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# Architecture of Electric Road System

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**Executive Summary**

Creating a system architecture is important when many different stakeholders are involved in creating and facilitating the management of a complex system-of-systems such as Electric Road System (ERS). While ERS has gained recognition as a technological solution, few studies address the system´s interfaces from a holistic perspective. This work addresses the gap by presenting an complete architecture of ERS. To achieve this, use cases covering many aspects of the electric road were created. The interface between the stakeholders in those use cases were analysed and the activities were broken down. The aim of this paper is to create a common architecture to clarify the interfaces of ERS and to enable interoperability through standardization. The architecture is then used to analyse implications for measuring energy consumption with regard to different electric road segment lengths. Futher a method of how a transition of ERS can be described and how its effects could be evaluated is presented by using the architecture.

## 1 Introduction

Electric road systems (ERS) are road transportation systems that support electric power transfer from roads to vehicles in motion that have emerged as a potential solution for addressing climate change, air pollution, and energy efficiency in the freight sector [EIA]. Where long-distance heavy traffic is concerned, there is actually no cheaper alternative which is equally energy-efficient, has such low carbon dioxide emissions and for which the energy supply is assured in Sweden and the rest of Europe. Yet, a large-scale deployment of ERS faces many challenges as it changes the interfaces, the roles of stakeholders, and the business models of the established system [1]. It is therefore vital to clearly specify the architecture of the new system, taking into consideration that ERS could evolve from a system to a system-of-systems (SoS) [3]

The aim of this study is to present an architecture of ERS that can be used to analyse critical usage cases and create standardized protocols that are necessary to facilitate a large-scale deployment of ERS. The following research questions are addressed;

*How can the interfaces of ERS be described?*

*What challenges are there for manaing ERS operation with regards to thedifferent ERS technologies?*

*How can the goals and potential effects of an ERS deployment be systematically assessed and evaluated?*

## 2 Method

The architecture description has been created based on available published system design of ERS and a series of stakeholder workshops [4]. The architecture was modelled using the Systems Modelling Language tool (SysML) which is developed for the systems engineering domain and applied to analyse cases within the defence and telecom industries. SysML is based on the Unified Architecture Framework (UAF) which can capture concepts within an enterprise and therefore covers strategic and operational considerations, services, resources, important actors, enterprise phases, capabilities, requirements and as well as standards used or to be used. By using this methodology for creating an ERS architecture, stakeholders could focus on specific usage cases without losing sight of the wider system perspective.

## 3 Definitions

In order to approach the field of system architecture scientifically, it is necessary to define the terminology as precisely as possible, and we will therefore introduce definitions of some key concepts. System is defined by Rechtin and Maier [1] as a set of different elements that are interrelated to perform a unique function ths is not performable by the elements alone. Architecture is the fundamental organization of a system embodied in components, relationships to each other and to the environment, as well as the principles guiding the design and evolution. Last but not least a SoS consists of multiple, heterogeneous, operationally, distributed, occasionally independently, operating systems embedded in networks at multiple levels that evolve over time [1].

ERS will over time evolve from a system to a SoS and it is therefore very important to clearly specify the architecture of the system. Maier states that "the greatest leverage in system architecting is at the interfaces. The greatest dangers are also at the interfaces" [1]. One way of understanding how the interfaces between various systems are managed is through the SoS approach. An SoS comprises multiple systems and is characterized as a large-scale system.

The potential transition to ERS could be described through threethree phases[see Figure 1]. The first is the *demonstration phase*. In this phase the focus is on promoting the ERS as a viable and competitive alternative to the well-established fossil fuelled transportation industry. The economic viability is not the abjective here, rather it is to study, develop and verify the most optimal technological solution.

The second phase is the *pilot phase* in which the process of developing a long-term plan for ERS takes place. Finding suitable business models, setting up regulations and looking into all the peripheral services that surround an electric road infrastructure. Pilot projects are treated like islands, where it is sutiable to start deploying ERS in niche markets which fills a specific need, and thus the investments are much bigger compared to the demonstration phase. Yet, this phase only involves a small-scale deployment of ERS.

The last phase is the deployment phase. The electric road is now being implemented on the main highway corridors and is integrated into the wider society. There is also a certain degree of market maturity where the ERS is now the most lucrative choice for haulage contractors. This phase also include deployment of ERS between different regions and juristictions as well as different market segments in which actors could compete to deliver ERS products and service solutions to users.

