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Method to develop an overall architecture for Cooperative ITS

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Abstract

The number of people using road transport is constantly increasing what leads to more and more challenges for traffic safety and traffic efficiency. The field of Intelligent Transport System (ITS) already addresses these challenges since several years through constantly improved and newly developed telematics technologies. Though, a breaking change is expected by the deployment of cooperative ITS (C-ITS): it will tear down the silo structures in existing ITS and brings together so far separated stakeholder groups, systems and services, mainly facilitated through communication.
This advancement will not be realized in a revolutionary way, actually wiping away existing implementations and replacing them with new systems, designed from scratch. Ideally, a smooth transition is realized. This requires intensive conceptual and strategic work prior to the actual deployment which becomes manifest in an architecture description.

Currently, no such architecture exists but there is a fragmented landscape of ITS architectures which needs to be taken into account when introducing a new technology like C-ITS. Until now no suitable approach exists that guides through the development of a joint architecture based on existing systems and new technologies, therefore this thesis starts with the description of a suitable method for the description of an architecture before actually developing an architecture based on the respective method.
The approach in the thesis at hand first identifies requirements of the new system, then analyzes architectures of existing services and theoretical models, develops a new architecture respecting both the requirements and structures of existing systems and new technologies, and finally applies the architecture description, resulting in an overall architecture.

The approach results in three major products: a method for the description of an overall architecture, a theoretical and generic architecture framework and finally the overall C-ITS architecture as result of practically applying the first two products. The generic framework consists of three levels, ranging from the rather abstract Framework Architecture to the generic Reference Architecture and implementation specific System Architecture. For each of the different levels a set of viewpoints is detailed, describing the organizational, functional and technical aspects of the respective architecture abstraction level. This rather traditional structure is extended with an additional architecture element, that is needed to fulfill the requirements on modern architectures: the Modular Construction System. It enables flexibility and dynamics through a modular architecture design and at the same time guarantees stability and continuity.
The practical applicability of the method and the generic framework is finally demonstrated through a practical example. A Reference Architecture is described for C-ITS, an initial

filling of the Modular Construction System is realized. Finally, the System Architecture for the C-ITS Corridor Germany, one of the first European deployments of the C-ITS technology, is realized. Together these building blocks result in an almost complete, exemplary description of the overall C-ITS architecture.

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1. Introduction and thesis outline

An increasing number of vehicles make use of the existing road infrastructure what leads to higher traffic density, an increasing number of accidents, traffic jams and complex traffic situations. Different telematic technologies were deployed in the past to address exactly these challenges and already resulted in significant advancements. However, the maximum benefit is not yet achieved and new technologies like Cooperative ITS (C-ITS) are expected to contribute to further improvements of road safety and traffic efficiency in the future.
The application of C-ITS as a new technology opens up new possibilities – and involves new challenges. Core characteristic of C-ITS is communication: hence the communication between vehicles and with the roadside infrastructure (based on wireless communication, e.g. ad-hoc and cellular networks) shall help to achieve these goals. The combination of communication networks with existing telematics infrastructure and driver assistance systems will provide a higher information density and entropy, faster information distribution and improved timeliness of information.
The new technology not only improves existing telematic technologies and supports driver assistance systems, it provides the opportunity to achieve the goals for road safety and traffic efficiency. In the long run C-ITS is expected to significantly contribute to automated driving: Passing more and more responsibility from the driver to the vehicle not only involves advancements of autonomous vehicle systems. A smooth and safe traffic flow with automated vehicles requires interaction and cooperation between vehicles and with the infrastructure. The first steps towards automated driving will be taken with the deployment of C-ITS.

Before the whole bundle of advantages of C-ITS comes into operation a range of challenges raised by this technological evolution needs to be addressed. The thesis at hand deconstructs the necessary steps for the integration of new ITS technologies like C-ITS into existing systems and their architectures. Therefore, a systematic approach is developed that analyzes the available models and building blocks and results in a method for the description of an overall architecture. This is topped off with its practical application, leading to an ample description of the overall C-ITS architecture.

1.1. Problem statement

Various Intelligent Transport System (ITS) implementations already today support the road operators and service providers to improve road safety and traffic efficiency. Roads are equipped with numerous sensors, dynamic displays provide a multitude of options for notifications. In parallel, many cars driving on the road are equipped with different driver assistance systems addressing similar goals like the ITS infrastructure. Furthermore, they

not only inform the driver but additionally support him in his driving task. Those two systems are the basis for C-ITS.
The connecting link between already existing ITS implementations and their reutilization in C-ITS is the communication between entities. It enables new functionalities and features of previously isolated system blocks resulting in what is called C-ITS. But although it sounds rather simple to add communication to those already existing systems, resulting in connectivity between vehicles and with the roadside infrastructure, this is a complex task which not only brings the opportunities of a new technology but as well several challenges to the field of ITS.

