensus of any kind.

In this thesis the aforementioned use of deduction, and quantitative methods being fed with qualitative data, is to some extent not consistent with the nature of the study in itself. Bridging this gap is done by seeking to understand the *relative probability* of the manifestation of the future behaviors. More tangibly measurable and less ontologically subjective, the technical specifications and the indicators of technical competence are studied instead. As the thesis as a whole strives to answer if measuring these factors provides results relevant to estimating the probability of future behavior, it is then exposed to both questions about the choice of any input data, as well as the relevance of any relative estimation on the drive for open innovation as any result will only point towards more probable behavior, not provide executable predictions.

Summarizing, the thesis concerns itself with investigating the possibility to estimate the probability of future behavior via the measurement of more tangible underlying drivers. It thereby does not try to shift the nature of the question and its object itself into more objective parts of ontological and epistemological theory, but rather to investigate the ties to the more tangible possible drivers.

3.2 Creating a basis for analysis

This section describes how the input data for the conduced analyses were synthesized. The resulting product is both deemed to reflect the vision of major actors, and provide an adequate data structure to allow for the needed computations and assessments.

3.2.2 Literary studies as a starting point

The first step of the study was to conduct a literary study into the fields of ITS networks and autonomous vehicles. Surveying the most recent reports released by consultancy firms on the subject (Wee 2015, Thomson Reuters 2016) it became clear that in-depth technical understanding would be needed to stay more relevant. A broad search of technology and market structures was conducted, identifying three of the central sources of information in the thesis – The report *A functional architecture for autonomous driving* from Behere and Torngren (2015) and the books *Advanced technologies for intelligent transportation systems* (Picone, Busanelli et al. 2014) and *Intelligent transport systems: Technologies and applications* (Perallos 2015). New searches into areas not deemed sufficiently described was constantly conducted, especially in the phase of identifying key technologies for systems, to ensure that qualitative assessments were correct and corroborated. Sources have also been checked for accuracy and discarded if found to lack in validity.

3.2.2 Synthesizing a probable future structure of a completed autonomous drive network

To analyze where Open Innovation is more likely to occur in the field of ITS networks for autonomous vehicles, the structure, functions, interactions, and some key technologies needed to be identified - as described in section 4, Framework. This section describes how the different starting points for this process was chosen, where delimitations were made, and how the resulting parts were fused together.

3.2.2.1 ITS reference architectures

As a starting point for understanding the taxonomy and logic within these complicated networks, two contemporary works were initially consulted (Picone, Busanelli et al. 2014, Perallos 2015). These gave in depth explanations about a wide range of important aspects of the state of ITS networks at the time of writing, describing initiatives in many fields and their technical make-up - such as the WAVE project which is a vehicle-to-vehicle communication scheme. However, all the referenced ongoing projects were found to be limited in scope, and not focus on the network as a completed whole. Instead the so called ITS reference architectures were identified as being of particular interest for the thesis.

The ITS reference architectures are conceptual maps of how future completed versions of ITS networks could look, and are used by actors to align research and development efforts with each other globally to ensure a higher level of similarity between individual projects within both private and public sectors (Perallos 2015). Two initiatives are dominating these efforts, the FRAME architecture developed in Europe, and the National ITS Architecture (nITSa) developed in the US. Virtually all other initiatives of reference architectures in the world are either entirely or partially based on one or a combination of the two - with the identified exceptions in Norway and Finland (FRAME forum 2016.)

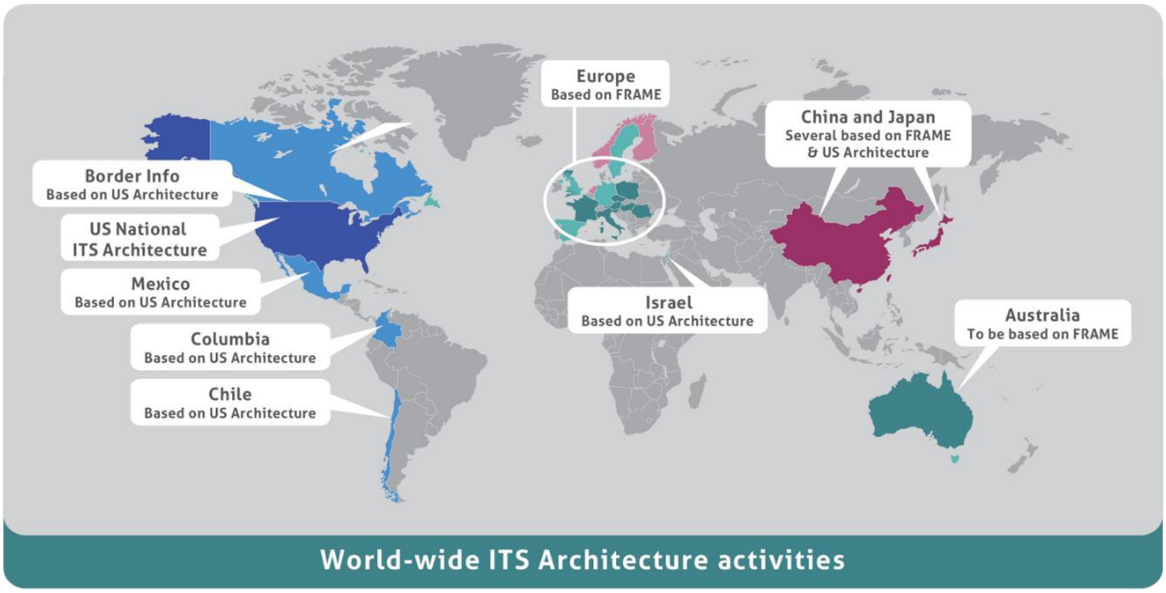

Figure 2, ITS network architectures deployed globally.

Both FRAME and nITSa are, among other things, made up out of layers concerning themselves with functional and physical representations that can be used to align projects to fit with the larger network (FRAME online 2016, Office of the Assistant Secretary for Research and Technology 2016). The functional representations (sometimes called logical) explains which system in the network are planned to have what functions, and how they conceptually are to interact with other functions in other systems. These functional representations however do not define the actual dataflows and applications, but instead maps out (in a sense) what value is created by a system in the network and what is passed around to achieve this. The physical representations on the other hand defines exactly what dataflows are envisioned to be present in a finished system -

breaking down general information exchange between systems into individual well defined packages, such as vehicle_signage_variable_speed_limit_message which is exchanged between roadside infrastructure and a vehicle (Office of the Assistant Secretary for Research and Technology 2016b, Office of the Assistant Secretary for Research and Technology 2016c). This type of information fits well as input into the interoperability effort evaluation model described in section 4.2.2. Unfortunately, FRAME and nITSa both have their problems.

FRAME's physical representation is not a set one, but instead contained and handled in tools which enables the user to explore and align their projects as needed - and no complete definitive chosen structure was to be found (FRAME online 2016b). nITSa on the other hand is not a complete architecture, as it is to be amended using a sister architecture called CVRIA which has been produced to specifically focus on the connectivity aspects in the envisioned ITS network (U.S. Department of Transportation 2015a). nITSa and CVRIA also has considerable overlap in scope (U.S. Department of Transportation 2015b), meaning that fusing them together is not simply a question of adding them together, redundant posts needed to be eliminated to avoid duplication of flows (Spreadsheets available for download, as explained in Appendix).

Out of these two possible reference architectures a combination of nITSa and CVRIA was deemed to be the choice that would produce a more objective map to analyze, as the use of FRAME would have entailed construction of the network structure itself.

3.2.2.2 Used ITS network architectures

This section explains the fusing of nITSa and CVRIA, something that is to be done by the responsible organizations later the same year as this thesis is written (U.S. Department of Transportation 2015a). However, as this new planned version of nITSa (version 8.0) is not available a manual fusion by the author was conducted.

nITSa is a large architecture. And CVRIA is large as well. nITSa specifies 2361 dataflows between 97 individual systems. CVRIA specifies 2613 dataflows between 102 systems. For an illustration of the complexity, please see figure A2 and A3 in Appendix B, where nITSa systems are visualized. In said figures a connection is made if there are any information exchange at all, and does not specify anything else. Analyzing this level of complexity was rejected.

Because of the size problem, the scope of the map was reduced. To keep it interesting for the auto manufacturer where the thesis was written, the vehicle unit was chosen as a central point in the created map. The delimitation to the scope of the map can be expressed as

The subset of systems included in the map is limited to systems that directly exchange dataflows with the vehicle. All dataflows between any systems within this subset is taken into account.

This delimitation of scope means that any system without a direct connection with the vehicle is removed from consideration, and opens up for the possibility of the analysis to disregard systems of interest for Open Innovation. Other systems was removed as well, for reasons detailed in table A4 in Appendix C, resulting in the subset found in table A5.

Additionally, many of the systems within this vehicle-centered subset shown in table A5 is in reality likely to group together into larger systems handling all the tasks of the envisioned singular systems (Picone, Busanelli et al. 2014, Perallos 2015). For example, there is little gained in treating information designated for the antenna of the vehicle as part of a separate flow apart for the others heading to the vehicle. The basis for the conducted grouping is the qualitative study of literature, especially drawing on the examples and descriptions found in the books used by Picone, Busanelli et al. (2014) and Perallos (2015), combined with the grouping of functions found in nITSa logical representation (Office of the Assistant Secretary for Research and Technology 2016d). Grouping decisions with a more subjective touch are explained in Table A6 in Appendix C and are all originating from CVRIA. Resulting groupings can be found in table A1 in Appendix A.

3.2.2.3 Description of created groups of systems

This section explains the nature of the groups of architectural systems created. These groups will throughout the thesis be referred to simply as "systems", as the grouping has been made to reflect a likely embodiment of real systems which takes on multiple roles of the systems envisioned in the architectures.

Emergency Management

This denotes a system that is an augmented version of today's emergency response central, such as 911 dispatch.

HMI

Human Machine Interface is the hardware and software that enables drivers and passengers to interact with the vehicle. This group was renamed Application Layer and slightly changed in scope when the in-vehicle systems were considered. In its Application Layer form the group comprises all applications and interfaces connected to an OS. This is analogous to the Application Layer described in *Advanced technologies for intelligent transportation systems* (Picone, Busanelli et al. 2014).

ISPS

The Information Service Provider System (ISPS) has to coordinating role in the envisioned future ITS network. The US Department of Transport Identifies two roles of the ISPS in their walkthrough of nITSa. The first role is a coordinating one, storing, processing and disseminating transport information to both systems and vehicles. In this role, information between different ISPS' are also exchanged, enabling coordination between clusters of systems connected to each other. The second role is that of a trip planner and coordinator. The ISPS provide specific directions to travelers by receiving origin and destination requests from travelers, generating route plans, and returning the calculated plans to the users. In addition to general route planning for travelers, the ISP also supports specialized route planning for vehicle fleets (Architecture Development Team 2012).

In the ISPS group all systems directly supporting such functionality has been fused, including the handling of some routing and access systems. This reflects an envisioned version of the ITS network where the ISPS, as a natural hub that already needs to handle the access requests and positions of vehicles that are to be served, shoulders the role of central routing coordinator.

Location Source
This is basically any system providing the general position of the vehicle, for example any satellite positioning system such as GPS or GLONASS.

Map Provider
The Map Provider is the system that disseminates and maintains the maps used by vehicles to navigate. In the version of an ITS network envisioned in the thesis precision vehicular localization is heavily aided by comparing sensor readings of the environment with reference models of the travelled world (see section 5.1.2.2). This means that the Map Provider in the thesis' version disseminates very large, complex, and precise multilayered environmental representations.

Network Infrastructure
All infrastructure used for relaying information between objects, such as the communication from a vehicle to the ISPS via a base station. It does not encompass flows from ISPS to the Map Provider or the like, only the information sent to and from objects in the field. This could include 5G technology, Wifi standards, or WAVE (Picone, Busanelli et al. 2014). It will however be shown later in the creation of the interoperability map that the scope of the Network Infrastructure description in the used reference architectures is too narrow to fully appreciate its importance, see section 5.1.1 for argumentation and results.

Other Vehicle
Other vehicle in the final map only denotes a personal vehicle without special features that the modeled primary vehicle interacts with. Special vehicles was removed for the sake of clarity, such all commercial vehicles, emergency vehicles and the like.

Payment Management
The systems facilitates and administers toll payments. The credit cards and personal payment devices has been included in this group.

Roadway Infrastructure
Here all infrastructure that makes up the roadway are found. This includes traffic lights, train signals, parking, and video surveillance to name a few. Anything that is part of the road network that an autonomous vehicle would need to interact with to function.

Vehicle
The vehicle is an autonomous vehicle made up of a multitude of parts. Any antennas or databuses, the basic mechanical vehicle, and any complex software parts are included within the denotation of the Vehicle. The Vehicle is later in the thesis broken down into the parts that hosts functionality relevant to the ITS network, and connecting flows are allocated to said parts instead of being treated as just targeting the vehicle as a uniform entity. Please see section 3.2.2.5 for details.

3.2.2.4 Fusing CVRIa and nITSa

The physical dataflows was used to merge nITSa with CVRIA, as it these that were chosen to be used to gauge interoperability effort needs. Dataflows in CVRIA with the same name as dataflows in nITSa was eliminated. The two architectures are very similar, for example the column in CVRIA's physical representation called AInterconnectNameInfo perfectly mirrors nITSa's physical representation's column AFname - both containing information describing the information being transacted between systems. CVRIA was added to the entirety of nITSa, just as the process is going to be when US DoT creates nITSa 8.0 (U.S. Department of Transportation 2015a). This means that some overlaying hierarchical information might become a little skewed towards nITSa, but it is the more tested architecture of the two, having been around longer (Office of the Assistant Secretary for Research and Technology 2016a). An augmented version of the dataflow table in CVRIA 2.1.0 was used, and combined with an augmented version of the dataflow table in nITSa 7.1. The resulting list of dataflows was 3729 entries long before applying the restrictions to the scope of the map. After applying the restrictions, any flow that was labeled as a "request" and not as "information", was removed in order to only take into account flows of significance. This due to the framework for interoperability assessment described in 3.2, where only significant adjustments are to be considered. 949 dataflows was left to be included in the final evaluation of the number of dataflows envisioned between systems and their complexity.

The number of internal functions using external data to be counted posed a problem stemming from the fact that nITSa does not declare applications within systems. This meant relying on the use of CVRIA's architecture for all application usage input, as the functional view in nITSa that could have been used is in no way connected to any program function structure, but rather with what the systems as a whole is thought to create in terms of use (Office of the Assistant Secretary for Research and Technology 2016d). The analysis should still be sufficiently accurate as the overlap between the two is large in terms of dataflows, and CVRIA applications was deemed to have good fit in relation to the dataflows exchanged between systems in nITSa.

3.2.2.5 Technology within the vehicle

To increase usefulness of the thesis the vehicle was broken down further, and the general parts needed for autonomous drive was identified by studying relevant academic sources. This section briefly describes how such a system looks and operates, but is not intended to serve as a thorough review of the subject.

Purposely described by Behere and Torngren (2015) an autonomous vehicle will need three types of functional components; perceptive, decisive, and platform manipulating. Figure 3 shows the three types and the parts that sort under each.

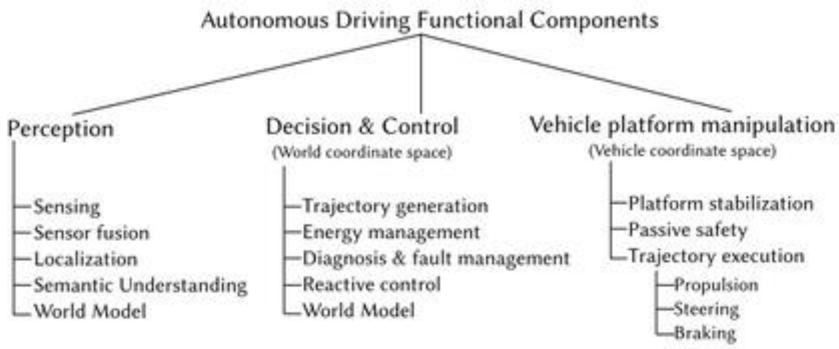

Figure 3, Törngren and Behere's identified systems in an autonomous vehicle

This subset of functions are according to Behere and Törngren (2015) also closely mirrored when it comes to the actual software systems that would make up a finished vehicle's internal autonomous components. Their view is also shared by Okuda, Kajiwara et al. (2014), who present a more interconnected view of a finished system that largely identifies the same parts. See figure A7 in Appendix D.

The two sources, together with complementary research articles reviewed whilst conducting the key technology search that forms the basis for the patent landscape analysis' serves as the main input to the analyzed autonomous in-vehicle system.

3.2.2.6 Fusing the network architecture view with the internal vehicle map

The dataflows going to the vehicle as a unit was broken down into individual streams with specific parts of the in-vehicle network as targets. The evaluations were conducted using CVRIA and nITSa flow explanations (Office of the Assistant Secretary for Research and Technology 2016e, Office of the Assistant Secretary for Research and Technology 2016f) in comparison to functionality (Office of the Assistant Secretary for Research and Technology 2016g) and data needs described in sources describing the systems. Only flows that could clearly be connected to a specific part was taken into account, and the number of applications in need of interoperability efforts was based upon a combination of what flows were connected and the functions of the connected parts of the in-vehicle network. The assignment of dataflows and applications with respect to the in-vehicle systems was a subjective procedure, based on all information found on the referenced CVRIA and nITSa pages combined with the descriptions of in-vehicle systems. This means that the created map is the author's own assessment of the situation, and should be treated as such. See validity discussions in section 6.3 for full assessment of the impact of this subjectivity. See Appendix for raw data, and figure 10 for the complete created interoperability map.

3.3 Estimating technical capabilities

This section details which key technical areas have been chosen to be mapped, and the results of said mappings. The process follows the framework presented in section 3.2.3.

3.3.1 Systems examined

Key technologies were sought for within all systems with a connection to another system with at least a 4 on the interoperability effort scale, as these are systems with a high interoperability effort needed.