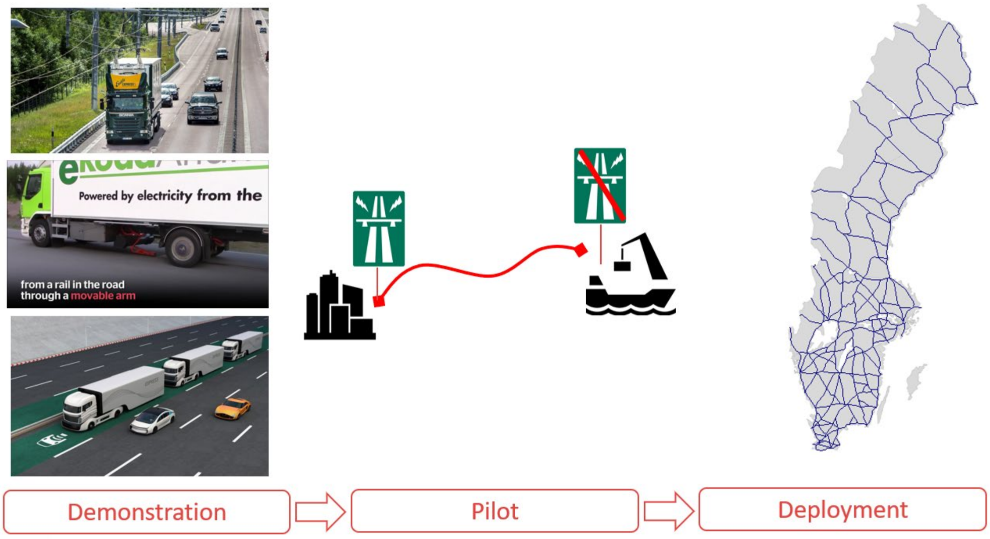


Figure 1. Transition to Electric Road System depicted through three phases.

# 4 Results

The results of this study are presented through the following structure.

1. Description of a electric road interfaces
2. Analysis of monitoring electric road usage for various segment lengths
3. A proposal of methodology to describe the goals of a ERS deployment and how the effects can measured in a structured way.

## 4.1 Electric road interfaces

The development of a common architecture is important to capture the internal structure of ERS interfaces and the stakeholder relationships. Figure 2 describes the architectural description of possible intended usages of the system stakeholders and its properties and also defines the communication between the stakeholders. Figure 2 describes the relationships between all logical elements. These ERS figures are rather complex to describe and interpret in this document, but functions as the basis for further analysis.