The guiding principle for the transition from ITS to C-ITS is that C-ITS as a new technological solution is not supposed to replace existing systems but will complement and enhance them. Therefore, it is necessary to combine C-ITS with existing ITS implementations what implies that it will be necessary to integrate C-ITS in the existing ITS landscape and its architectures. Furthermore the connectivity will bring together systems that previously were operating in strictly separated silos. To actually extract benefits from the link-up of different systems with C-ITS, it is additionally necessary to align the architectures of the systems to give them together the maximum room for development.

There are already numerous ITS solutions including corresponding architecture descriptions but unfortunately these are from an overall ITS perspective only fragments which were developed based on the limited requirements and needs of the respective system. Hence, there is no common basis for architecture descriptions that enables reproducible and seamless the integration of new technologies. In addition, the inhomogeneous architecture landscape hampers the combination of functionalities residing in different systems into new cooperative services.

Aside from the challenging structural architecture situation there is no process defined so far that gives advice on how to integrate new technologies and their architecture in an existing overall architecture description or proposes how to align diverse architectures.

1.2. Goal and solution approach

Goal and objective of this thesis is the development of an architecture for C-ITS or an architecture that includes C-ITS.
Currently, there is neither any overall (C-)ITS architecture description available nor an existing systematic approach for the development of a new architecture in a field with already existing architecture descriptions. Therefore, the approach developed in this thesis needs to address both aspects to result in an overall architecture for C-ITS that covers existing ITS and their architectures as well as the implications of the expansion to C-ITS.
This thesis first develops and applies a **method** that is based both on existing theoretical architecture models as well as architectures implemented in practice. Analyzing them and extracting the suitable elements leads to an abstract architecture framework that supports the structured description of an architecture. It incorporates the configuration, requirements and boundary conditions of existing ITS architectures and provides the basis for

the C-ITS specific advancement. This skeletal structure is then evolved by the author to the **overall C-ITS architecture**. Therefore the same approach like before is used to orient the generic structure to C-ITS. This includes the extension of the generic architecture with additional, new elements like the Modular Construction System and guidelines for the composition of the internal modular structure. Besides the development of this new C-ITS architecture framework, selected elements are embellished. As far as possible existing architecture descriptions are taken into account and adapted, missing aspects are generated. The result is an overall architecture that focuses on C-ITS and its characteristics and at the same time complies with the manifold facets of a generic architecture framework, like different abstraction levels and viewpoints.
The generic implementation of the method is complemented by its practical application to a specific scenario or system. In this thesis, this is demonstrated for the German part of the C-ITS Corridor. Finally, almost the full portfolio of architecture aspects is modelled.

The method developed in this thesis is used to integrate new technologies into existing architectures but as well supports the transfer of existing architectures to the same basis, so that it will be easier to make cross-system modifications to several architectures. Apart from that the approach is designed in a way that it may not only be adopted for C-ITS but could be reapplied in the future for the integration of other innovations or technologies.

The results of this thesis contribute to C-ITS architecture activities in Europe and Germany and shall help to successfully deploy C-ITS in Europe. The deployment of C-ITS in Europe (C-ITS Corridor) allows the practical verification of the achieved results.

1.3. Motivation for the development of an overall architecture and benefits of its implementation

Working on a system's architecture before actually starting the implementation is beneficial and increases the probability of a successful deployment. With the deployment of C-ITS in Germany and Europe (Austria, the Netherlands and others) coming into reach the need for a C-ITS architecture that ensures the integration of C-ITS into European and national legacy ITSs arises.

Early discussions and starting to work on the description of an architecture before the actual implementation begins, brings various benefits to the deploying stakeholders. It forces the stakeholders to make sure that a picture of the system as a whole exists (at least addressing the services that shall be implemented at this point in time). Having the 'big picture', and thereby a clear view of the system and its architecture present enables more elaborate design decisions: it allows flexible assignment of organizational, functional and technical aspects to different players or stakeholders, modules and hardware elements.
Many systems in the past just evolved over time without a clear architectural structure. This resulted in the continuous extension of existing systems, new features and functionalities simply were added where it was possible but often without an underlying concept. This resulted in complex branched structures which become more and more difficult to maintain. With each extension they become more complicated and soon only a bunch of

experts is able to make changes to these structures. Changes in general usually lead to a huge modification effort - so that sooner or later nobody dares to touch the system at all. Crucial changes in technologies often lead to a complete and expensive redesign. This is not only from an economic perspective dramatic but often as well for the people who have to work with the system every day.
Besides the complexity of the system itself it is very difficult to connect with other systems. Monolithic structures with only few specialized, often proprietary interfaces are implemented. It is both difficult to transfer the benefit of one system to other systems as well as to receive beneficial data or information from other systems. Connectivity and sharing of data (open data, big data) are gaining tremendous importance in the field of ITS, the future advancements certainly will be based on these technological evolutions. Therefore, defined and standardized processes and interfaces within an architecture support the flexibility in later development and procurement processes. They significantly contribute to long-term feasibility and interoperability of the deployed system.
Hence, the description and definition of an architectural structure early in the design phase of a system is not only a nice academic exercise but has provable benefits, where most of them are traceable back to saved costs and increased economical benefits.