Key technologies were sought in literature. To qualify as a Key Technology for a system it had to be important for the system to be able to fill the envisioned role, and it had to be an advanced technology that preferably was still under development. The key technologies mapped are all integral pieces of their respective systems that are hard to develop, and as such points to measure an actor's capability of developing the system it resides in.

3.3.2 Patent search methodology

The patent searches was done using Questel's Orbit tool. This tool enabled extraction of relevant metadata en masse from the patents found in each search. It also set a maximum pace for the work, allowing the author to properly think through chosen strings before surveying the results, and sat an arbitrary and non-discernible limit on search string complexity - making sure the author did not get carried away with string construction. Quality in the search results was checked by sampling ten random patents in each search. The patents was chosen using Excel's RANDBETWEEN function that generates a random number in an interval, said interval being the row of the first and last patent in the list.

These patents were evaluated as to whether they were an exact match to the technology sought. It they were a good match, one point was given, and if they were substantially within the same area, and of importance, they were given 1/2 point. A score of at least 7,5 out of 10 was needed to be deemed a representative picture, and the average score was 8,33. Normalized patent assignees as generated by orbits NPA function was used to identify the companies, and a script applied to remove any country denotations in the extracted company list. For complete hit lists, please see link to spreadsheets in Appendix.

4 Theoretical framework

This section is intended to give the reader a general review in the field of open innovation, followed by a thorough explanation of the theoretical frameworks and models used within the study. It ends with a summary of the resulting theoretical scope of the performed study.

4.1 The field of open innovation

Working with this thesis on-site at a major auto manufacturer, the concept of open innovation was not unanimously supported. Nor was there a general consensus regarding what was meant with openness. The complex scope of open innovation is outlined in this section to highlight the number of other reasons and effects that open innovation are connected to. The intended use is to put the scope of the thesis into perspective.

The expression "open innovation" was coined by Henry Chesbrough at the start of the new millennia, referring to the observed trend with companies seeking innovation input from source outside of the traditional R&D process. Such input includes research collaborations, open source releases of code, opening up of interfaces, standardization efforts, and so on (Chesbrough 2003). Since then, the field has grown. In 2014 Chesbrough, together with Vanhaverbeke and West, reviewed the progress made and summarized the major points being made (Chesbrough, Vanhaverbeke et al. 2014). Looking at the most cited research, several interesting points has been made:

Teece, in his *Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance* (Teece 2007), presents research outlining how open innovation is relevant from a firm strategy perspective. This includes highlighting the importance of open innovation as a source of alignment to an ever-changing global market, the increasing outsourcing of economies of scale shifting focus on economies of scope. Of interest for this thesis is also the increased need of contributors that platform thinking has generated, how increasing network effects and path dependencies has amped up the importance of developing technology that fits the market from the start.

Rothaermel and Hess (Rothaermel and Hess 2007) conducted research placing open innovation within the realm of organizational structuring, and discussing how to work with innovation in fragmented market that bio-tech has become. West and Gallagher add to the discussion on both how to organize for open innovation and the conceptual types of motivation behind engaging in such activities to meet three identified challenges; maximization of value created by internal R&D, incorporation of external knowledge in internal activities, and providing motivation for external sources to supply this knowledge (West and Gallagher 2006).

Vanhaverbeke and Cloodt explored the usefulness of open innovation to overcome obstacles in markets with highly distributed capabilities, such as the ag-bio sector. The authors argued that in complex networks of actors collaborating to produce an end-product, these value constellations need to work closely together and also make sure to handle profit sharing in a satisfactory way (Vanhaverbeke and Cloodt 2006).

Summarizing the resulting scope, it means that referring to open innovation as a focus area can be a preamble to discussing things like organizational theory, business models and value extraction, and technology intelligence for enabling all types of innovation activities deviating from the traditional linear process. The point being that the subject is broad and very qualitative. In this thesis, the entire spectra of situations, solutions, and drivers for open innovations are not addressed. Instead the very specific situation at the point of writing within the development of ITS networks for autonomous vehicles is considered. Any solution that leads to alignment between created systems cooperating to deliver the functions within the network is considered – without trying to identify which would be preferable. Only technical drivers are sought, in an effort to measure as objectively as possible. This will now be explained in detail.

4.2 Used theoretical framework

The used theoretical framework can be divided into three parts. First, primarily the works of Cherbrough, Teece, and Vanhaverbeke are used to create a basis and to identify confirmed open innovation drivers. Next, frameworks for estimating each driver is presented. The driver called *interoperability* receives a framework based on the most important drivers of interoperability identified by researchers constructing interoperability assessments for the COSYSMO framework. The driver called *capability distribution* relies on patent landscaping of key technologies for estimation. The two drivers chosen for investigation are redefined to reflect the technical environment that they are to be analyzed within in the chosen exemplification. Finally, a way of evaluating the relevance of the proposed method of finding how open innovation is more likely to be used is put forth. This relevance evaluation is based on comparisons between existing open innovation initiatives within the exemplified field and conducted analyses.

4.2.1 Open innovation and its drivers

Open innovation is defined by Henry Chesbrough in his Open Innovation: Researching a New Paradigm (Chesbrough, Vanhaverbeke et al. 2006) as *"[...] the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation"*. This means that all types of activities with the purpose to support these flows of knowledge are contained within his concept of open innovation. Examples of such activities can be licensing of patents, the creation of joint ventures, standard setting activities, or various versions of open source schemes, just to mention some. Subsequently, the reasons to engage in Open Innovation activities can vary wildly, the effects it has on the parties engaging the activities and the surrounding environment differ, and the type of value created through the activities take many shapes (Refjord 2006), (Petrusson and Pamp 2009).

The goal of this thesis is to create a basis for identifying where open innovation is more likely to take place, and thereby the reasons actors have for engaging in open innovation is of prime concern. The International Chamber of Commerce (ICC) mentions a rough list of reasons for an increase in open innovation initiatives including globalization, product complexity, industry convergence, advancements in ICT, increasing tradability of IP, and private venture capital (Brant and Lohse 2014).

Grassmann and Enkel (2010) corroborates much of ICC's list, similarly finding that open innovation is driven by reasons of technical, financial, and strategic character - combined with enabling features of international industry today analogous to ICC's points such as the transferability of IP and an ever more active role played by universities as knowledge brokers. This thesis will focus on the reasons of technical character, based on the assumption that these can be more objectively measured than the others (Gassmann, Enkel et al. 2010). Drivers of market character has been identified in previous research, such as crowding, how many actors are innovating in an area, and prestige, the reputation of an actor having created seminal inventions before, identified by Stuart (1998)

Within markets with complex products, which intelligent transport systems is an example of, a multitude of innovations need to come together to form the end product (Weeratunga 2015). This can lead to a situation when companies may use open innovation to create networks of systems that they could not have created by themselves. This type of situation is described in *Organizing for Innovation: When Is Virtual Virtuous?* (Chesbrough and Teece 2002) where the authors describe what they call *systemic innovations*. These are defined as Innovations whose *"[...] benefits can be realized only in conjunction with related, complementary innovations"*. This type of innovations are in need of significant adjustments in relation to other parts of the network they are embedded in in order to work (Vanhaverbeke and Cloodt 2006). 3G is an example of such a situation, as is the agbio sector, as they are both made up of a plethora of different technical areas that needs to cooperate to supply the final product. ITS networks have the same characteristics, with varied technology expertise needed and systems that must work together to create intended value. Systemic innovations is driven by insufficient technological capabilities due to technological complexity and is an important underlying driver for open innovation efforts (Chesbrough and Teece 2002). That open innovation occurs when actors have insufficient capabilities to develop all systems that are to interact with each other have also been identified in case studies around Nokia and IBM. Products are becoming increasingly complex and multiple technology areas are needed to cooperate in building up the product (Huurinainen, Torkkeli et al. 2006).

Insufficient technological capabilities is thereby shown to be a reason to engage in open innovation when innovations are dependent on other inventions to create the desired benefits. But the pull to engage in open innovation to create systems that together create value in this situation is surely not of the same strength between all parts in a system. Some parts are bound to be more important to co-develop or to standardize the interfaces between than others. Vanhaverbeke and Cloodt (2006) argues that the level of cooperation chosen between firms in a value network is connected to the amount of coordination needed to ensure quality, technological specifications, and product specifications. Connecting this to the reasoning in *When is it virtious?* (Chesbrough and Teece 2002) about the fact that systemic innovations need significant adjustments in relation to other parts of the network they are to be active in, the resulting relationship between drivers for open innovation in the given situation can be formulated as,

The technical need for open innovation when developing systems in a complex technical network, given that one actor don't possess the necessary technical capabilities in interdependent systems, is directly connected to the amount of significant adjustments needed between said parts to ensure functionality.

This is based on the assumption that the stronger the drivers the more likely it is that companies will engage in open innovation activities. To estimate the relative need for OI between parts of a complex technical system two things are therefore to be analyzed: the distribution amongst firms of technical capabilities needed for building the system, and the amount of significant adjustments needed between parts.

Open innovation initiatives are subsequently defined as any initiative between actors developing systems within the ITS network with the purpose to align the created systems with each other. This includes both initiatives creating standards open to any actor to use, and initiatives creating closed systems.

4.2.2 Assessing adjustments needed in an ITS network environment

This part of the thesis describes and defines the way in which adjustments are measured. First the question of adaptation is slightly redefined to fit the field of the thesis, secondly the new formulation is broken down into different layers, then a suitable framework is picked, and lastly this framework is put in the context of the theoretical layers of the newly formulated layers. The purpose of the argumentation is to transform the ambiguous concept of "number of adjustments" into measurable variables.

As described earlier in the thesis, the need for adjustments to a part to enable it to function together with other parts inside a larger system is a distinct driver for Open Innovation schemes. Within the realm of information technology, this is referred to as interoperability. It is defined by IEEE as *"[The] ability of two or more systems or components to exchange information and to use the information that has been exchanged."* (Geraci, Katki et al. 1991) Another widely used definition is the US Department of Defense's *"The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together"* (Kasunic 2001). Both of these shows that interoperability is what the adjustments referred to in open innovation literature are supposed to achieve. With this in mind we can reformulate the question to read

How much effort is needed to achieve interoperability between interconnected parts in the system?

The connection between interoperability and open innovation is also formulated by researches working from a system development viewpoint. Almeida, Oliveira, and Cruz identifies open source and open standards for ICT development as the best ways of achieving interoperability (Almeida, Oliveira et al. 2011).

Interoperability can be divided into three layers; Technical Interoperability, Semantic Interoperability and Process Interoperability (Benson 2012). Technical Interoperability is the need for an information exchanging link of any kind at all, be it in the form of a cable, web interface etc. Semantic interoperability has a prerequisite in Syntactic Interoperability (Dedera), which means that the information exchanged needs to be expressed in a language recognized by the receiving end. *"Semantic interoperability allows computers to share, understand, interpret, and use data without ambiguity"* - (Benson 2012) meaning that the data can be used by an application as input in processes. Process Interoperability is outside of the scope of the thesis, by virtue of not being of technical character (Benson 2012). Measuring the gap between the corporate cultures regarding system usage in a not-yet created system without access to the personnel in these cultures is not feasible.

A simple explanatory analogy for the levels of Interoperability is a conversation between two persons. If they can hear each other at all, Technical Interoperability is achieved. If they are communicating in languages that the other understands, Syntactic Interoperability has been achieved (Not that this would still be true if one spoke French and one English, as long as the receiver could understand what was being said). If what is being said by one of the two persons makes sense and can be used to draw conclusions, Semantic Interoperability has been achieved.

4.2.2.1 Interoperability effort frameworks

There are many frameworks for evaluating system development efforts, and quite a few that concerns themselves with the interoperability question. A review of the area was conducted using a review of the area by US Department of Defense as a starting point

(Morris, Levine et al. 2004). A framework was sought that handled interoperability in a way that an external analysis without the need for organizational information. Because of this, the thesis is built on the drivers for the interoperability part of a quantitative estimation framework called COSYSMO. This framework estimates the effort needed to achieve interoperability using calculations of quantifiable variables weighted by constants. The constants is based on the context of the project, and are usually calculated using historical data from previous projects (Lane and Valerdi 2011). The framework has been co-developed and used by numerous actors within the highly complex military industry, including Raytheon, Northrop Grumman, Lockheed Martin, SAIC, General Dynamics, and BAE Systems (Valerdi and Christopherson 2013).

For this thesis, only the interoperability effort is considered, and only from a technical standpoint, as described by delimitations and in accordance with identified open innovation drivers. To ensure that the COSYSMO framework was a suitable choice for the thesis, and that the author of this thesis had understood it, the authors of the article concerning COSYSMO's interoperability variables were contacted and consulted. See Appendix G for exact question and answers. The answers indicated that three technical variables were likely of importance, corresponding with Lane and Valerdi's (2011) work. The three variables are the number of interfaces in need of significant interoperability efforts, the complexity of the dataflows between the interfaces, and the number of functions using input data. The answers also indicated that other variables could be important as well, such as the ones found whilst researching the subject in the form of security demands, latency demands, and signal integrity demands. However, as no research have been found that support their inclusion they have not been taken into account in the analysis. Nor was usable constants for system development in ITS networks found.

Comparing the variables identified as cost drivers in COSYSMO with the levels of interoperability, one can easily connect them to each other. The examples in *Why interoperability is hard* (Benson 2012) highlights such connections when explaining the difficulties in achieving interoperability. The three COSYSMO drivers covers Technical Interoperability with the number of connections between parts in a system, and syntactic and semantic interoperability with the other two.

4.2.2.2 Resulting interoperability effort assessment

The drivers was validated in a qualitative discussion session with Christer Bergström Ph.D, who is in charge of coordinating system development at the auto manufacturer where the thesis was conducted (Bergström 2016). He shared the viewpoint of the three drivers as central for estimating development and engineering effort in system environments. Further, Bergström explained that the drivers could be viewed in two groups, with number of connections and data complexity cooperating to raise the effort needed, and with the number of functions raising the effort by itself when increased.

With this validation and refinement a final model for estimating the interoperability effort was formulated. In it, higher levels of effort required either a higher number of functions, or higher numbers on both the number of connections and the data complexity. Medium effort levels is considered to be found when the levels on these are of more average magnitude, or one of the number of connections or data complexity is higher. Please see figure 2 for rankings, where a higher number denotes a higher level of effort needed. This model rates relative effort to achieve interoperability, not absolute, meaning that there is a possibility that even lower scores in the model would act as notable open innovation drivers given a lack of complete capabilities for an actor. Without historical data, or a previous study in the field to benchmark against, the weighting of the drivers becomes arbitrary, and it is therefore kept in this more simplified state (see Appendix G).

Interoperability effort assessment model

	Lower # of active functions	Average # of active functions	Higher # of active functions
Lower # of connections Lower data complexity	1	2	3
Average # of connections (Or reversed) Lower data complexity	1	2	3
Average # of connections Average data complexity	2	3	4
Higher # of connections (Or reversed) Lower data complexity	2	3	4
Average # of connections (Or reversed) Higher data complexity	3	4	5
Higher # of connections Higher data complexity	3	4	5

Figure 4, Interoperability assessment model.
Higher equals higher effort needed to achieve interoperability

4.2.2.2.1 Interactions within the vehicle

The model used to assess interoperability effort in the ITS network had sufficient input data for all interactions outside of the vehicle itself. The framework has been applied to interactions within the vehicle as much as possible, but has been combined with qualitative estimations based on expert descriptions in literature. This because the vehicle is treated (almost) as a single part of the ITS network in the input sources used, and is not broken down into individual modules. This was considered to be an unsatisfactory level of analysis for vehicle manufacturers, and the qualitative literary sources was brought in to complement the scope of the architecture. Please see sections 3.2.2 and 5.1.2 for more detailed descriptions of sources used and assessments made.

4.2.3 Estimating capability distribution

What is sought is insight into what technical know-how needed to develop systems within the ITS network is possessed by which actor. This section will briefly outline why patent mapping is a relevant method, explain why a limited version of said method was employed, and what this limitation means for the results.

There are many methods used for technology intelligence analysis, found well outlined in Lichtenthaler's *The choice of technology intelligence methods in multinationals: towards a contingency approach* (Lichtenthaler 2005). Among these are indicator-based methods based on patent mapping. Indicated as usually employed for competitive analysis and scanning for new technologies, the existence of patents shows clear connections to actors' capabilities. In the companies surveyed by Lichtenthatler the aim could be either to understand the capabilities of a competitor, or to understand what new technologies are emerging. Based on the same connection between an actor filing a patent and said actor having knowhow in the area the thesis aims to find what actors has patents within certain technological areas, to map out which actors has the sought capabilities. The use of patent information for mapping which actors possess capabilities within technology areas are also brought forward in general in *The many applications of patent Analysis (Breitzman and Mogee 2002)*, and using the nutrition and health industries (Fabry, Ernst et al. 2006). In all of these studies, the frequency of patent families and citation analysis of the results are focused on to enable analysis of the relative strength of actors.

The thesis will not make any relative assessments of the capabilities of actors found, as the size of the search results make them sensitive to being skewed. Granstrand (1999) explains some sources of skewing of the connection between the number of patents a company holds and its capabilities. The usage of patent blanketing, fencing, and surrounding, found within his research exemplifies how frequency based measuring of capabilities could be found to be tainted. Using patent citations within the areas of cutting edge development of the ITS network becomes hard considering the age of the patents in question (the patent families found in the search conducted within the Trajectory Generation system has an average age of 6 years). With this in mind, the choice was made to treat any number of patent families found in an area as an indication of capabilities to develop that system, and no relative assessment was made.

The mapping can be done via classifications, keywords, or a combination. As most systems within the ITS network are firmly placed in the area of ICT (see section 3.3.1), the use of classifications as anything but limiting totally irrelevant patents becomes futile. Both Leydesdorff (2008), and Widodo and Budi (2011) describes how classifications within the area of ICT has degenerated and converged too much to provide useful information. This lead to the usage of keywords to define the searches.