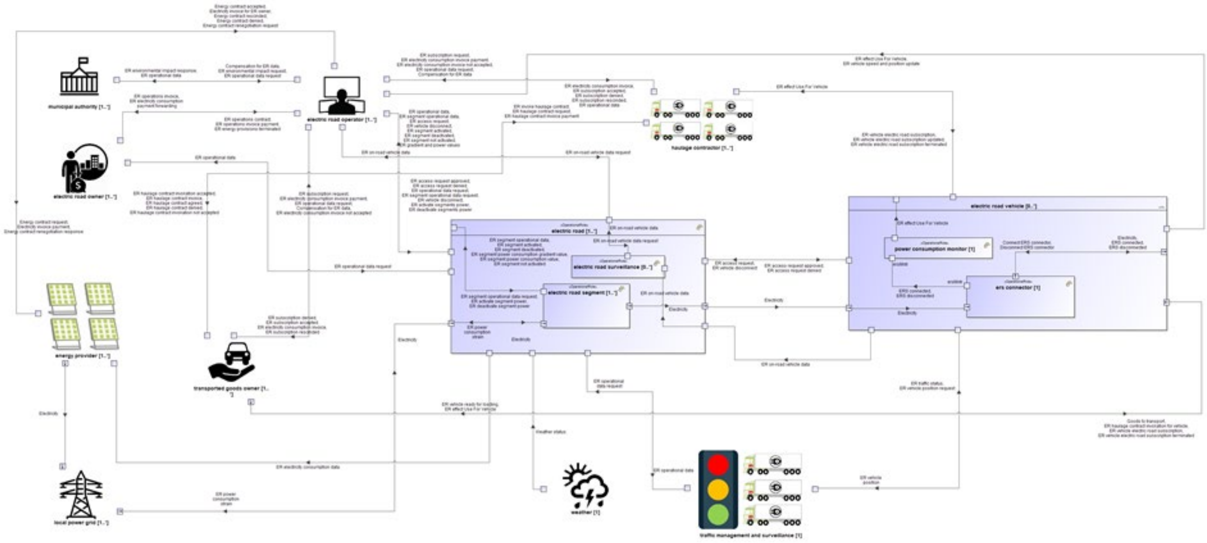

Figure 2- Architectural description of Electric Road Usage

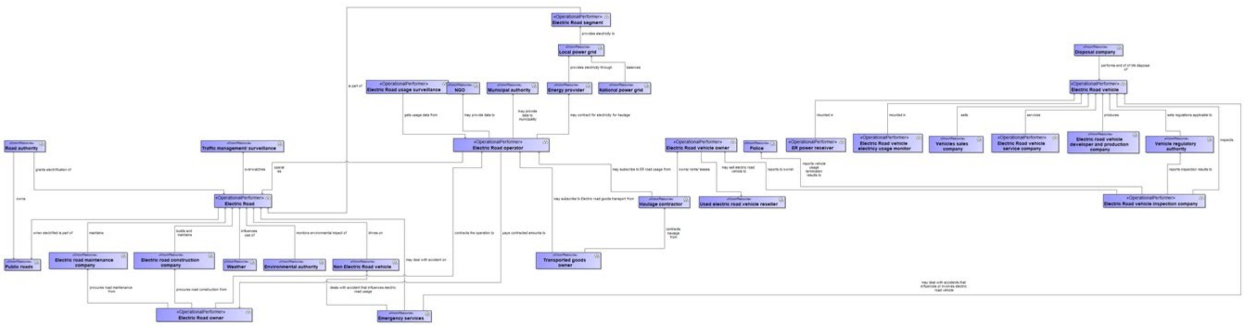

Figure 3 - Relationship between all logical elements

## 4.2 Monitoring electric road usage

An important underlying activity to analyse electric road usage is the Power Consumption Monitoring activity that is described in Figure 3. The electric road usage is derived from Figure 1 and focuses on the connection of vehicles to the electric road, the usage during the ongoing connection and lastly the disconnection from the electric road system. The signal for access approval to the electric road must be received before the monitor can engage in metering activities. The start metering parameter is an on-off switch to start recording the effect usage during the period when the metering is switched on. When it is turned off the total effect use is sent to requested outer activity.

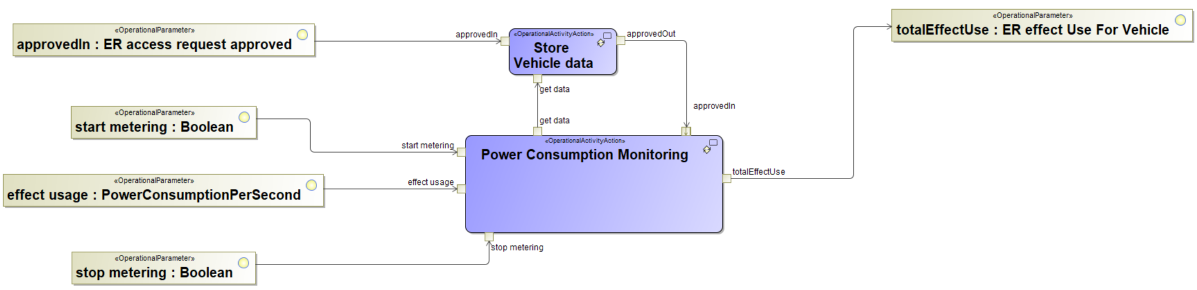


Figure 4 - Power Consumption Monitoring activity

To enable the connection to the electric road, a sequence of events is needed starting with the electric road vehicle requesting for access for the usage of the electric road. This must be approved by the electric road operator and if the request is denied the whole process will end there. If the request is accepted the operator will then activate the segments, one at a time, which the approved electric road vehicle will drive on.

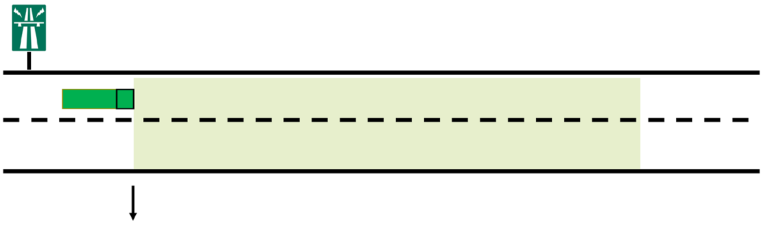


Figure 5 – ER connection start

The electric road vehicle will then connect to the ER power receiver to receive power in the form of electricity. The power consumption monitor will thus start logging the power consumption for invoice and monitoring purposes.

## Challenges for short segments

At highway speed if a segment is 20 meters in length or less, it seems unlikely that more than one electric road vehicle could make use of an individual segment. The main challenge for short segments is that the segments depending on their length they need to be activated in advance as the electric road vehicle progresses through the electric road segments. The handling of this is highly dependent on the length of the segments. An electric road vehicle travelling at 36 km/h will pass 10 meters in one second. 72 km/h means 20 meters in one second and 108 km/h means 30 meters. How quickly segments can be activated or deactivated will also matter in determining how long in advance segments will need to be activated to prepare for the arrival of an electric road vehicle.

It is assumed that the vehicle can periodically transmit its speed and position to the electric road operator, making it possible for the operator to determine how fast the electric road vehicle is progressing though the segments and then deactivate or activate segments in advance to make the transition between segments easy. Obviously, if there are several vehicles present on the road, the activation and deactivation segments may overlap and this need to be considered, i.e. a segment cannot be deactivated if another electric road vehicle is already using it.

Another assumption is also made use of here, namely that the segments automatically should report to the Electric road operator regarding current power consumption as well as power consumption gradients. If this is done, the position as well as speed information can be correlated by the electric road operator with the segment power consumption for further verification.

## Challenges for long segments

In cases where the segment is much longer, assuming for example 1 km, there will be multiple vehicles on each single segment. The sequence of activities is then not as complicated.

The disconnection process also starts with a request from the electric road vehicle. After a successful disconnection the vehicle must nevertheless be reported and keep the operator informed. The main reason is to stop the logging of the power consumption. For transparency reasons the summarized data is then sent to four interested parties.

To avoid, deter and punish unauthorized use of the ERS, it is important to understand the behaviour surrounding the connection process to the ERS. For unauthorized usage to be detected and dealt with, the following scenario needs to be managed. The segment lengths are such that more than one electric road vehicle can make use of each segment. Figure 5 illustrates a use case where a unauthorized usage is enabled because the authorized electric road vehicles is present or that the activation sequence has activated segments in anticipation of the arrival of the authorized electric road vehicle.

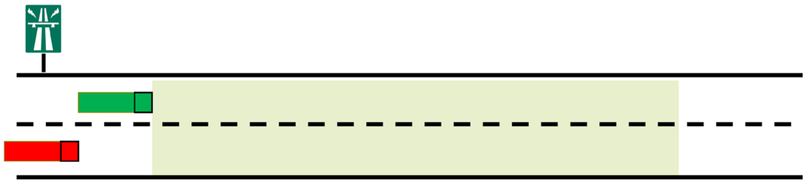


Figure 6 Possible scenario for unauthorized use

Figure 6 shows a usage case of ongoing unauthorized use on the ERS. Given the long electric road segments, unauthorized use can commence without being detected.

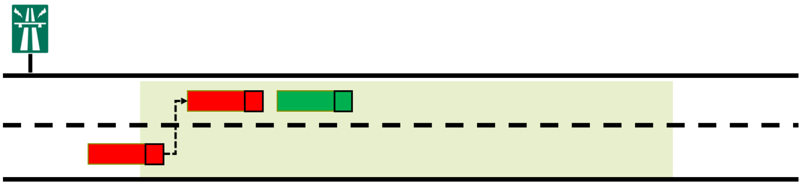


Figure 7 Ongoing unauthorized use on the ERS

In Figure 7, based on the received information from the electric road concerning segment power consumption as well as perceived gradients (changes in the consumption taken together with information concerning the subscription from the allowed access as well as the position and velocity information that the allowed access transmits to the operator), it should be possible to detect that an unauthorized access exists.

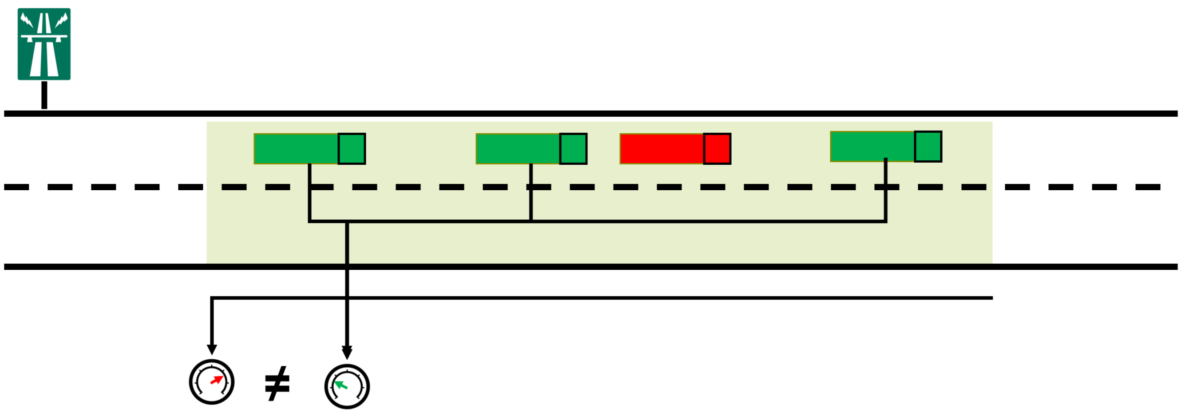

Figure 8 – Unauthorized usage detected due to changes in the perceived power gradients

Based on the data of where the unauthorized access is occurring or has occurred, the addition of ER surveillance equipment can be tasked with taking photos of the unauthorized access, see figure 8. To identify the unauthorized vehicle, there must be surveillance of a large portion of the segment. The positioning of the surveillance equipment should be strategically placed along the electric road to account for possible places where the unauthorized access can get off the road. Alternative surveillance solutions to could be the use of drones or patrol cars.