Within the parts identified in the mapping of the ITS architecture different technological capabilities are needed. Ideally one would like to map all capabilities needed and find out all actors in possession of each, as well as the freedom to operate situation in relation to each, in order to paint a true picture. However this was not feasible considering the time constraints of the thesis. Instead, it was estimated which actor has the needed capabilities by analyzing patent landscapes concerning a cutting edge technology of key importance within an area. As an additional delimitation, only systems with a higher effort needed to achieve interoperability was analyzed, also this due to time constraints.

What has been done then is that areas of high significance for delivering the desired technical function for a part of the system that are also singled out as subjected to intense R&D efforts have been measured. The logic behind this is that one could not deliver a complete part of the system with the needed specifications without mastering the key technology in question, and therefore the only actors with the capability to do so would be the ones engaging in R&D efforts in this area. For example, one would question any actor's chances of acting as a Map Provider in a system needing extremely detailed maps (which equals very large files) in need of continual updates without mastering making partial updates (thereby minimizing update time and bandwidth requirements).

4.2.3.1 Limitations of capability assessments

This approach of analyzing capabilities of actors in a limited part of a system, without an FTO analysis, and without measuring relative strength has repercussions for how the results should be interpreted.

The mapping of only a limited part of the technology needed means that there might be actors with large knowledge-bases in other key areas for a system that are not found. On the other hand it means that the searches can be very specific and relevance for the development capabilities of the systems kept. For example, the capability of predicting traffic flow in real time using the advanced algorithms that are Ant Colony Optimization, Artificial Neural Networks, or Fuzzy Logic algorithms are measured – not traffic predictive capabilities in general (see section 5.2.1.1).

No effects resulting from patent blocking has been analyzed either. And the hitrate of patents found, meaning the portion of patents found to be true matches to the searches, are not 100%. This means that there are patents, and actors, represented that might not possess the exact capabilities searched for. That risk decreases with the number of patent families found, as the risk of many families being found without them having relevance is smaller than for a single family.

To summarize, the scope of the searches are specific which means that actors with capabilities needed for system development might not be found, but that the relevance for those found are increased. Lower hitrates means that there might be actors found that are not in possession of the capabilities, however this is less likely when multiple families are found.

4.2.4 Evaluating the results of the proposed study

What is to be evaluated is if the results of the analyses are consistent with what can be expected from theory.

The summary of the theoretical ground used in this thesis is that: the technical need for open innovation between parts in a complex technical system, given that one actor don't possess the necessary technical capabilities in interdependent parts, is directly connected to the amount of significant adjustments needed between said parts to ensure functionality. If the study is successful in mapping out capabilities and the need for interoperability efforts, the open innovation projects within the area should therefore have the following properties:

- The scope of the initiatives should predominantly include cooperation around systems with higher needs for interoperability

- The actors engaging in open innovation initiatives should not possess all the capabilities needed to develop all systems within the scope of the initiative

- Actors engaging in initiatives should be found to complement each other's capabilities.

To test this a few existing initiatives will be investigated with respect to scope and actors. As the development of the ITS network is not completed, the existence of complete solutions are not anticipated.

4.3 Theory summary

Figure 5 summarizes the coverage of the framework used to analyze the relative strength of Open Innovation drivers of technical character in the targeted ITS architecture.

At each level of the figure the identified possible choices of scope and methods are presented. What has been chosen is in bold typeface, and what has been delimited is presented in normal typeface. To the right the reader can find the general reasons for the choices made. The inclusion of the visualization aims to put the scope of the thesis into perspective.

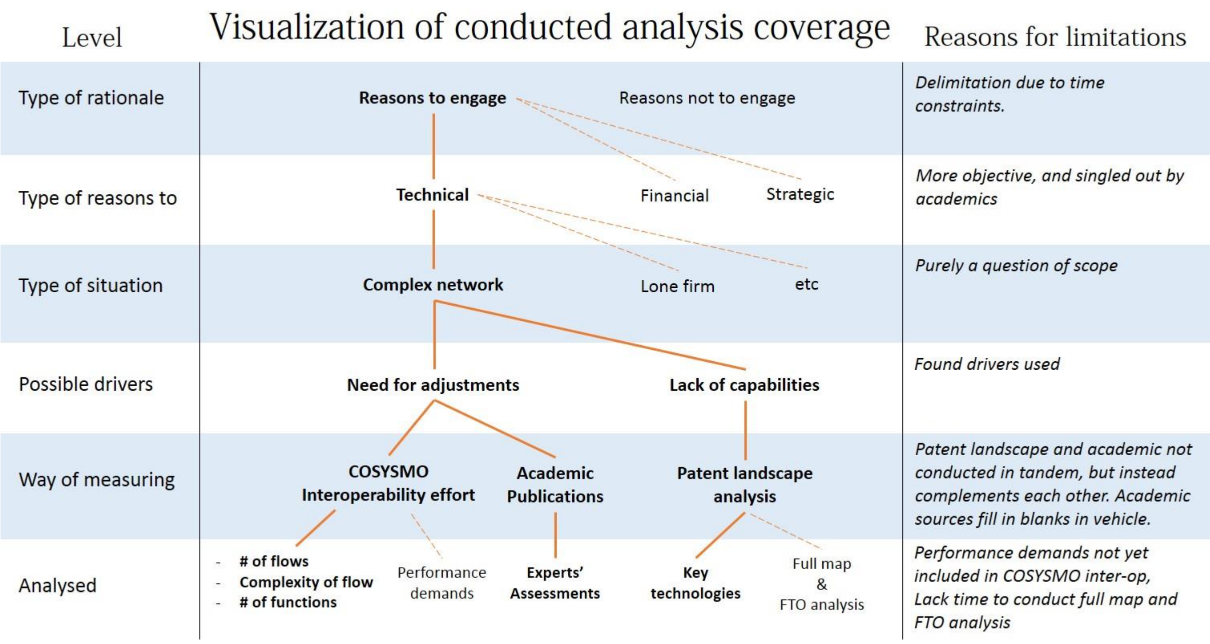

Figure 5, Visualization of conducted analysis coverage.

5. Analysis

This section describes the analyses performed on the input data in accordance with framework in section 4 and the methodology in section 3. All data used in the analyses are available for download as a compressed file containing spreadsheets, the link found in Appendix. These spreadsheets contain most steps taken to reach conclusions, but were not created for external review.

5.1 Evaluating the interoperability effort needed between systems in the architecture

The evaluation was done according the model presented in section 4.2.2.2. The complexity of the dataflows was assessed subjectively by the author, with low complexity assigned to dataflows containing simpler information such as alerts, medium complexity assigned to flows containing multi-functional data such as vectors, and high complexity assigned to flows containing large objects such as maps or a very high number of individual objects as is the case with the exchange between the Vehicle and the ISPS. The visualization in figure 6 details the found interoperability levels. After completed evaluations, the results were checked against used literature and architecture descriptions of both nITSa and CVRIA, and a previous post known in CVRIA as Roadway Management was incorporated into the ISPS group, as it was found to be sufficiently similar. The resulting view was also checked against the European architecture, FRAME, and deemed to be consistent on a functional level - i.e. no clear discrepancies was found. The fit between FRAME, nITSa, and CVRIA being anticipated as their consistency had already been noted by the US Department of Transportation (Office of the Assistant Secretary for Research and Technology 2016h, U.S. Department of Transportation 2015b).

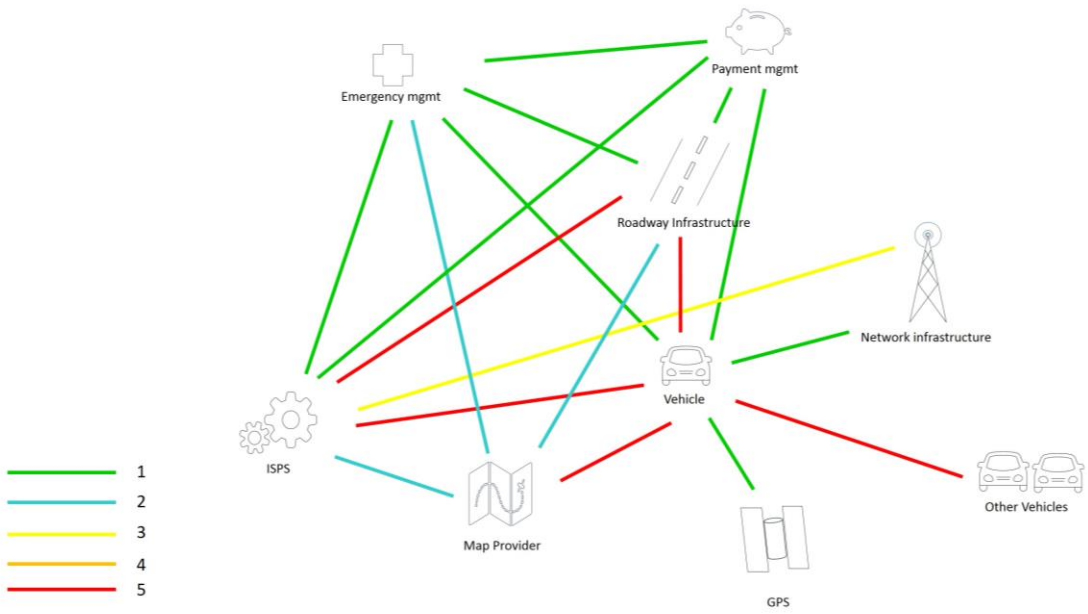

Figure 6, Interoperability effort assessment of combination of nITSa and CVRIA

Removing all connections below a three in effort, the connections in figure 7 are left.

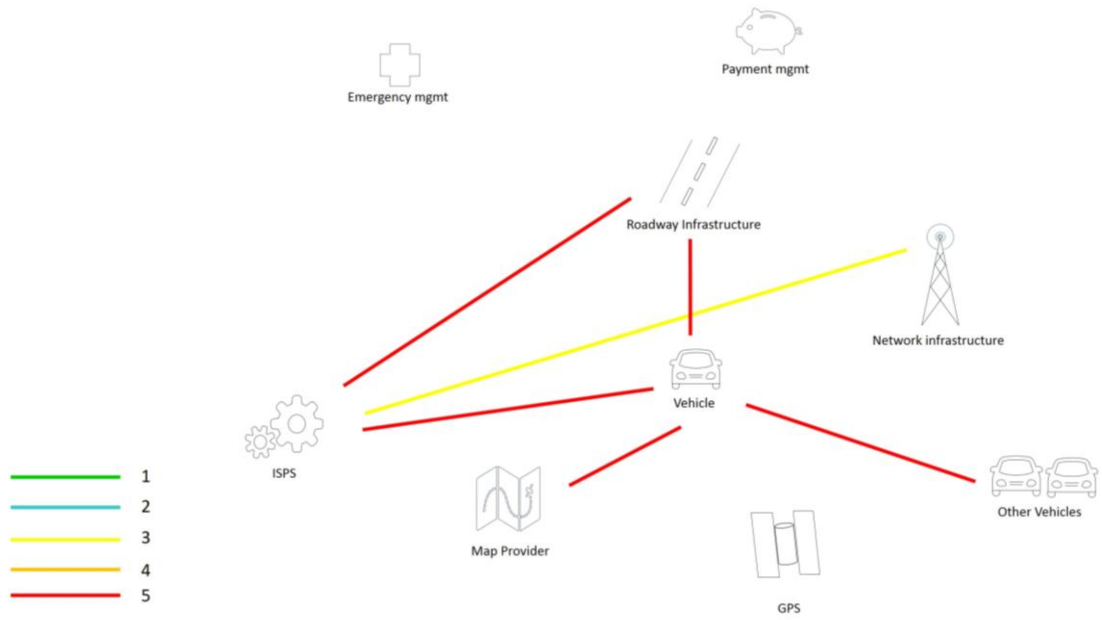

Figure 7, Connections in nITSa combined with CVRIA with a level of effort needed of 4 or higher.

Achieving autonomous driving is dependent on the ITS network, and the systems in the network with higher interoperability efforts needed plays pivotal roles in relation to the self-driving unit. The vehicle needs to be able to communicate with other autonomous vehicles to coordinate driving efforts and avoid accidents (Picone, Busanelli et al. 2014). Communication with a map provider supplies the vehicle with both a general map to navigate with, but also (in the envisioned embodiment used in the thesis) with environmental and topographic data supporting increased localization accuracy (Laftchiev, Lagoa et al. 2013). The ISPS supplies the overreaching traffic coordination power, supplying route selection and congestion data, helping to route communication, and creates a bridge over to other ITS networks (Office of the Assistant Secretary for Research and Technology 2016i). Roadway infrastructure communicate a host of information to the vehicle, including roadway geometry, location corrections, and automated vehicle control data (Office of the Assistant Secretary for Research and Technology 2016c).

5.1.1 Assessment of Network Infrastructure is incomplete

The Network Infrastructure system is not represented in a satisfactory way within this architecture, as the intermediary position such technology would have is not represented within the flows. The vehicle would need to communicate with infrastructure and other vehicles, as well as remove systems such as the ISPS, and the role played in routing the information exchanged by network infrastructure is not included within the architectures in a sufficient way. As the architectures are to be technology agnostic, such deficiencies are not surprising - the only thing that is being indicated is what type of network infrastructure should be used, not how the network infrastructure in itself would be affected and affect other systems (HNTB 2011). As described in both different ITS network architectures, the Network Infrastructure would play pivotal roles in a finished ITS network. Large chunks of the communication exchanged between systems would need to pass a base station and transmitter, be redirected in an ever changing network structure of moving vehicles, and likely require different handling depending on its nature. The development of 5G would be of particular interest. Unfortunately there was no time to go through the technology situation within all relevant communication protocols and technology areas (Picone, Busanelli et al. 2014, Perallos 2015).

The interoperability assessment based on the architectural dataflows in nITSa and CVRIA is thereby also to be taken as incomplete. This importance of Network Infrastructure is also expressed by Weeratunga (2015), where both the importance for initial development and customizing of communication capabilities to address the specific needs in V2X communications was highlighted.

To summarize the argumentation made here, network infrastructure shows up as having only few interoperability needs in relation to other systems but this stems from the technology agnosticism affecting the scope of the architectures. It can be both inferred logically and sourced from external reviews that network infrastructure will play a pivotal role in the creation of an ITS network and that the choice of network infrastructure will affect the systems using it, and vice versa. No assessment of the real interoperability effort needed in relation to systems has been conducted. With this in mind the network infrastructure part of the ITS network will be treated as essential but not assessed - meaning that such capabilities are needed in any connection between systems outside of the vehicle, and access to these capabilities during development will be seen as an advantage. Its special status will be denoted by a red asterisk in the visualizations.

5.1.2 In-vehicle interoperability assessment

The systems to be considered are outlined in the structure in figure 8 below. It is based on the structure described by Behere and Torngren (2015), corroborated by Okuda, Kajiwara et al. (2014).

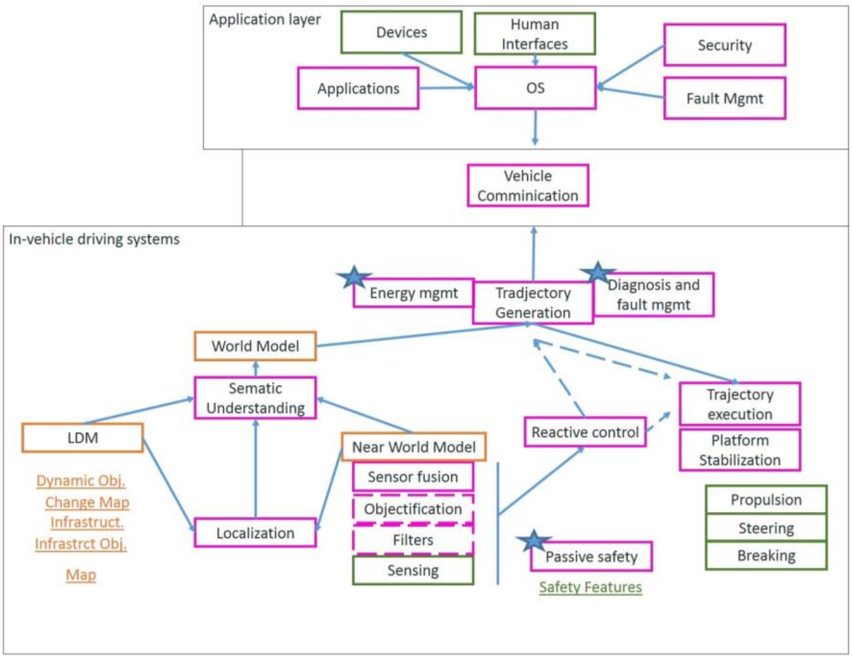

Figure 8, Structure of in-vehicle systems

The yellow boxes in figure 8 denotes data objects such as databases or maps that are created or handled by the systems, the purple boxes are software systems, the green boxes are components of more material type, and blue arrows shows how the systems communicate with each other. Systems with a blue star communicates or is involved with many different systems, but are not considered to add direct autonomous drive functionality, and are therefore not analyzed. The application layer is not analyzed either, but is visualized as the Human Machine Interface features in the used ITS architecture representations.

5.1.2.1 Sensing

To facilitate navigation and decision making in the vehicle sensors are used to gather information about the surrounding environment, as well as the state of the vehicle itself. But sensing is not the same as perceiving. As Behere and Törngren (2015) explains;

"A commonly heard phrase in the robotics community is, 'Sensing is easy, perception is difficult.'. Sensing means gathering data on physical variables using sensors, while perception refers to the semantics (interpretation and "understanding") of that data in terms of high level concepts relevant to the task being undertaken. As such, sensing is just one part of an overall perception system".

Perception is thereby built up in steps, and external perception culminates in a so-called near world model - a hypothesis regarding the environment the vehicle is faced with created by cross referencing processed data from numerous sensors (Behere and Torngren 2015). The raw data from the sensors are filtered to eliminate noise and enable tracking and identification of objects using complex mathematical processes, such as Kalman Filtering or Probability Hypothesis Density filtering (Panta, Vo et al. 2007). The interoperability effort needed between these two parts has not been possible to estimate, but it can be noted that Behere and Torngren (2015) identifies a tendency in products offered of such processing schemes being directly integrated into the sensors, as is the observed case with objectification capabilities. Objectification refers to the translation of a found physical thing within sensor range into a specific type of object - the difference between measuring that something is blocking the path 20 meter in front of the vehicle, and saying that there is a bicycle 20 meters ahead. Crucially, Behere and Torngren (2015) identifies this level of achieved data abstraction as the point where the sensors can be treated as black-boxes, indicating that the effort needed to achieve interoperability between a component with such an output and subsequent parts are lower. The sensor fusion part then combines the data or objects received from sensors and outputs the most likely representation of the environment, creating the aforementioned near world model.