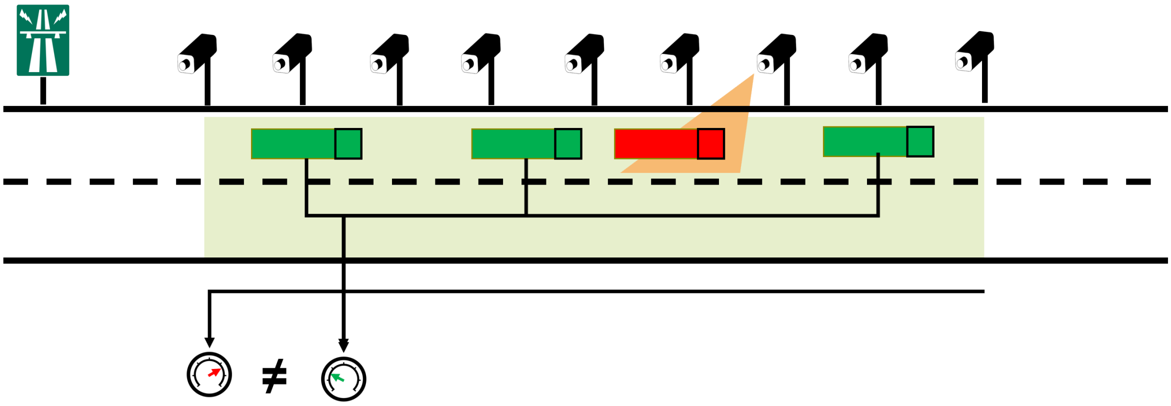

Figure 9:  Unauthorized usage detected and identified

### 4.3 Assesing the potential of electric roads

For each of the three phases of a potential transition to ERS, a vision is developed with a associated vision statement (Figure 10). These visions the basis for describing how the potential of ERS could be assessed in evaluated in different phases.

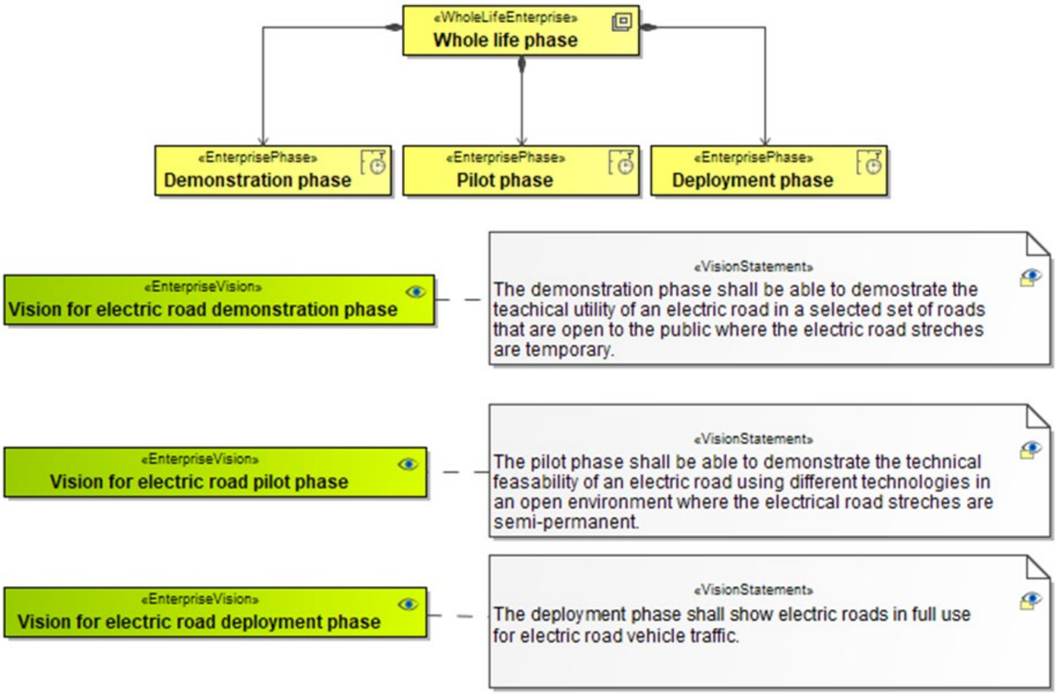


Figure 10: ERS enterprise phases and vision Statement

To each phase, there should be an associated goal. The goal is a statement about a condition to be reached or sustained through appropriate means over the entire phase. The goal also amplifies the vision and communicates what must be satisfied in order to successfully attain the vision. The goals coupled to each ERS phase can be seen in Figure 11.