The connections between sensors, filters, and objectification are therefore assessed as being very high, 5. Connections between objectification, sensor fusion, and the created near world model are assessed as of in average need of interoperability efforts.

5.1.2.2 Localization

GPS localization is not exact enough to facilitate the level of precision needed for autonomous driving. A promising way of achieving the needed accuracy concerns the comparison between environmental readings and a representation of how the world should be perceived. Simply put, the vehicle would sense the surrounding environment, find features and distances to said features, and then find where the corresponding features are present in the comparative representation, and so determine its exact location. It would thereby require input from both sensors and access to a detailed environmental description going beyond simple roadmaps. This description would be large and changing, and thereby in need of constant updates and amendments from the supplying source (Laftchiev, Lagoa et al. 2013), (Levinson, Montemerlo et al. 2007).

Input data from the LDM and the created near world model are considered to drive higher levels of interoperability efforts to enable comparison localization. However, the resulting location are assessed as being in need of much less effort to be usable by semantic understanding, and passed on to trajectory generation.

5.1.2.3 Local Dynamic Map (LDM)

Behere and Torngren (2015) explains the component that is the LDM in the following way:

"An LDM is technically implemented as a database, but can be conceptually thought of as a layered map. The bottom-most layers represent the most static beliefs about the world, while the topmost layers represent the most dynamic, in the sense of time. For example, the lowermost layer may be populated with a static map of the immediate surroundings of the vehicle (roads, permanent features, etc.). The layer above it may be populated with more-or-less static road objects (trac lights, lane markings, guardrails). The next layer may contain temporary objects like diversions due to construction work. The final layer would be populated by fast-moving objects detected by the rest of the perception system (other vehicles, pedestrians, etc.)".

Added to this in accordance with Picone, Busanelli et al. (2014) and their description of the scope of features for V2V communication is the inclusion of objects detected by other vehicles. The resulting LDM is used by both the semantic understanding system where it is interpreted and combined with the near world model, and by the localization function as input.

5.1.2.4 Semantic Understanding

This part takes all the information created and sourced from localization, sensing, and LDM and creates a world model where a more complete understanding of the vehicle's surrounding is contained. This can also include creating associated descriptions of likely future behavior for objects based on their type and past positions (Behere and Torngren 2015). As an analogy for the function performed, consider the following example: you are about to cross the street, and you use your senses for determining how the surrounding looks. You determine that there is a truck coming from the left, confirmed by both your hearing and sight. You know that your position is in front of a crosswalk. Your friend tells you that the stoplight for the crosswalk is broken (analogous to some types of LDM information). As you know that the object is a truck you know that it will have problems stopping fast. This situation awareness is what is created in the semantic understanding. This also means that it needs to be able to take in and combine information from both LDM and the near world model, and combine with the location data. This is in the thesis interpreted as an indication of a need higher levels of efforts to achieve interoperability between these systems. (Geiger, Lauer et al. 2011).

5.1.2.5 Decision and Control

Is made up out of a number of parts, however only trajectory generation will be considered in this thesis. Energy management concerns battery life handling, and diagnosis and fault management concerns handling of system errors and problems within the ego-state of the vehicle - both important functions, but not deemed to be directly relatable to actual autonomous driving, as well being hard to understand which connections they would have to other parts and how they would affect these. Reactive control refers to systems that step in and triggers automatic responses to certain sensory detections, often handling the processing of detecting threats to issuing commands to trajectory execution often an order of magnitude faster than the central trajectory generation system can react. These systems are often constructed to act as redundancies, and as such not to be dependent of other parts to function. They have therefore not been further analyzed with respect to interoperability efforts. (Behere and Torngren 2015).

5.1.2.6 Trajectory generation

This is where the decisions based on the situational awareness is taken. This is done by constantly generating new sets of obstacle free trajectories for the vehicle in relation to its surroundings and the goal of the journey, and choosing the optimal one to pursue.
This is described further in section 5.2.1.6, as it is considered a key technology area. The trajectory chosen is communicated to Trajectory Execution, which is the system in charge of translating the chosen path into actual commands for the vehicle. The interoperability effort needed between these two systems are deemed to be of medium strength as the executing part need not be aware of the environment understanding as these variables have already been factored in when setting the trajectory. Stabilizing systems are already standard in vehicles, and not considered in this thesis, and neither are reactive controls as their communications path is unclear and they are almost by definition stand-alone functions since they are to function independently and switch on when a certain stimuli is detected - such as apply brakes if an objects is detected that are going to be hit imminently. Trajectory generation handles these type of situations as well, and the reactive controls are redundancy measures, just like a blink reflex is to closing your eyes if you see someone chucking a bunch of gravel towards your eyes. (Howard, Knepper et al. 2008, Behere and Torngren 2015).

The assessments of interoperability efforts needed between systems connected to trajectory generation are subsequently high when it comes to interactions with the application layer and the world model. Trajectory execution interactions are deemed to be less complex, and thereby in need of lower level of effort.

5.1.3 Resulting map over interoperability effort needed between in-vehicle systems

Taken together the map presented in figure 9 over interoperability within the vehicle was created. The same scale as used in the evaluation of the architecture was used, with red denoting connections in need of higher effort to achieve interoperability. Note that this view of internal functions needed for autonomous driving is sourced solely from official publications and is not in any way validated in relation to any existing structure. It is however created by taking into account a multitude of sources, all pointing in this direction, elevating the validity some.

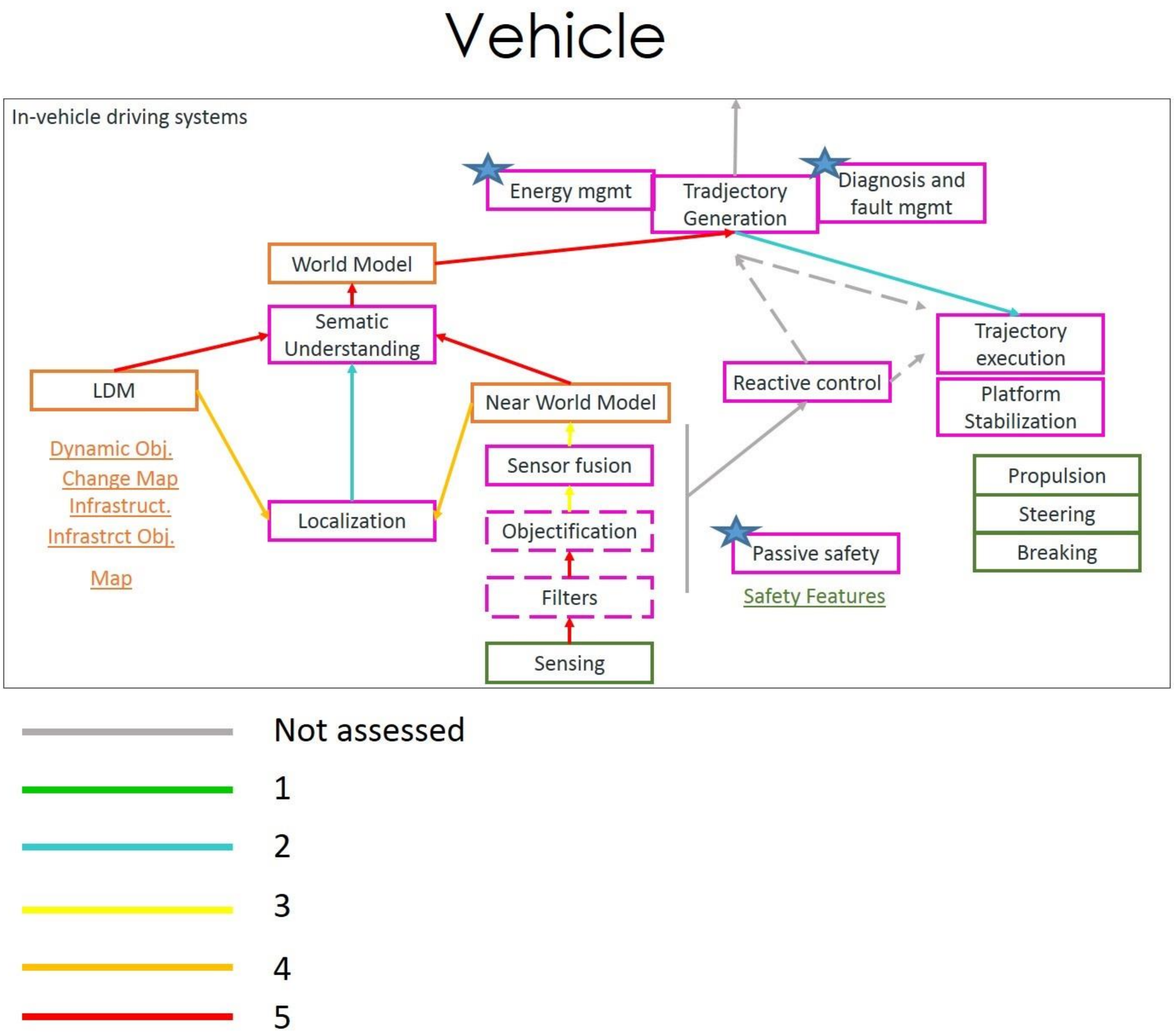

Figure 9, Assessed interoperability efforts between in-vehicle systems

5.1.4 Fusing the network architecture view with the internal vehicle map

As described in section 3.3.1.6, the ITS network structure synthesized from nITSa and CVRIA was combined with the in-vehicle network of systems. The dataflows going to the vehicle as a unit was broken down into individual streams to specific systems within the vehicle, based on data and explanations of the flows as input (Office of the Assistant Secretary for Research and Technology 2016e, Office of the Assistant Secretary for Research and Technology 2016f, Office of the Assistant Secretary for Research and Technology 2016g)

Only flows that could clearly be connected to a specific part was taken into account, and applications active was based upon a combination of what flows were connected and the functions of the connected parts of the in-vehicle network. This was a somewhat subjective procedure, and should be treated as such. See validity discussions in section 6.3 for full assessment of the impact of this subjectivity. See Appendix for link to raw data, and figure 10 for the complete created interoperability map.

5.1.5 Completed interoperability map

The interoperability efforts needed between systems to create a future ITS network for autonomous vehicles varies significantly. Figure 10 details all flows and their assessments, as does table A8 in Appendix E.

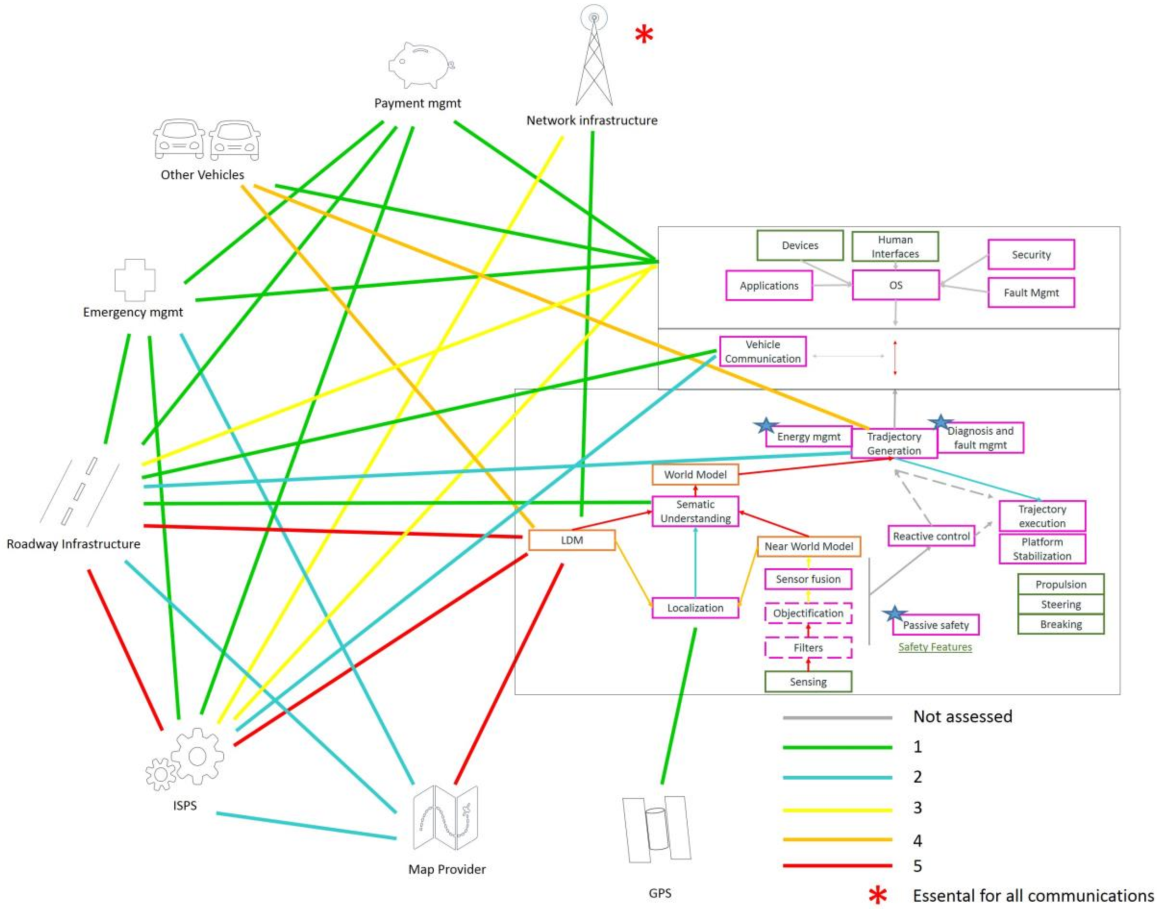

Figure 10, Full assessment of interoperability efforts needed between systems in an ITS network for autonomous vehicles

A subset of systems within the envisioned ITS network were found to have significant interoperability efforts needed between each other. The thesis will especially focus on these systems in the analysis stage, and also focus the technology capabilities mapping to these functions as well. Figure 11 shows the system connections with the higher effort levels of 4 or 5.

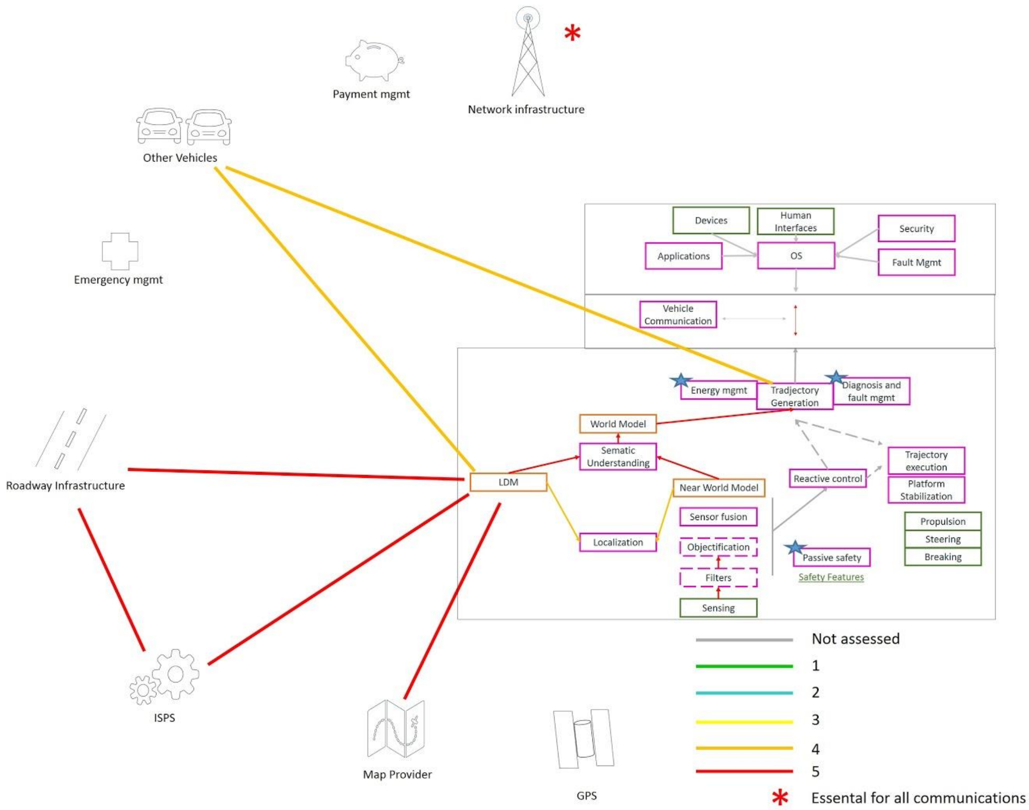

Figure 11, System connections with an effort level of 4 or higher in the complete interoperability assessment

Two clusters of higher interoperability can be discerned, one encompassing sensors, filters and objectification. The other including Map Provider, LDM, ISPS, Roadway Infrastructure, Semantic Understanding, Trajectory Generation, Localization, Near World Model, World Model, Trajectory generation, Application Layer, and Other Vehicle Communications. Most of these parts were used as input for capability assessment.

5.2 Analysis of capability distribution

As explained in section 3.4, what has been done is that areas of high significance for delivering the desired technical function for a part of the system that are also singled out as subjected to intense R&D efforts have been analyzed. Systems analyzed are those with a connection to another requiring an interoperability effort of 4 or higher, visualized in figure 11.

5.2.1 Key technology searches

Each area will now be presented, starting with a short explanation, the key technical capability chosen, the search terms used, and the hitrate as described in section 3.3.2 expressed as percentage points. Results of the conducted searches can be found in Appendix F, and in section 5.2.2, where the results of the analyses are presented. For all search results, see link to spreadsheets in Appendix.

5.2.1.1 ISPS

Reviewing the area as described by McNally, Marca et al. (2003), Boyce and Williams (2015), and Perallos (2015), the mastering of mathematical algorithms for predicting traffic patterns and congestion was identified as a key capability for delivering the trip planning functionalities that the ISPS shoulder. Perallos (2015) explains that

"In recent literatures, soft computing techniques have been considered as powerful tools for traffic forecasting. These techniques mainly consist of Support Vector Machines, Neural Networks, Fuzzy Algorithms (GAs)"

Focusing on this type of algorithms, Salehinejad and Talebi (2010) was consulted. Combining the sources, the use of the Artificial Neural Networks, Fuzzy Logic, and Ant Colony type of algorithms was identified as the most relevant approach to reach the goal of supplying dynamic traffic predictions.

Search string: vehicle* And Traffic And (predic* D traffic) AND (real time or dynamic*) AND (neural or Fuzzy or Ant)

Number of patent families found: 306

Hitrate: 86%

Additional observed resource of importance for ISPS development
Feeding data points into the algorithms to facilitate traffic flow predictions, and subsequent trip optimization, requires the gathering of data points. In this case it means knowing the position and speed of as many vehicles as possible, and as many chosen paths as possible. This was underscored by McNally, Marca et al. (2003), and a possible source of this type of data identified in cellular phones. As cellular phones with GPS technology are widely deployed today access to the movements of these could supply a well distributed view of the movements of vehicles, supplying the data points needed to be able to conduct efficient trip planning. This type of information flows should most easily be obtained from phone manufacturers and/or OS suppliers, but other sources might exist.

5.2.1.2 Map Provider

As described earlier in the thesis, the Map Provider has an extended role within the chosen version of an envisioned ITS network. The extension being that the map supplied to the vehicle is to be used for both navigation and to enhance localization. Min, An et al. (2011) describes such a setup, and identifies a central problem to be solved to enable the Map Provider to supply the functionality needed. The size of the map sent grows very large when the level of resolution and precision increases as needed. And to enable safe navigation and localization, frequent updates will be essential. Updating such a large file takes both time and bandwidth, unless it can be partially updated. Remotely and partially updating complex map data is therefore identified as a key capability. No clear system, technology, algorithm, or the like was identified and the value delivered in itself was targeted when searching instead.

Search string: ((((MAP+) 9D (UPDATE+ 3D PARTIAL+)) AND (SEND+ OR SENT OR TRANSMIT+) AND NAVIG+) NOT MEDIC+)/TI/AB/IW/CLMS/DESC/ODES/OBJ/ADB/ICLM AND (G01C+ OR G06F+ OR G08G+ OR G09B+)/IPC

Number of patent families found: 119

Hitrate: 85%

5.2.1.3 Roadway Infrastructure

Perallos (2015) identifies automatic video analysis as a key technology for the roadway infrastructure. Further, the objectification and object tracking software is deemed to be central, and the technique of background subtraction widely used. This type of technology is what allows for the deployment of digital cameras throughout the roadway system to monitor traffic patterns and events.

Search string: ((((BACKGROUND 3W SUBTRACT+) AND (CHANGE+ OR DIFFERENC+) AND DETEC+ AND CAMERA+ AND TRACK+ AND (MULTIPL+ 3W (VEHICLE+ OR CAR+ OR OBJECT+))))/TI/AB/IW/CLMS/DESC/ODES/OBJ/ADB/ICLM AND ((TRACK+ OR MAP OR IDENTIF+ OR FOLLOW) 9W (OBJECT+ OR VEHICLE+ OR CAR+ OR TRAFFIC+))/CLMS AND (CAMERA+ NOT (((VIRTUAL 4W (REALITY OR INTERACT+)) OR CHEMICAL+ OR MEDIC+ OR ISOMER+ OR (COMPRESS+ 9W FRAME+))))/TI/AB/IW/OBJ/ADB/ICLM)

Number of patent families found: 128

Hitrate: 80%

5.2.1.4 Localization

As explained earlier in this thesis, localization via comparing scans of the environment very detailed representation of the world is a promising method within this area, see section 5.1.2.2.

Search string: ((Locali* OR (determ* 9D Positi*)) 7D (Compar* OR Match* OR Simil* OR refer*)) AND (Compar* 9D (Enviromen* OR featur* OR Buildi* OR Objec* OR Surrou*)) AND sens* AND vehicle* AND Kalman AND navig* CLIAMS (Locali* OR (determ* 9D Positi*))

Number of patent families found: 209

Hitrate: 80%

5.2.1.5 Semantic Understanding

Semantic understanding, as explained in section 3.2.2.5, refers to the association of behaviors and characteristics to found objects. This more qualitative function has been mapped in relation to the effect it produces, and not connected to a specific technical version or algorithm.

Search string: (((UNDERSTAN+ OR INTERPRET+ OR RECOGNI+) 7D (SURROUNDI+ OR EXTERI+ OR GEOMETR+ OR GEOGRAPH+ OR ROAD+ OR TOPOLOG+ OR ENVIORMENT+)) AND SEMANTIC+ AND "3D" AND (OBJECT+ OR ROAD+ OR VEHICLE+) AND SENS+)/TI/AB/IW/CLMS/DESC/ODES/OBJ/ADB/ICLM AND (G06K+ OR G06T+ OR G09G+)/IPC

Number of patent families found: 211

Hitrate: 85%

5.2.1.6 Trajectory Generation

As explained in section 5.1.2.6, trajectory generation is the part that generates the path that the vehicle is to take. The patent landscape maps such generation based on predicted behavior of other objects for vehicles only.

Search string: ((Trajector* 2D (generati* OR generate*)) AND predic* AND (velocit* OR latera* OR Traject* OR path* OR heading*) AND (Self-driv* OR Vehicle* OR car*) AND (Evade* OR maneuv* OR control* OR Steer*)) NOT (Flight OR Aircra* OR encodin* OR Growth* OR train) CLAIMS: (Self-driv* OR Vehicle* OR car* OR Motor-veh*) IPC: (Self-driv* OR Vehicle* OR car* OR Motor-veh*)

Number of patent families found: 225

Hitrate: 85%

5.2.1.7 Other Vehicles

A central challenge of interacting with other vehicles is to be able to exchange the information with a low enough latency. Latency refers to the time it takes from when a message is sent to when it reaches the intended target. Lower latency means lower reaction times in case of accidents, and safer vehicles (Picone, Busanelli et al. 2014). This can be achieved through very low latency routing in base stations with the dataflow using a wide area network such as 4G or 5G, or achieved through V2V communications - cutting out the middle man. One of the main goals of 5G is to reduce latency (Zeira A. 2016) and might supply this as a default when launched, but launching seems to be a few years away.

Quicker routing can also be achieved standalone by giving a certain type of dataflows special treatments within the base stations, allowing them to have dedicated resources. This is also forecasted to be an integral part of 5G (Hu, Patel et al. 2015). Access to dedicated routing can thereby be key. Unfortunately, mapping the patent landscape surrounding this functionality failed, what was found was that Nokia is already testing such a base station (Nokia 2014). Instead, capabilities relating to V2V networks has been mapped. A V2V network is also referred to as an Ad-hoc network, meaning that it is constantly reconfiguring its structure and connections. Handling routing is such an environment with low levels of latency can be considered key, and this is the patent landscape that has been examined (Picone, Busanelli et al. 2014).

Search string: (((((AD-HOC OR "AD HOC") 2W NETWORK+) AND ROUT+ AND +LATENC+ AND ((DYNAMIC+ OR AD-HOC OR REAL+ OR TYPE+) 6D (CHOOS+ OR SELEC+ OR

PRIORITIZ+ OR PICK+ OR MANAG+)) AND (CONFIGUR+ OR STRUCT+ OR FORM+))/TI/AB/IW/CLMS/DESC/ODES/OBJ/ADB/ICLM AND ("ADHOC" OR AD-HOC OR "AD HOC")/CLMS)

Number of patent families found: 387

Hitrate: 75%

5.2.1.8 Filtering

Within the sensing part of the vehicle, the filtering of sensor data is needed before the data can be used. The filtering process is applied to raw data from sensors, removing noise, outlining objects, and connects the state of objects with previous readings - creating a connection for readings over time. Possessing this filtering capability is therefore important no matter what sensor is used (LaValle 2012). Kalman filtering and Probability Hypothesis Density filtering was identified as the most pertinent in the field, and mapped for use in dynamic situations (Panta, Vo et al. 2007).

Search string: (((probability 5D hypothesis) 7D density) OR ((Extended 4D Kalman) AND object* AND target*)) AND Filte* AND sens* AND (Radar* OR Lidar* OR Laser* OR video* OR Pictur* OR Light*) AND (spee* OR velo* OR Vect* OR trajec* OR headin* OR Path*)

Number of patent families found: 1011

Hitrate: 90%

5.2.2 Completed capability map

Table 1 shows the actors with highest of capabilities found, with number identifying the number of patent families found for an actor in a mapped area. Only 21 companies were found to possess capabilities in over half the mapped key technologies, with no company holding capabilities within all areas. Of these 21, only Mitsubishi, General Motors and Toyota are auto manufacturers. Please see Appendix for slightly larger list, and link to compressed directory with complete results.

Company Name	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
MICROSOFT	6	7		2	14	1	15	2	47	7
QUALCOMM	13		10	2	15	3	1	1	45	7
MITSUBISHI ELECTRIC	20	7		2	2	3	1	2	37	7
PANASONIC	1	2		5	2	1	7	7	25	7
SIEMENS	6	4	3		3	2	2	1	21	7
NEC	4	1	1		2	3	1	1	13	7
TOYOTA MOTOR	2		5	1		1	1	24	34	6
IBM	1	5		1	6	8	4		25	6
GENERAL MOTORS	7	1	5		4		1	3	21	6
XIDIAN UNIVERSITY	9	1			4	2	1	1	18	6
TOSHIBA	6	2	1		3		1	2	15	6
SAMSUNG ELECTRONICS	26		2		3	5	4		40	5
SONY	24			2	4		5	2	37	5
CANON	10		1		1	5	1		18	5
HONEYWELL	7		3		2	4	2		18	5
ROBERT BOSCH	2	1	6			1		6	16	5
HITACHI	7	4	1	1				2	15	5
SOUTHEAST UNIVERSITY	6	5	1		1	1			14	5
CONTINENTAL TEVES	1		6	1			1	1	10	5
INDUSTRIAL TECHNOLOGY RESEA	5		1			1	1	2	10	5
PHILIPS	3		1		1		2	1	8	5
CHONGQING UNIVERSITY	10	4			8	1			23	4
ERICSSON	9	1			9			2	21	4
FORD GLOBAL TECHNOLOGIES	4	5	1					11	21	4
INTEL	3				9		3	2	17	4
DIGIMARC			1		1	1	13		16	4
GOOGLE	1		8				3	3	15	4
LOCKHEED	12		1		1		1		15	4
BEIHANG UNIVERSITY	10	1		1				2	14	4
NISSAN MOTOR	2	1		7				3	13	4
GENERAL ELECTRIC	6		2		1		1		10	4
APPLE	2	2			2		3		9	4
CEA - COMMISSARIAT A L ENERG	4		2		2		1		9	4
SOUTH CHINA UNIVERSITY OF T	4	2			2		1		9	4
XEROX	2				1	5	1		9	4
AUDI	1	1	1					3	6	4
ALCATEL LUCENT			1	1	1	1			4	4

Table 1, Top actors in completed capability assessment

5.3 Comparing maps created by the framework to examples of existing initiatives

The evaluation of the framework is done by comparing the results created by applying the framework to an envisioned completed ITS network to examples of existing open innovation initiatives, as described in section 4.2.4.

5.3.1 Examples of existing open innovation initiatives

In this section examples of open innovation initiatives will be presented. These examples are used as input to evaluate the validity of the results created by the study in section 5.1 and 5.2, as described in section 4.2.4. In addition to en general description, each initiative has had information gathered regarding what systems they are covering and which actors are part of them. This information is presented in relation to the interoperability effort map and capability map. The examples have been gathered by noting initiatives referenced in the academic sources throughout the study.

5.3.1.1 HERE

HERE is a joint venture owned by Daimler, BMW, and Audi (which is a part of VW Group). It was bought from Nokia in 2015 (Daimler 2015).

According to its website the company offer solutions concerning real time traffic predictions and route selection, analogous to key functionality of an envisioned ISPS. It also promotes what is called "HERE HD Live Map", which fits the description for an LDM supplied by a Map Provider, as well as "HERE Auto" which can be translated within the chosen architecture for the thesis as the application layer. (HERE 2016) Looking at the scope of the joint venture in relation to the interoperability map, there are multiple systems which are in need of interoperability efforts in relation to the systems being developed. This is shown in figure 12, where systems within the scope of HERE are circled in dashed black.

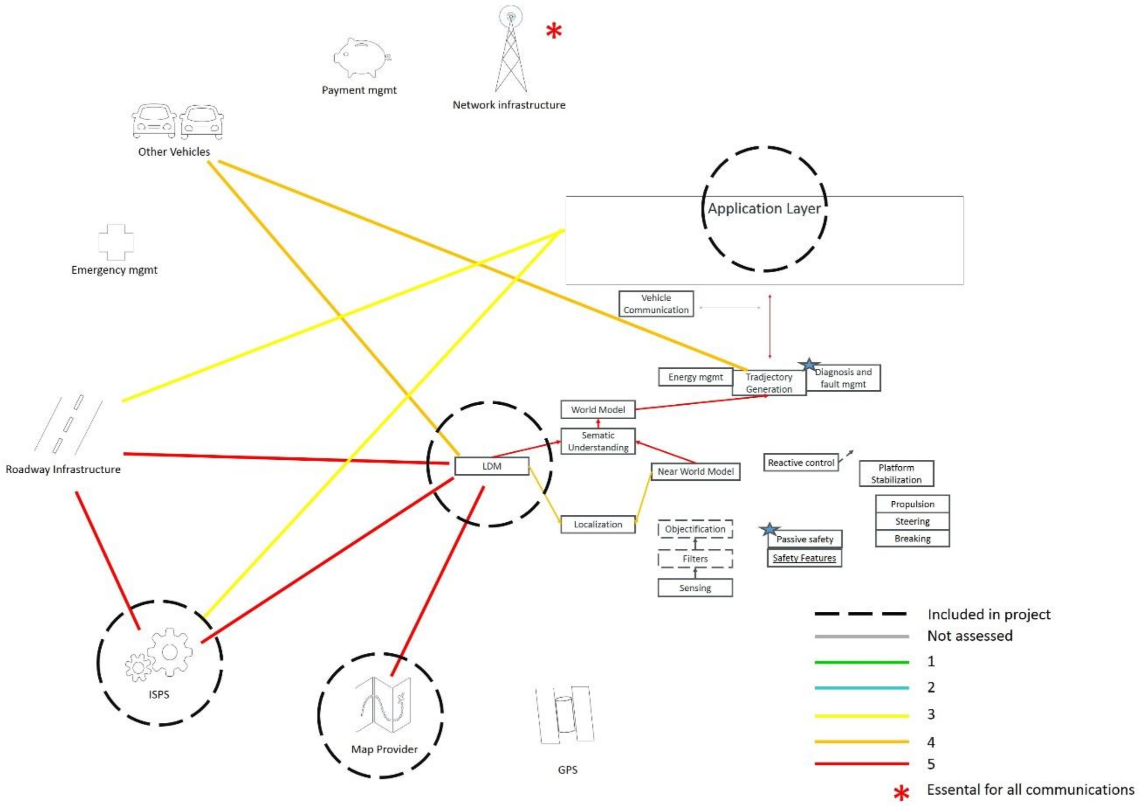

Figure 12, Scope of HERE

Looking at the capabilities of the company, and its owners, the capabilities as outlined in table 2 has been found within the subset of systems with higher interoperability efforts needed. The HERE website also states that billions of GPS source are used as input for the traffic prediction service, indicating that a collaboration with an actor in the mobile device sector has already been established (HERE 2016). This solves the need identified in section 5.2.1.1 for large volume of input data for ISPS algorithms.

Company	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
AUDI	1	1	1					3	6	4
DAIMLER	4	5		1					10	3
HERE		4		2		1			7	3

Table 2, Capabilities found for HERE actors

5.3.1.2 DESERVE

DESERVE is a consortia that develops advanced driver assistance systems (ADAS) in the form of a modular system design and tools for other to develop modules within the modular design. It seems to currently be in a stage where the focus is mainly on trajectory generation and interactions with the application layer (DESERVE 2016a). However, the planned deliverables extends that scope to include perception systems, and V2X communications (DESERVE 2016b). Figure 13 visualizes the scope.