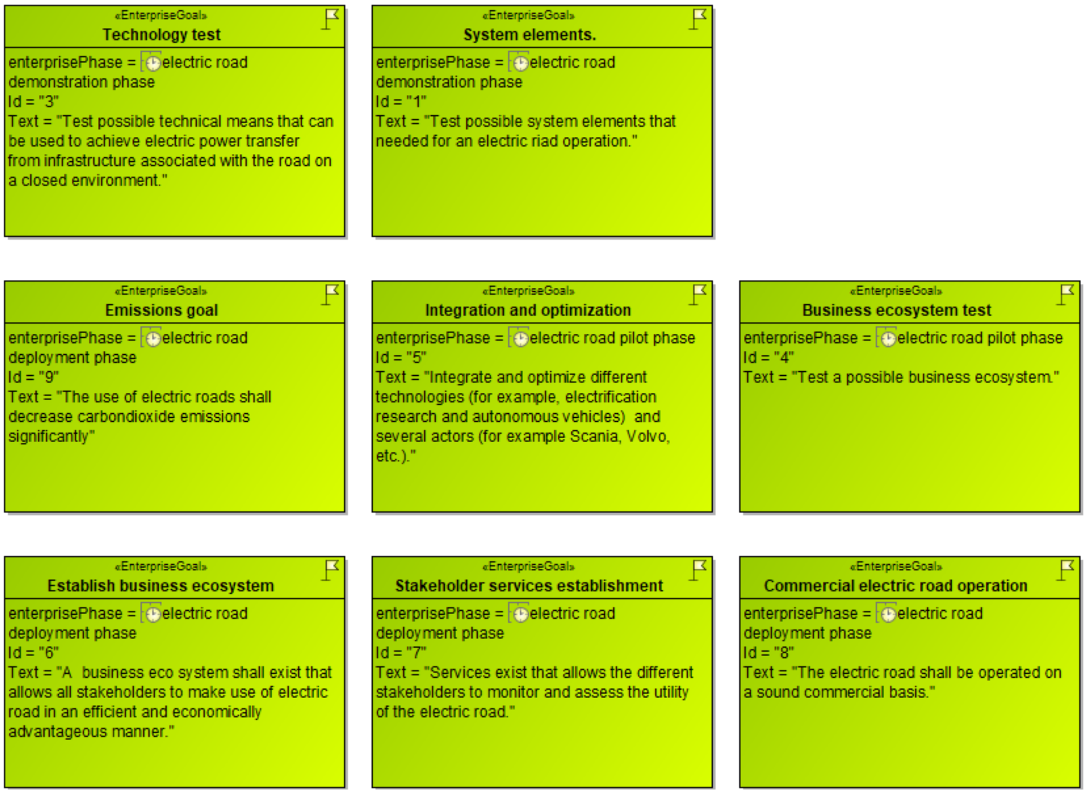


Figure 11 - Enterprise Goals for the ERS

Each phase of ERS then exhibits a number of capabilities. Each of the exhibited capabilities for the phases can be seen in Figure 12. The capabilities are used to capture the high-level specification of the ERS enterprise abilities and the enterprise ability to execute a specified course of action over the three enterprise phases.