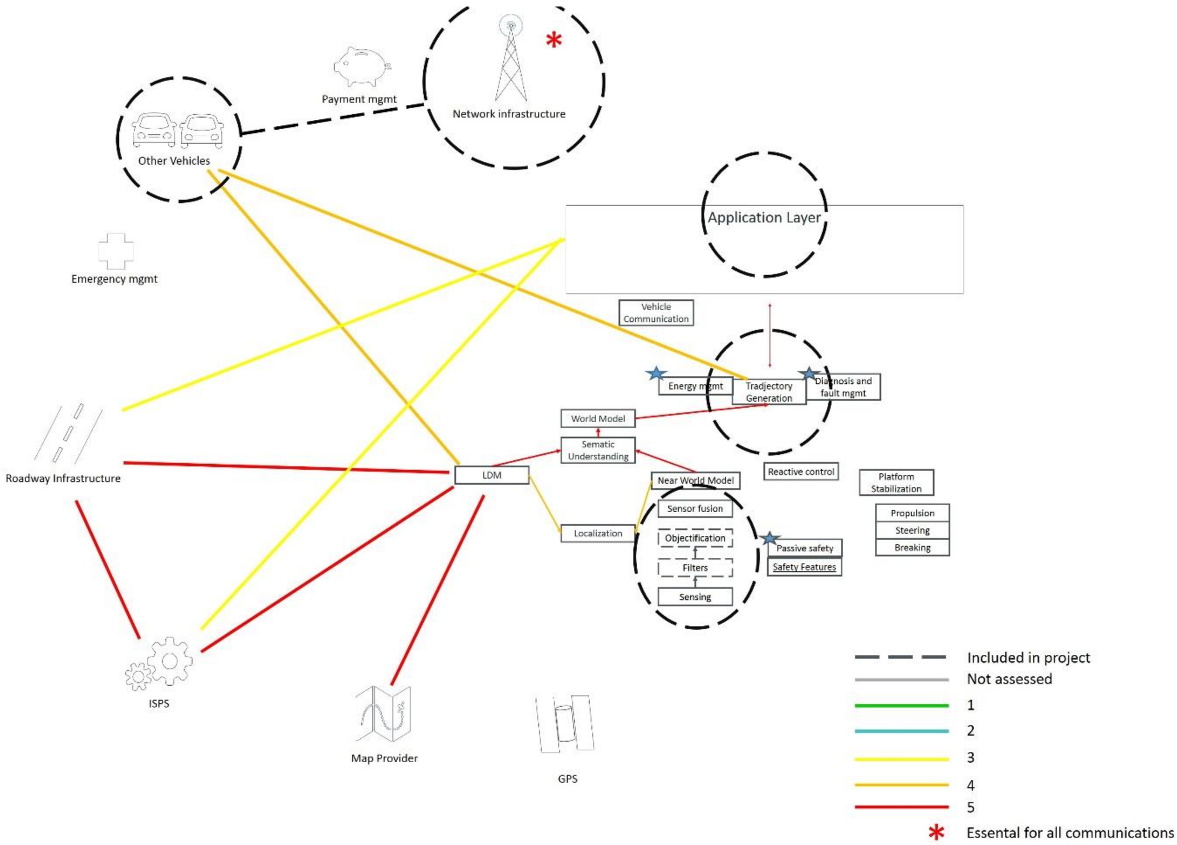

Figure 13, Scope of DESERVE

The used in-vehicle architecture is also noted to be very similar to the one described in this thesis (DESERVE 2014).

The consortia is made up of the actors found in table 3

Infineon Technologies AG, Germany	Continental Automotive France SAS, France	RE:Lab s.r.l., Italy
Volvo Group Trucks Technology, Sweden	Institut für Kraftfahrzeuge (ika), RWTH Aachen University, Germany	Daimler AG, Germany
Centro Ricerche Fiat, Italy	Centro Tecnológico de Automoción de Galicia, Spain	Ficosa S.A., Spain
VisLab, University of Parma, Italy	Interuniversity Consortium for Optimization and Operations Research, Italy	Inria, France
AVL List GmbH, Austria	IRSEEM – Embedded Electronic Systems Research Institute, France	ARMINES, France
Robert Bosch GmbH, Germany	VTT – Technical Research Centre of Finland	TTS, Finland
INTEMPORA S.A., France	Institute of Microelectronic Systems, Germany	dSPACE, Germany
NXP Semiconductors, The Netherlands	Technolution B.V., The Netherlands	

Table 3, actors in the consortia DESERVE

And actors with capabilities in examined key technologies are shown in table 4.

Company Name	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
ROBERT BOSCH	2	1	6			1		6	16	5
CONTINENTAL TEVES	1		6	1			1	1	10	5
DAIMLER	4	5		1					10	3
VOLVO TRUCKS	1							1	2	2
VOLVO			2						2	1
CENTRO RICERCHE FIAT	1								1	1
CONTINENTAL AUTOMOTIVE								1	1	1
CONTINENTAL AUTOMOTIVE SYSTEMS								1	1	1
INFINEON TECHNOLOGIES					1				1	1

Table 4, Capabilities found for actors in DESERVE

5.3.1.3 ADASIS

As described by the ADASIS homepage, the overall aim of the project is to define, create, and adjust an LDM for use in ADAS applications. Interfaces for having ADAS interact with the LDM is an objective, as is creating protocols able to handle the resulting data streams. (ADASIS 2016)

Actors connected to the project, with the specific expertise they bring to the table identified on the ADASIS homepage, are:

ADAS suppliers:
Continental Automotive

Map & data providers:
TomTom
Nokia L&C

Vehicle manufacturers:
BMW
Daimler
Ford
Honda
Opel

Navigation system manufacturers:
Robert Bosch

The scope of the project seems to be located entirely within the large group of systems with connected identified higher interoperability efforts, with no mention of emergency management, payment services, trajectory execution, or perception systems. See figure 14 for visualization.

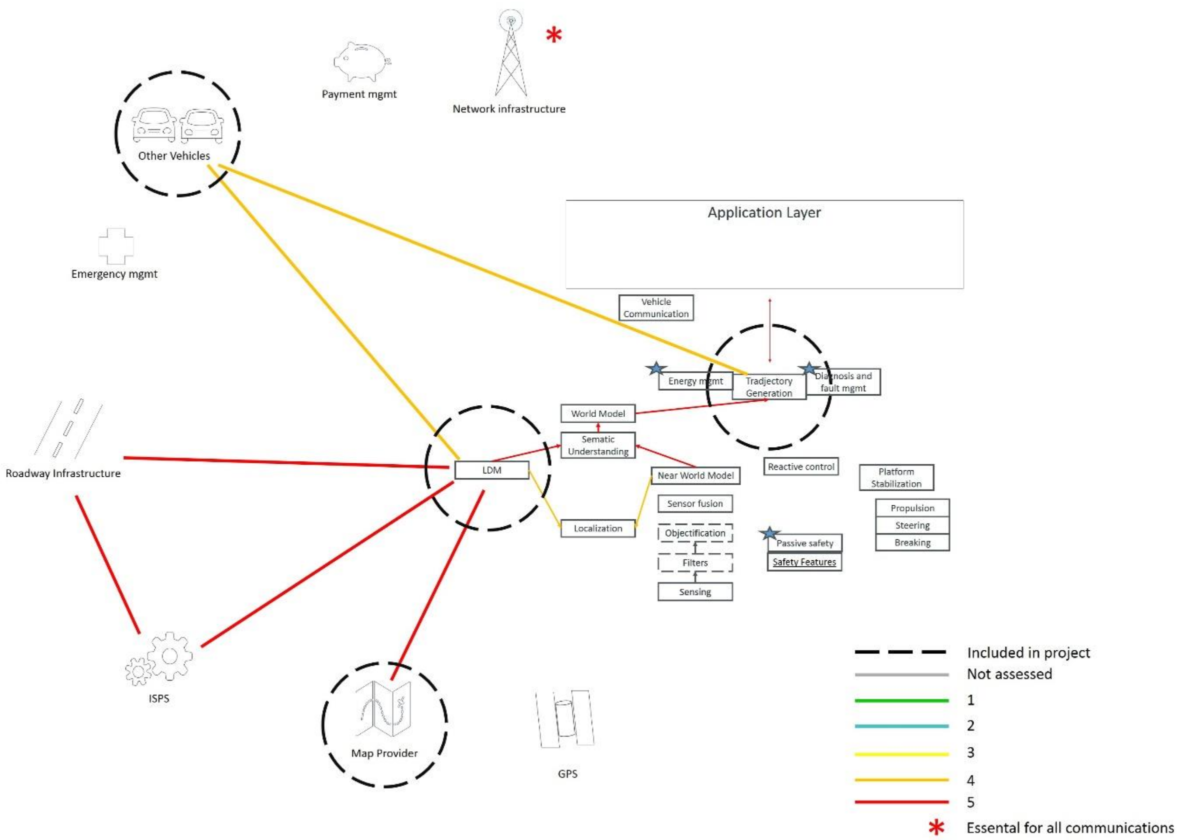

Figure 14, Scope of ADASIS

And the actors within the consortia had the capabilities in table 5 found.

Company Name	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
ROBERT BOSCH	2	1	6			1		6	16	5
CONTINENTAL TEVES	1		6	1			1	1	10	5
FORD GLOBAL TECHNOLOGIES	4	5	1					11	21	4
NOKIA	4	1			7				12	3
HONDA MOTOR	4						1	6	11	3
DAIMLER	4	5		1					10	3
HONDA		1						7	8	2
FORD MOTOR	1							1	2	2
TOMTOM				1			1		2	2
CONTINENTAL AUTOMOTIVE								1	1	1
CONTINENTAL AUTOMOTIVE SYSTEMS								1	1	1
TOMTOM ASIA			1						1	1
TOMTOM BELGIUM								1	1	1
TOMTOM GERMANY				1					1	1
TOMTOM GLOBAL CONTENT				1					1	1

Table 5, Capabilities found for actors in ADASIS

5.6.1.4 Car2Car

The Car2Car communication consortium is made up of car manufacturers and a large body of additional partners. It concerns itself with the convergence of V2V communication protocols, and alignment of such communications with V2I communications (Car2Car 2016). More simply put, making sure that all vehicles can communicate with each other in a way that is compatible with communications with roadway infrastructure. The scope is visualized in figure 15. Participating actors are found in table 6, capabilities in table 7.

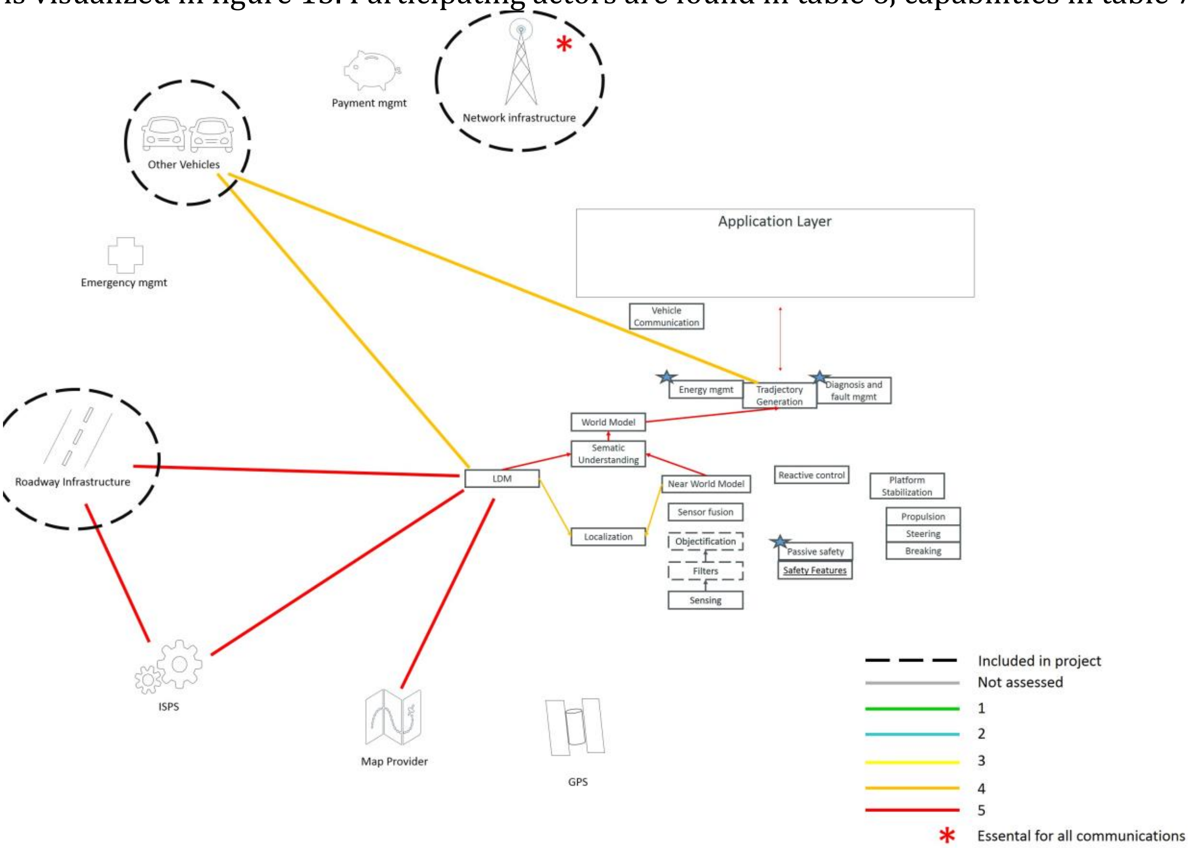

Figure 15, Scope of Car2Car

Audi	MAN	Atmel	eict	LG	Siemens
BMW	OPEL	Autotalks	escrypt	Marben	Spirent
Daimler	Pegeaut Citroen	Robert Bosch	HSAE	NEC	Swarco
Ford	Renault	Cetecom	Hessen mobil	Nordsys	Tass
Honda	VW	Cohda wireless	Hitachi	NXP	TE connectivity
Hyundai	Volvo	Commsignia	Huawei	PAULs Consultancy	ublox
Jaguar	Volvo Cars	Continental	iau	Qualcomm	valeo
Landrover	YAHAMA	Delphi	kapsch	Renesas	vector
Kawasaki		Denso	Kostal	Savari	Visteon
KTM		dSPACE	Lesswire	Secutity innovation	

Table 6, Actors in Car2Car

Company Name	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
QUALCOMM	13		10	2	15	3	1	1	45	7
SIEMENS	6	4	3		3	2	2	1	21	7
NEC	4	1	1		2	3	1	1	13	7
ROBERT BOSCH	2	1	6			1		6	16	5
HITACHI	7	4	1	1				2	15	5
CONTINENTAL TEVES	1		6	1			1	1	10	5
FORD GLOBAL TECHNOLOGIES	4	5	1					11	21	4
AUDI	1	1	1					3	6	4
DENSO				10	1			1	12	3
HONDA MOTOR	4						1	6	11	3
DAIMLER	4	5		1					10	3
HYUNDAI MOTOR		1		3				1	5	3
LG ELECTRONICS		7		3					10	2
HONDA		1						7	8	2
HYUNDAI MOBIS				2				5	7	2
HUAWEI TECHNOLOGIES					4			1	5	2
HYUNDAI		1		4					5	2
VOLKSWAGEN	2		1						3	2
VOLVO CAR	1							2	3	2
FORD MOTOR	1							1	2	2
VOLVO TRUCKS	1							1	2	2
DELPHI TECHNOLOGIES	4								4	1
DENSO IT LABORATORY		2							2	1
HITACHI AUTOMOTIVE SYSTEMS		2							2	1
RENAULT								2	2	1
SIEMENS ROKE	2								2	1
VOLVO			2						2	1
ATMEL			1						1	1
CONTINENTAL AUTOMOTIVE								1	1	1
CONTINENTAL AUTOMOTIVE SYSTEMS								1	1	1
DELPHI 2 CREATIVE TECHNOLOGIES		1							1	1
HITACHI ENGINEERING		1							1	1
JAGUAR LAND ROVER								1	1	1
KAWASAKI HEAVY INDUSTRIES	1								1	1
LG INDUSTRIAL SYSTEMS		1							1	1
LG INNOTEK								1	1	1
SWARCO TRAFFIC SYSTEMS		1							1	1
U BLOX	1								1	1
YAMAHA	1								1	1
YAMAHA MOTOR	1								1	1

Table 7, Capabilities found for actors in Car2Car

5.3.2 Evaluation of framework

As described in section 4.2.4, patterns in open innovation initiatives was expected if the mappings were consistent with the real situation. What was to be evaluated was if the scopes of the initiatives predominantly included systems with higher needs to interoperability efforts, if actors engaging in the initiatives lacked capabilities within the systems, and if actors' capabilities complemented each other's. Looking at the four initiatives analyzed the following can be concluded:

No initiative has a scope that includes a system that does not have a higher need for interoperability effort with another system.

Companies engaging complemented each other's capabilities, especially in the case of ADASIS. In ADASIS, the companies was identified as to what role they were to play within the initiative, and these roles correspond well to the capabilities found within the capability assessment. Comparing the supplied areas for actors with which capabilities was identified in the patent searches, found in table 5, there are clear similarities. Continental is identified as having capabilities within trajectory generation, and TomTom has capabilities within the Map Provider area, Nokia has capabilities within vehicle communications. If "navigation system" is defined as including localization and ISPS capabilities, then Robert Bosch is identified as having capabilities within this area. However, the term is not explained further which makes the comparison hard to make. Interesting enough both Ford, Robert Bosch, and Honda seems to have capabilities within the trajectory generation area as well.

The CAR2CAR initiative stands out against the others. It only concerns communications, and represents a push towards a general standard. It is composed of a wide range of actors, including actors with a capabilities in seven of eight assessed technology areas – compared to the actors in the other initiatives where no actor has capabilities in more than five areas. It is also made up of a larger collection of actors.

To summarize the evaluation the three initiatives where actors are trying to combine technology and develop products, and tools for creating products aligned with actors' systems, are consistent in both initiative system scope and the actors that are engaged. The fourth initiative, where a more open, general, standard is pursued is consistent with expected scope as it centers on systems with needs for higher interoperability efforts, but not in regard to the actors engaged.

6 Results

The results of the study include the created framework for assessing technical open innovation drivers, the results of its application to the area of ITS networks, and the evaluation of the framework. This section will describe the framework in detail, the type of result it creates, and the results of the evaluation. The maps created, and most of the input data, can be found in their entirety in Appendix E & F, and a link to a compressed directory is found at the beginning of Appendix.

The scope of the framework is restricted to technical drivers of open innovation initiatives within ITS networks. The technical drivers identified are Interoperability and capability distribution. If two systems with high efforts needed to create interoperability between them are to be created and an actor do not possess capabilities needed to create both systems, open innovation is more likely to be initiated.

A combination of two ITS network architectures, nITSa and CVRIA, and systems collaborating within the vehicle to achieve autonomous driving has been created. It was limited to include only systems in direct contact with the vehicle, and these were grouped to reflect probable system constellations. The resulting structure represent a probable envisioned future ITS network structure and is described in enough detail to allow for detailed analysis with created framework.

Relative interoperability effort needed between systems is a dependent on the number of individual dataflows between systems, the complexity of the exchanged data, and the number of functions using interchanged data. The complexity of dataflows and the number of flows combine to driver effort needs, whilst the number of functions drive the effort needed by itself. A general assessment chart has been synthesized that reflects these results, and the results themselves has been visualized. The full matrix can be found in Appendix E.

Which actors have the capability to develop a certain system can be mapped out using patent keyword searches. In the study a limited mapping was conducted, focusing only on chosen key technology areas within systems with higher interoperability efforts needed. A matrix summarizing the results of all the searches can be found in Appendix F.

The application of the framework to the future envisioned ITS network synthesized created maps of interoperability and actor capabilities that fit the scope and make-up of existing open innovation initiatives in three out of four cases. The existing initiative not consistent with what was expected when analyzing the number of engaged actors and their capabilities concerned a general standardization effort.

6.3 Result analysis

The results of the study is considered together with the methods used to create them in order to assess validity. Four parts of validity is defined by LeCompte och Goetz (1982). They are external validity, internal validity, external reliability, and internal reliability.

6.3.1 Internal validity

Internal validity concerns how well the results of the study reflect reality (LeCompte, 1982). In the thesis, this has been the main concern when constructing methodology. Limitations posed by time constraints and the inability to validate input structures and results due to the restrictions put up by the auto manufacturer has hindered this.

As what has been attempted to estimate is the relative pull towards open innovation initiatives in a network that has not been created yet, achieving perfect external validity is impossible by definition. The study has been using input structures and information that reflects a consensus amongst developing actors as much as possible. This is especially reflected in the choice of ITS reference architectures that are in themselves both guiding development to ensure alignment and created to reflect current visions as well as possible. The sources found has also been in consensus in most cases.

The results of the study has been evaluated against existing open innovation initiatives, and found to have a good fit in relation to what could be expected in scope and participants.

The internal validity of the thesis is considered to be high for this point in time. The results are not expected to stay valid over time as actors develop both systems and capabilities, and the consensus about structure shifts.

6.3.2 External validity

External validity is used to measure how well connections found can be applied to the general case (LeCompte, 1982). This has not been evaluated in this thesis as the connection measured has been established by several leading researchers. The survey of existing initiatives is too limited to provide a basis for assessment if one wanted to generalize the results, and the methodology for evaluation between the maps and reality is not anchored in relevant theory for the field of open innovation. The methodology is tailored to the situation, with quantifications of drivers being bound to a tool that only deals with software development.

The possibility to draw general conclusions about open innovation and its drivers from this study alone is low. To enable such conclusions a larger study would have been more suitable, and measuring of additional types of drivers necessary to assess relative relevance.

6.3.3 Internal reliability

Throughout the thesis internal reliability has been tried to be raised. It refers to how much the results of the study is affected by the circumstances surrounding it. To strengthen it, objective quantitative assessments has been used as much as possible, and the opinions of experts sought. However, to be able to conduct the study in time and without the possibility to consult technical experts, many choices and evaluations rests on the author and the author’s skills. The qualitative evaluations made by the author has been created using extensive input from expert sources, and the choice and interpretations of methods foreign to the author has been explained and corroborated from leading researchers and industry experts when possible. Even so, the internal reliability is considered to be low – and validation of choices from technical experts are advised before using the results.

6.3.4 External reliability

External reliability is the possibility of replicating the study and getting the same results. This is generally considered hard to achieve the more qualitative elements the study includes (LeCompte, 1982). There are qualitative elements in both the interoperability and capability assessments, however they are well founded in theory and sources. In the interoperability effort assessments qualitative elements are well defined, and complexity of dataflow are evaluated together with the purely quantitative measurement of the number for information bearing dataflows between systems. In the capability assessment the choice of key technology area is highly qualitative, but well sourced and corroborated. The searches themselves are highly qualitative and could be reconstructed for very different results, but given that one tries to replicate the results exactly the extensive documentations provides perfect replicative ability of the searches.

The possibility of replicating the results of the study at the time of writing is considered medium to high, as it is well documented and qualitative elements either well sourced or tempered by purely quantitative evaluations. However the consensus in this field with high levels of development might shift over time, and patent searches yield different results as families are abandoned and filed for.

7 Conclusions and discussion

In this section the conclusions of the thesis are presented with the research questions providing the structure. This is followed by a discussion regarding both the created framework, its scope, and the results of its application to ITS networks. Lastly the section includes a concise description of the contributions the thesis makes.

7.1 Conclusions

Answers to the three research questions are gathered here, and then their role in the study is shown by placing them in the context of the work conducted.

1. What technical aspects drives open innovation?

The technical need for open innovation for an actor developing systems in a complex technical network is driven by the actor's lack of necessary technical capabilities needed to create interdependent systems and the interoperability effort needed between said parts to ensure functionality.

2. How should technical drivers of open innovation be assessed for ITS networks?

Interoperability should be assessed based on the number of functions active the connection between systems and a combination of the number of individual dataflows and the complexity of the data in them. Capability distribution should be assessed using keywords based patent mapping. The correspondence of the results of the application of the framework is fairly high. The framework produce interoperability maps which highlighted systems correspond with the scope of analyzed open innovation initiatives. The profile of actors engaging in the initiatives are consistent with the capability map and expected results for initiatives working with system development, but not for the development of general standards.

3. How are the systems that make up an ITS network configured in relation to open innovation drivers?

The systems are described well in CVRIA and nITSa, and in 5.1.5 as evaluated for the open innovation driver of interoperability effort. They are configured in a complex network with multiple connections requiring high levels of effort to achieve interoperability. The studied ITS network configuration is both relevant for almost every area, and tomorrow.

Answers in context: In the creation of ITS networks, open innovation initiatives are sought by actors without capabilities in all systems that are to be developed for systems have a high need of interoperability. Using interoperability effort drivers identified in the IT system development effort tool COSYSMO a map of which systems need to be co-developed can be created. As input for this mapping a combination of nITSa and CVRIA is relevant. Which actors has key capabilities needed to develop systems with higher interoperability efforts can be mapped out using patent keyword searches.

The framework creates results where the relative pull towards engaging in open innovation initiatives for an actor that is to create a system within ITS networks can be evaluated. The maps have been shown to be consistent with theory when it comes to system development collaborations, but not in the case of general standard creation.

Exploring the possibilities of moving the field of open innovation to more tangible, objectively measurable, parts of the epistemological and ontological spectrums was a goal in itself for the author when undertaking the thesis. This has not been achieved. What can be argued to have been achieved is the strengthening of the case for the existence of causality between the examined technological factors and actor capabilities, and the probability of actors engaging in open innovation initiatives in the case of ITS networks.

7.2 Discussion

There are many parts of the study that would have benefitted from more work and a wider scope. There are also question about causality that the author wants to raise to put the results in a more complex context. This section explores these two aspects, and identifies some paths that later research could explore to add more to academia.

The scope of the capability assessments would have been a priority of enlargement to improve on the quality and number of conclusions possible to draw. An FTO analysis would have made it possible to bring in the control dimension inherent in patent mappings, enabling even more powerful conclusions to be drawn – especially if combined with litigation behavior. No not only know who has the capability to develop a system but also who can, and is known to take action, stop others from doing so would be useful for any actor hoping to navigate the market.

The author also speculates if the relative level of detail in reference architectures could be influenced by how far along development of systems has come. And if open innovation and collaborations influence development in a positive manner, then one of the three drivers of interoperability, number of flows, could be larger for these systems. Leading to slightly higher interoperability effort needed between systems that are being co-developed. The effect should be limited as it is only a part of the assessment, and also because of it being buoyed by the very large number of actors from different fields involved in the creation of the reference architectures, and the creator's impartibility.

To turn the framework into a more predictive one, past behavior of actors could be included. As corporate culture is hard to change (Schein, 2004) the willingness of engaging in open innovation activities for an individual actor might change slowly over time. Research into the area would be needed to enable inclusion. An inclusion of the drivers found by Stuart (1998), crowding and prestige, could also create a more useful and complete map for decision making. As these drivers should be possible to measure by looking at patent landscapes, the amount of work necessary might be reasonable.

The fact that actors engaged in the creation of a general standard regardless of whether or not they had capabilities in interconnecting systems or not raises questions about the relative strengths of technical drivers versus other types. More examples would need to be examined to draw any strong conclusions, but such research would be very interesting.

Before using the results of the study, an evaluation of the scope of the thesis is recommended. As described in this thesis, open innovation is a complex subject with many types of drivers and inhibitors possible to consider. And evaluating the relative relevance of technical drivers as opposed to other types might serve to put the usefulness of the study into perspective.

7.3 Contributions of the thesis

A framework is constructed that allows for the assessment of two technical drivers of open innovation in ITS networks.

The results of the application of the framework to the probable structure of a finished ITS network for autonomous vehicles contributes to the knowledge base available to actors within the field.

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All used sources are found here. nITSa and CVRIA sources has been broken down into specifics as the websites are very confusing.

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9 Appendix

Spreadsheets containing raw data and assessments are available for download at:
https://drive.google.com/file/d/0B_1LodQec14nbkp2UGx6RWhGbkk/view?usp=sharing
Outtakes of the data in the spreadsheets are presented in appendixes.

Appendix A: Groupings of systems with direct contact with the vehicle

OrgArchName	Entity denimination	Group
nITSa	Emergency Management	Emergency mgmt
CVRIA	Emergency Management Center	Emergency mgmt
CVRIA	Driver	HMI
nITSa	Driver	HMI
CVRIA	Center	ISPS
CVRIA	Cooperative ITS Credentials Management System	ISPS
CVRIA	Data Distribution System	ISPS
nITSa	Information Service Provider	ISPS
CVRIA	Object Registration and Discovery Service	ISPS
CVRIA	Service Monitor System	ISPS
CVRIA	Transportation Information Center	ISPS
nITSa	Location Data Source	Location Source
CVRIA	Vehicle Location and Time Data Source	Location Source
nITSa	Map Update Provider	Map provider
CVRIA	Map Update System	Map provider
CVRIA	Wide Area Information Disseminator	Network Infrastructure
nITSa	Other Vehicle	Other Vehicle
CVRIA	Remote Vehicle OBEs	Other Vehicle
nITSa	Payment Administration	Payment mgmt

CVRIA	Payment Administration Center	Payment mgmt
CVRIA	Payment Device	Payment mgmt
nITSa	Roadway Payment	Payment mgmt
CVRIA	Traveler Card	Payment mgmt
nITSa	Traveler Card	Payment mgmt
CVRIA	Electric Charging Station	Roadway Infrastructure
CVRIA	ITS Roadway Equipment	Roadway Infrastructure
CVRIA	ITS Roadway Payment Equipment	Roadway Infrastructure
nITSa	Parking Management	Roadway Infrastructure
CVRIA	Parking Management System	Roadway Infrastructure
CVRIA	Roadside Equipment	Roadway Infrastructure
nITSa	Roadway	Roadway Infrastructure
nITSa	Basic Vehicle	Vehicle
nITSa	Vehicle	Vehicle
CVRIA	Vehicle Databus	Vehicle
CVRIA	Vehicle OBE	Vehicle

Table A1, System groups

Appendix B: Visualization of nITSa complexity

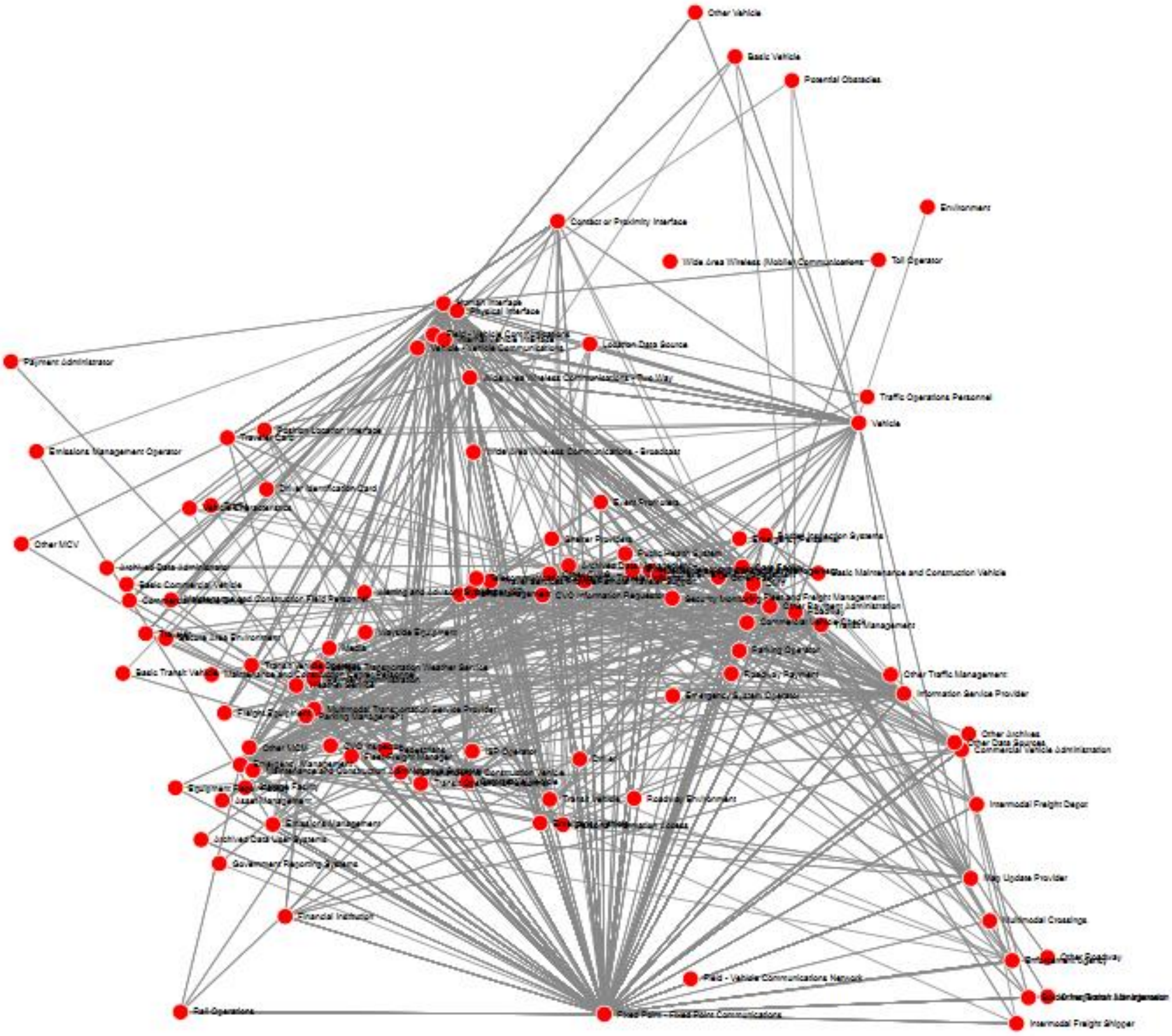

Figure A2, zoomed out visualization of nITSa complexity.

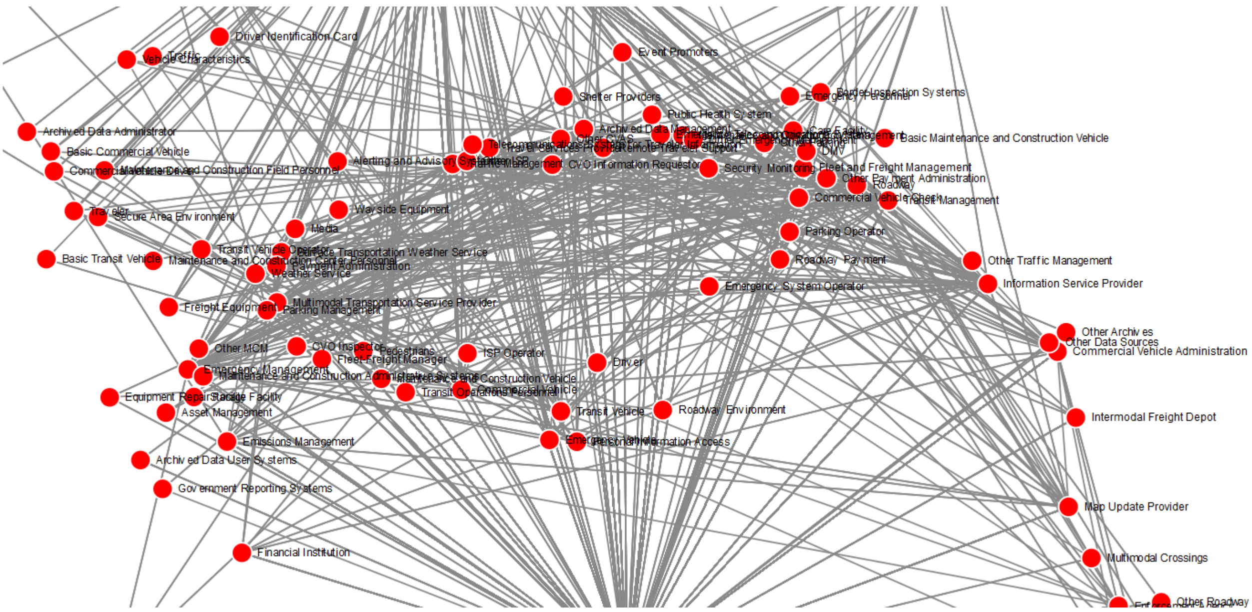

Figure A3, zommed in complexity of nITSa complexity.