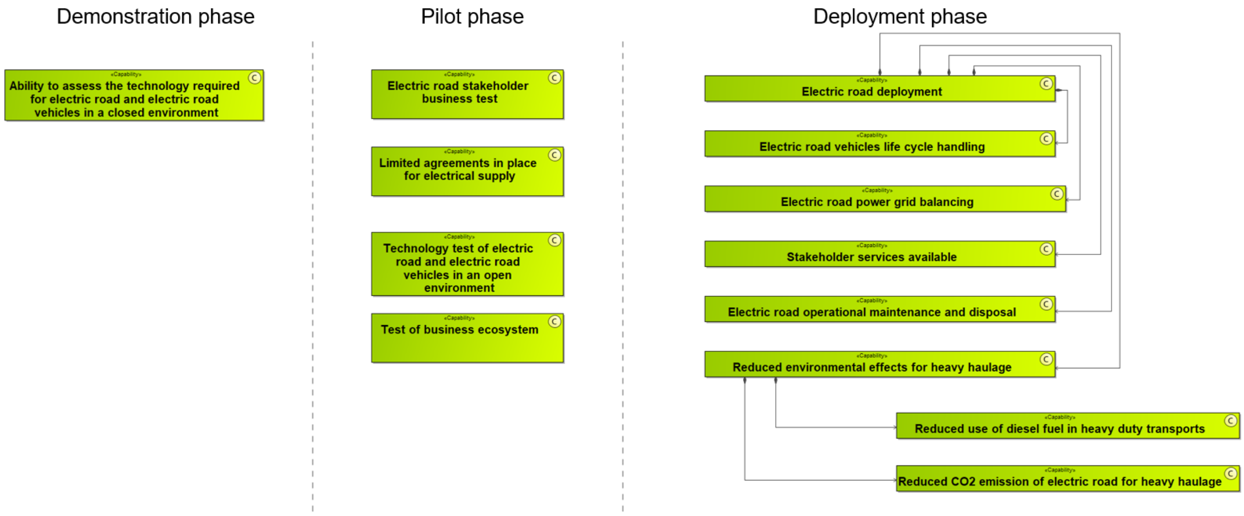


Figure 12 - Capabilities for all ERS Phases

In the deployment phase (Figure 12), the following capabilities are all dependant on the “Electric road deployment” capability:

- Electric road vehicles life cycle handling
- Electric road power grid balancing
- Stakeholder services available
- Electric road operational maintenance and disposal
- Reduced environmental effects for heavy haulage

It is a pre-condition that the other capabilities in this phase are to be realized. Similairly, the following capabilities are dependent on the capability “Reduced environmental effects for heavy haulage”:

- Reduced use of diesel fuel in heavy duty transports
- Reduced CO2 emission of electric road heavy haulage

To evaluate the effectiveness of a the implemented capabilities, measurement sets are linked to each individual capability. These are called Measures of Effectiveness (MOE) and are used to quantify the desired and actual results of each phase. system. This makes it much easier to relate to the accomplishment of the mission objective and achievement of desired results. Each of the capabilities from the three ERS phases can all be seen with their respective MoE in Figure 13.


Figure 13 – Measurements used for evaluate individual capabilities.

After a measurement set has been created it will be linked to a capability, which in turn comes from a capability configuration. The linked measurement set is then assigned values and becomes an actual measurement set. This new set of values represent the desired effect of the capability and serves as a reference for fielded fapabilities. The capability configuration is a composite structure representing the resources and properties and their interactions in an enterprise, assembled to meet a capability.

The fielded capability is an actual, fully realized capability configuration. All resources and properties have now been assigned real data which is contained in the actual measurement set. Figure 14 to Figure 16 are used to demonstrate the status of the electric road system expansion progress throughout Sweden. The chosen time period was between year 2024 – 2030. The road stretches that are to be made to accommodate the electric road infrastructure are illustrated trhough the road network triangle in Sweden between Stockholm – Göteborg – Malmö. The chosen attributes are designed to measure CO2 emission, diesel particles, air quality, noise level, reduced use of fossil fuels and the traffic load at certain interchanges. While the roads are real, the data used are purely fictitious and are only for visualization purposes. This is a way to analyse the system performance using the actual data from the system-of-interest.

Figure 14 shows the beginning of the electric road deployment on the road E4 Jönköping – Malmö in year 2024. The achieved effect can be seen in the corresponding actual measurement set.

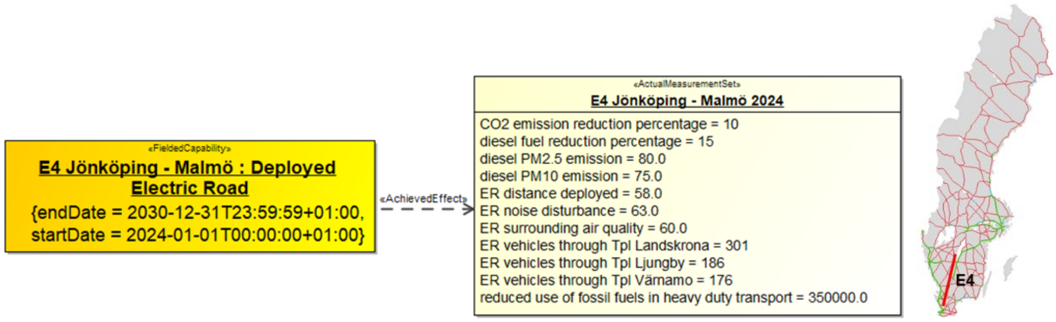


Figure 14: ERS Expansion Progress, Year 2024

Next, in Figure 15 the deployed road E4 Jönköping – Malmö has expanded, and so the achieved effect has also improved in year 2026 compare to 2024. Now there is also another electric road stretch that has been deployed, which is the road E6 Göteborg – Malmö.

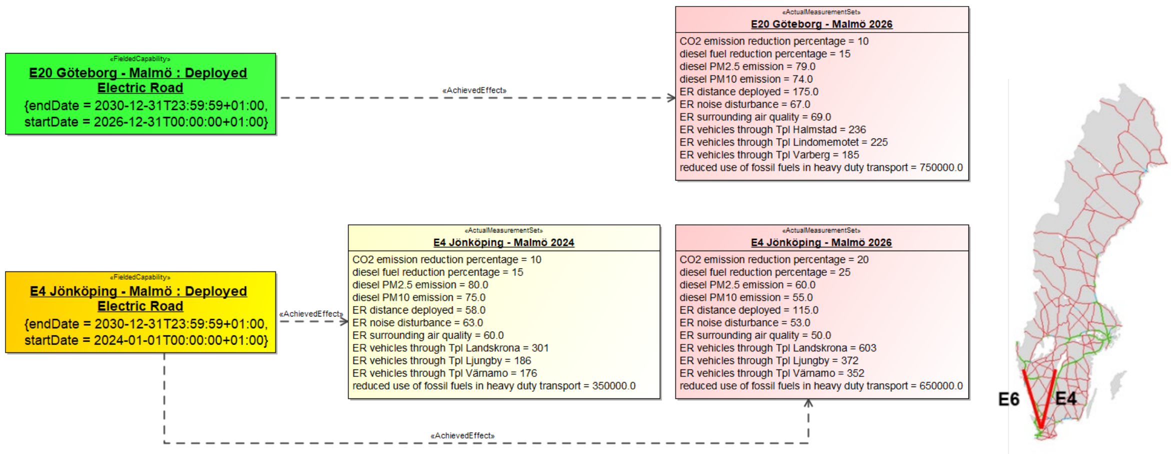


Figure 15: ERS Expansion Progress, Year 2026

In 2028 there is a new addition of an electric road stretch, the road rv40 Göteborg – Jönköping and lastly in 2030 (Figure 16) there have been no new additions of electric road stretches, the first electric road has come quite far in its development if one compares the achieved effect from year 2030 to 2024. The overall electric road infrastructure has also gradually expanded over the period with steadily improved measurement values.

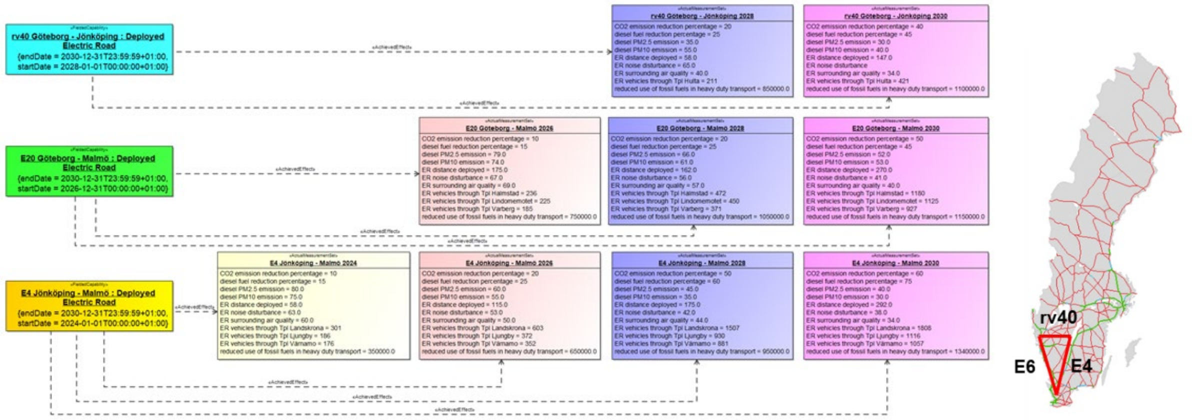


Figure 16: ERS Expansion Progress, Year 2030

## 5 Conclusion and future work

This work has proposed a systematic way of describing the interfaces ERS and the relationships between stakeholders. This description has then been used to describe critical usage case of electric road operations. Also, the main challenges for measuring energy consumption have been identified, based on different electric road segment lengths.

A conclusion is that for shorter segments, the main challenge is to cope with timing issues as well as the high number of switches needed between segments. For longer segments, the challenge is instead to identify possible unauthorized usage which could lead to lack of payment, but also more serious risk of damage of the infrastructure due to un-certified and checked power receivers.

Futher the work has presented a method of how a transition of ERS can be described and how its effects could be evaluated. The next step is to test the method and perform a description and evaluation of ERS deployments with real data as input.

## Acknowledgement

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Stefan Tongur is Senior Researcher at RISE Viktoria and interested in socio-technical transitions and business models. He defined the concept of electric road systems (ERS) in 2010 and has continued to study the development of ERS since then. He is published in e.g. Technovation, Environmental innovation and societal transition, and IEEE conference on Energy, power, and transportation. In 2018, Stefan defended his PhD thesis entitled "Preparing for takeoff – Analyzing the development of electric road system from a business model perspective" at KTH Royal Institute of Technology.