Appendix C: Systems removed for qualitative reasons and system groups

Personal Information Device	REMOVED - This system is any personal device such as a mobile phone or PDA with connectivity and route planning/guidance functions. The use of these as housing actively calculating systems for autonomous drive functionality is not something that has been mentioned in ANY literature surveyed in this thesis, and is therefore removed. I concede that this function might prove to be very important in the future, however I lack any understanding about how this unit would interact with in-car systems - making any analysis impossible. This means that: removing personal information device as an active part of an envisioned finished ITS is a delimitation, but that it is justified both from a scope, feasibility, and trend survey viewpoint.
Potential Obstacles	REMOVED - This is physical objects that the vehicle needs to take into account when traveling a road, such as a parked car. The cars internal systems handles this, and these flows are mapped based on academic literature.
Privacy Protection Gateway	REMOVED - Its position in the network cannot be determined. Privacy is an important part of the system, however based on the information at http://www.iteris.com/cvria/html/applications/app119.html , this problem seems to be solved by a designated network function, and as such does not actually influence the functionality and architecture of the rest of the system. I regret that I cannot get to the bottom of this issue, but I am not familiar enough with how network security gateways function and what influence their makeup has on the systems they are supposed to protect - data sent from one system to be used in another I can understand requires interoperability between those two systems, but if privacy protective gating protocols has a similar effect I cannot discern. It also only has two incoming and three outgoing flows, making relatively small.
Roadway Environment	REMOVED - This refers to the world as measured by onboard sensors, something that is handled individually in the sensors.
Other Vehicle functions related to specialty vehicles	REMOVED - All dataflows envisioned for specialty vehicles, such as vehicles transporting hazardous material, emergency vehicles and the like was removed from the subset. The removal of specialty vehicles allowed for a focus on core autonomous driving functionalities, removing such dataflows as those between hazardous material carrying vehicles requesting permission from road infrastructure to enter areas

Table A4, systems removed for qualitative reasons.

Basic Vehicle	Information Service Provider	Parking Management	Service Monitor System
Center	ITS Roadway Equipment	Payment Administration	Transportation Information Center
Cooperative ITS Credentials Management System	ITS Roadway Payment Equipment	Payment Device	Traveler Card
Data Distribution System	Location Data Source	Remote Vehicle OBEs	Vehicle
Driver	Map Update Provider	Roadside Equipment	Vehicle Databus
Electric Charging Station	Object Registration and Discovery Service	Roadway	Vehicle Location and Time Data Source
Emergency Management	Other Vehicle	Roadway Payment	Wide Area Information Disseminator

Table A5, Systems kept

Center	ISPS	This is an authorization and routing entity, handling requests and addresses for the network. I have placed it under ISPS, as a choice of architecture version - it could both be distributed and/or be its own unit, however the placement at the ISPS unit is more consistent with litterature sources, especially chapter 13, "Applications and Services for Users and Traffic Managers"
Data Distribution System	ISPS	Credentials and authentication functions lays here, as it is likely that they will need to be incorporated into ISPS to allow for secure distribution and management of real-time functions.
Object Registration and Discovery Service	ISPS	Placed at ISPS as ISPS has been designated as the controlling party within the system, handling both travel coordination in the form of trip planning, and keeping the databases of any objects active within the system. As such, it is natural for this system to also handle keeping tab on vehicles in the system - how else can it know who needs to know what?

Table A6, Systems making up the ISPS group.

Appendix D: IEEE view of in-vehicle system interactions

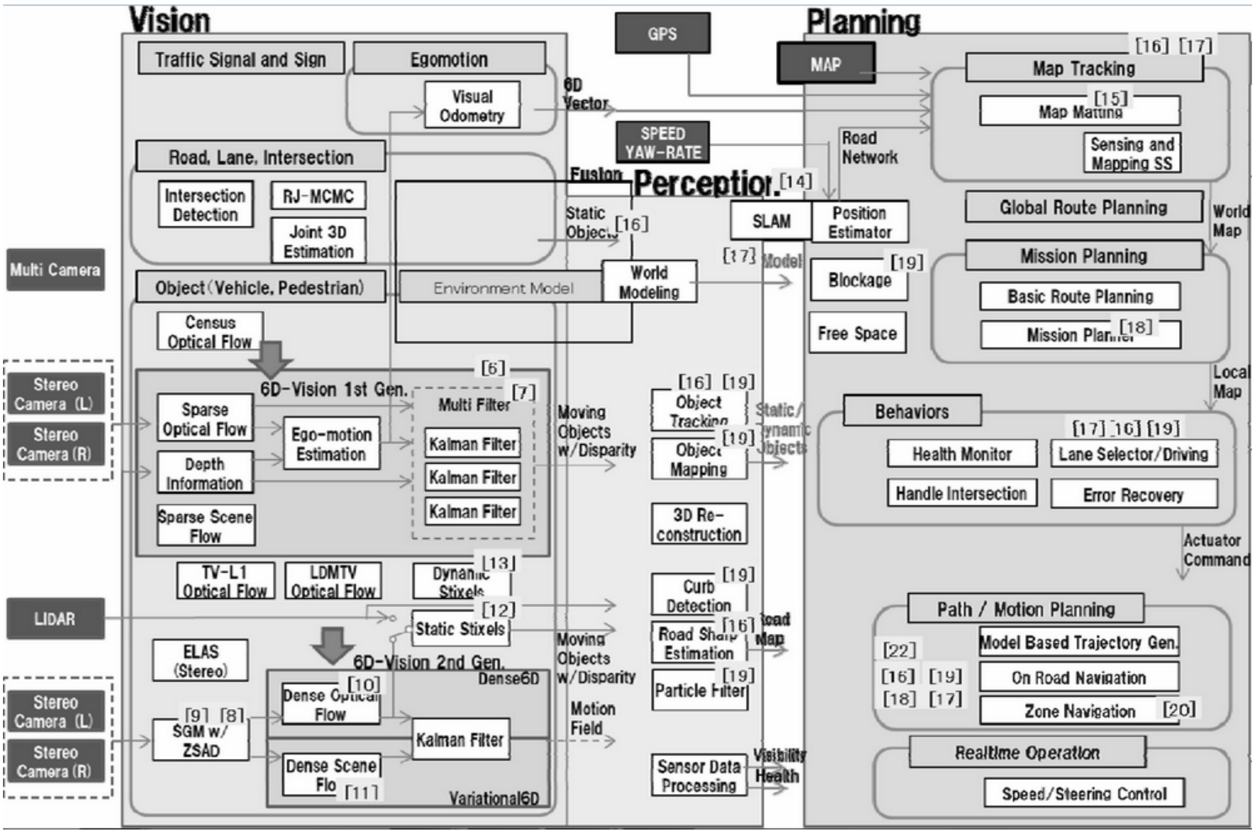

Figure A7, In-vehicle system interactions according to IEEE.

Appendix E: Interoperability assessment

Table A8, Interoperability assessments

		Volume 1-10 Low, 11-30 Average, 31-100 High	Data Complexity Qualitative assessment				System Complexity 0-5 Low, 6-10 Average, 11-70 High		
Source	Target	# of Dataflows	Low	Med	High	Total	# of active source apps	# of active target apps	Assessment
Emergency mgmt	ISPS	10	1	3	2	Medium	3	1	1
Emergency mgmt	Payment mgmt	1	1	0	0	Low	0	0	1
Emergency mgmt	Roadway Infrastructure	5	2	1	0	Low	2	3	1
Emergency mgmt	Application Layer	2	1	0	0	Low	1	1	1
Application Layer	Trajectory Generation	9	0	0	1	High	0	13	4
ISPS	Emergency mgmt	9	1	2	2	Medium	0	0	1
ISPS	ISPS	65	2	7	2	Medium	13	13	5
ISPS	Map provider	2	0	1	0	Medium	1	1	1
ISPS	Network Infrastructure	9	0	4	0	Medium	5	2	2
ISPS	Roadway Infrastructure	26	4	2	3	High	8	5	5
ISPS	Application Layer	14	3	2	1	Medium	4	3	3
ISPS	LDM	32	1	0	2	High	5	6	5
Location Source	Localization	1	1	0	0	Low	0	1	1
Map provider	Emergency mgmt	2	0	0	1	High	0	0	2
Map provider	ISPS	4	0	0	2	High	1	1	2
Map provider	Roadway Infrastructure	6	0	0	4	High	1	2	2
Map provider	LDM	9	0	0	4	High	1	1	5
Network Infrastructure	ISPS	7	0	2	1	High	2	4	3
Network Infrastructure	LDM	10	0	1	0	Medium	1	1	1
Other Vehicle	Application Layer	1	0	1	0	Medium	2	1	1
Other Vehicle	LDM	24	1	3	2	High	3	3	4
Other Vehicle	Trajectory Generation	6	1	0	3	High	2	3	3
Payment mgmt	Emergency mgmt	2	2	0	0	Low	0	0	1
Payment mgmt	HMI	2	1	0	0	Low	0	0	1
Payment mgmt	ISPS	5	2	1	0	Low	0	0	1
Payment mgmt	Payment mgmt	18	3	3	0	Medium	0	0	2
Payment mgmt	Roadway Infrastructure	6	3	0	0	Low	1	4	1
Payment mgmt	Application Layer	23	4	1	0	Low	1	4	1
Roadway Infrastructure	Emergency mgmt	6	3	1	0	Low	3	2	1
Roadway Infrastructure	Application Layer	17	4	0	0	Low	16	0	3
Roadway Infrastructure	ISPS	41	12	6	0	Medium	14	14	5
Roadway Infrastructure	Map provider	3	1	2	0	Medium	2	1	1
Roadway Infrastructure	Payment mgmt	10	2	1	0	Low	4	1	1
Roadway Infrastructure	Roadway Infrastructure	86				High	32	32	5
Roadway Infrastructure	LDM	66	8	6	4	High	8	10	5
Roadway Infrastructure	Semantic Understanding	1	1	0	0	Low	1	1	1
Roadway Infrastructure	Trajectory Generation	8	2	2	1	Medium	5	4	2
Application Layer	Emergency mgmt	6	1	0	1	Low	1	1	1
Trajectory Generation	Application Layer	16	0	1	1	High	16	0	5
Application Layer	ISPS	6	3	2	1	Medium	2	4	2
Vehicle Communications	ISPS	2	0	2	0	Medium	2	4	2
LDM	ISPS	3	0	3	0	Medium	2	4	2
LDM	Map provider	1	0	1	0	High	1	1	2
Localization	Location Source	1	1	0	0	Low	1	1	1
LDM	Other Vehicle	6	2	1	3	High	?		3
Trajectory Generation	Other Vehicle	4	1	1	2	High	?		4
Application Layer	Payment mgmt	20	4	1	0	Low	3	1	1
Application Layer	Roadway Infrastructure	7	4	3	0	Medium	?		1
LDM	Roadway Infrastructure	18	11	5	4	High	?		4
Semantic Understanding	Roadway Infrastructure	1	1	0	0	Low	?		1
Trajectory Generation	Roadway Infrastructure	5	2	2	1	Medium	?		2
Vehicle Communications	Roadway Infrastructure	1	0	1	0	Medium	?		1

Appendix F: Capability assessment outtakes

Company Name	Filtering	ISPS	Localization	Map Provider	Other Vehicle	Roadway Infrastructure	Semantic Understanding	Trajectory Generation	Total Sum of Number of Patent Families	Total Count of Systems
MICROSOFT	6	7		2	14	1	15	2	47	7
QUALCOMM	13		10	2	15	3	1	1	45	7
MITSUBISHI ELECTRIC	20	7		2	2	3	1	2	37	7
PANASONIC	1	2		5	2	1	7	7	25	7
SIEMENS	6	4	3		3	2	2	1	21	7
NEC	4	1	1		2	3	1	1	13	7
TOYOTA MOTOR	2		5	1		1	1	24	34	6
IBM	1	5		1	6	8	4		25	6
GENERAL MOTORS	7	1	5		4		1	3	21	6
XIDIAN UNIVERSITY	9	1			4	2	1	1	18	6
TOSHIBA	6	2	1		3		1	2	15	6
SAMSUNG ELECTRONICS	26		2		3	5	4		40	5
SONY	24			2	4		5	2	37	5
CANON	10		1		1	5	1		18	5
HONEYWELL	7		3		2	4	2		18	5
ROBERT BOSCH	2	1	6			1		6	16	5
HITACHI	7	4	1	1				2	15	5
SOUTHEAST UNIVERSITY	6	5	1		1	1			14	5
CONTINENTAL TEVES	1		6	1			1	1	10	5
INDUSTRIAL TECHNOLOGY RESEA	5		1			1	1	2	10	5
PHILIPS	3		1		1		2	1	8	5
CHONGQING UNIVERSITY	10	4			8	1			23	4
ERICSSON	9	1			9			2	21	4
FORD GLOBAL TECHNOLOGIES	4	5	1					11	21	4
INTEL	3				9		3	2	17	4
DIGIMARC			1		1	1	13		16	4
GOOGLE	1		8				3	3	15	4
LOCKHEED	12		1		1		1		15	4
BEIHANG UNIVERSITY	10	1		1				2	14	4
NISSAN MOTOR	2	1		7				3	13	4
GENERAL ELECTRIC	6		2		1		1		10	4
APPLE	2	2			2		3		9	4
CEA - COMMISSARIAT A L ENERG	4		2		2		1		9	4
SOUTH CHINA UNIVERSITY OF T	4	2			2		1		9	4
XEROX	2				1	5	1		9	4
AUDI	1	1	1					3	6	4
ALCATEL LUCENT			1	1	1	1			4	4
THALES	6		5		5				16	3
RAYTHEON	12		1		1				14	3
BEIJING UNIVERSITY OF TECHNC	9	3						1	13	3
DENSO				10	1			1	12	3
NOKIA	4	1			7				12	3
HONDA MOTOR	4						1	6	11	3
NORTHROP GRUMMAN	9					1		1	11	3
ZHEJIANG UNIVERSITY	3	7						1	11	3
DAIMLER	4	5		1					10	3
TOYOTA MOTOR ENGINEERING &	6		1					2	9	3
US NAVY	2				1			6	9	3
NANJING UNIVERSITY OF POSTS	1	1			6				8	3
BAYERISCHE MOTOREN WERKE		4					1	2	7	3
HERE		4		2		1			7	3
TONGJI UNIVERSITY		4			1			2	7	3
ENJOYOR		4				1		1	6	3
HARBIN INSTITUTE OF TECHNOL	3	2						1	6	3
HEWLETT PACKARD	4	1					1		6	3
PALO ALTO RESEARCH CENTER	3				2			1	6	3
RICOH	3					1	2		6	3
TSINGHUA UNIVERSITY	3		1		2				6	3
AIRBUS	2		2		1				5	3
AMAZON TECHNOLOGIES		1			3	1			5	3
CLARION	1	1		3					5	3
FRANCE TELECOM	1				3		1		5	3
HYUNDAI MOTOR		1		3				1	5	3
INSTITUTE OF AUTOMATION OF	2	2					1		5	3
NANJING UNIVERSITY OF TECHN	1	3						1	5	3
SHANGHAI JIAO TONG UNIVERS	2	2			1				5	3
AUTOCONNECT HOLDINGS		1			1		2		4	3
BATTELLE MEMORIAL INSTITUTE	1						1	2	4	3
DEUTSCH ZENTR LUFT & RAUMF/	2		1	1					4	3
SCHLUMBERGER	2						1	1	4	3
XI'AN JIAOTONG UNIVERSITY	1			1				2	4	3
DISNEY ENTERPRISES	1					1	1		3	3
LENOVO	1			1	1				3	3
NTT DOCOMO	1				1			1	3	3
SHENZHEN INSTITUTE OF ADVAI	1	1						1	3	3
UNIVERSITY OF SHANGHAI FOR :	1	1				1			3	3
WUHAN UNIVERSITY	1				1		1		3	3
ZHEJIANG UNIVERSITY OF TECHI	1	1				1			3	3

Table A9, Outtakes of capability assessment.

Appendix G: Mail correspondence with Dr. Ricardo Valerdi and Dr. Jo Ann Lane regarding the use of COSYSMO interoperability drivers

Answers from Dr. Valerdi is marked with * and answers from Dr. Lane is marked with **.

Dear professor Valerdi,

My name is Erik Wintzell, I am a master student at Chalmers University of Technology in Sweden, and I am currently writing my master thesis. I am writing you today to ask for guidance in how to apply one of your frameworks in the area of interoperability cost estimation to my thesis. I would be *most* grateful for your assistance.

The subject of the thesis concerns the use of open innovation to tackle interoperability challenges within intelligent transport systems, and as such I have been looking for a suitable framework to send my synthesised system architecture through to classify the needed level of interoperability effort present between the various subsystems.

Reading your work *"Systems interoperability influence on system of systems engineering effort"* I found a very interesting framework in your Method 2, as it would provide a way for me to gauge the effort needed in a quantitative manner. So to my questions, and thank you for bearing with me;

- There seems to be two categories of cost drivers in the model - system architectural, and market structural - and I am only in a position to measure the first category. Can the market structural drivers be left out?

*Yes, leave it out if it doesn't apply.

** Yes, you should only be using parameters of interest/influence. If you leave the parameters that are not of interest set to "nominal", it will not make any adjustments to the model since a "nominal" rating is set to 1. As you learn more about the environment, you may want to include them later.

- I am a little bit confused with the composition of the cost drivers in the system architectural category - is it correct to say that what is to be measured here is: Number of dataflows exchanged externally, Complexity of the data in said flows, and Number of internal functions using input data?

*correct, but there might be additional items that are pertain to transportation systems you might want to add.

** If I understand your question correctly, you are asking about how to use the cost drivers, and in particular, "number of interfaces" which has strong interoperability considerations for systems of systems such as the transportation environment. If you are developing a new system (it may or may not be part of an SoS), you would estimate the number of interfaces to be engineered—these would tend to be interfaces between components (or systems) provided by different organizations/vendors. If you are concerned with a transportation system of systems, then you would focus on the number of interfaces between the SoS constituent systems and any other SoS external interfaces (interfaces to systems not thought to be part of the SoS). With respect to estimation of effort, you should only count those interfaces that need to be engineered or modified (I would not count interfaces between existing systems that need no modification on either end). The complexity of each interface you are including in this count should be determined by data flow/signal characteristics/incompatibilities in either data formats or rates/precision/etc.

- Is there a way of factoring in technical demands upon the interoperability connection in itself such as latency, security, or demands on message integrity? If one does, can these be said to have as large an impact on the effort required?

*Yes, that is possible but the only way to determine their relative impact is with data.

**Yes, these are also other data characteristics that would be included in the COSYSMO complexity ratings. Also note that COSYSMO estimates the associated systems engineering effort. If you want to estimate development effort, then you would use a software cost estimation model such as COCOMO to estimate the software development effort and other models/approaches to estimate any hardware development/modification.