Addressing the interoperability between different systems requires an architecture scope that is much broader than a single domain or specific system architecture. Interoperability across domains and services is only possible with an overall architecture that clutches the architectural characteristics of several individual domains. As a consequence such an overall architecture has to pick up the requirements of many different stakeholders and their architectures, and generalize them to superordinate description levels. The abstraction elevates all aspects from the specific architecture description to the generic level, resulting in mirrored structures. Finalizing this logical approach results in a structure called overall architecture. The overall architecture with its generic superordinate structures finally allows to define interfaces and architecture structures that are required for the interoperability of system architectures from different domains. Through a trickle down mechanism the interfaces and structures are passed to the implementation level. The parents from the generic level are sufficiently generic to be be passed to standardization or guideline developing organizations.

1.4. Scope of thesis, constrictions and document structure

The thesis at hand develops a method with which an architecture for C-ITS can be generated and applies this method in practice.
The approach to develop an overall architecture for C-ITS itself does not define any limitations for the depth and breadth of its application hence a resulting architecture description may cover many different aspects and might be very extensive. This is the reason for introducing some constrictions that are met by the C-ITS architecture description in this thesis.

In general, an architecture is present across the whole life-cycle of a system or product and will change with the requirements of the different phases. Nevertheless, its core shall be designed in a way that transitions are possible without major breaks in the architec-

ture. In this thesis the market phases used in economy are considered as orientation and structuring element throughout the life-cycle of a product as they well reflect the stages a system passes from initial idea to operation to final phase out [Vernon, 1966; Hirsch, 1967]. Accordingly, the phases are research, development, production, maintenance and shut down.
The **first limitation of scope** for this thesis takes place on this level: one specific economic phase is selected for the description of the architecture. But nevertheless, the approach developed in this thesis which is the basis for the architecture description of any economic phase, needs to be sufficiently generic to enable the development of the architecture descriptions for all phases. The relation of economic phases and the overall architecture are briefly touched in this thesis without diving much into the details. When actually describing a system's architecture it is the task of the system architect to ensure fluent transitions between the architectures of the different phases.
In this thesis the operational phase of a system (production) is selected for the development of the C-ITS architecture approach and its practical application. The operational phase is selected because the system that is considered for the practical application of the approach is currently in the phase preceding the operational phase.

Even if the architecture focus is now limited to a specific economic phase the architecture description for this phase still is rather extensive if all possible aspects are addressed in detail. Hence, a **second restriction criteria** is necessary to limit the architecture description to a controllable scope. Therefore, the extension of the architecture description is analysed: A complete description of an architecture shall comprise organizational, functional and technical aspects describing the core functionalities of the system. Perpendicular to the viewpoints but closely linked to them are security and privacy aspects for the respective system. Optionally, the mentioned categories might be extended with others. The descriptions along both axis share elements, there are organizational elements like roles which can be from the security or privacy category. The same applies to the functional and technical viewpoint. Hence, the description of security and privacy aspects intersect through all the viewpoints, this slice of an architecture level with the category-specific aspects can be encapsulated in an architecture of its own: e.g. it is pretty common to have a security architecture complementing the system architecture description. Though the mentioned categories can be sliced out of the overall architecture they are tightly interwoven with the architecture and their viewpoints. This becomes apparent through the implications that design decisions in these categories have on the remaining architecture. Both privacy and security are often mentioned as crucial elements already of the early design phase, e.g. with 'security by design' or 'privacy by design'.
In the description of the architecture in this thesis only the generic aspects of a viewpoint are described in detail, rather specific aspects like security and privacy are not addressed here in detail. They require a very deep knowledge in the respective fields and presume an extensive not only functional but as well security or privacy specific analysis of the system. This is beyond the scope of this thesis, hence the topics are only briefly touched. Furthermore the generic approach for the description of an architecture developed in this thesis can be used to address those rather special aspects. The resulting architecture descriptions might easily be integrated as soon as they are available.

The described constrictions of the architecture in this thesis lead to the following structure: the introduction is followed by a brief description of relevant background information, mainly focussing on architecture and (C-)ITS (chapter 2). Then the theoretical part starts with the description of the generic approach for the development of an overall C-ITS architecture (chapter 3), which analyses both theoretical architecture models as well as existing architecture descriptions. The results and the complementing conclusions are summarized with the description of an architecture structure (chapter 4). In the subsequent chapters the single elements of the overall architecture are addressed in detail. First of all, the newly introduced architecture element Modular Construction System is characterized and explained (chapter 5). Before the different architecture levels and their viewpoints are detailed some generic thoughts are spent on how to actually develop the different architectures (chapter 6). This is then applied to the C-ITS Reference Architecture (chapter 7) and System Architecture (chapter 8). For the System Architecture the practical implementation of C-ITS in the German part of the C-ITS Corridor is taken as basis. The thesis is closed with a summary, retrospective and look ahead (chapter 9).

2. Background

The objective of this part is to provide all necessary background information to understand the methodological considerations and conclusions in the subsequent chapters. Focus is on the core topics underlying this thesis – **architecture** and **(C-)ITS**. This chapter comprises the respective definitions, their (historical) background, current status and future perspectives. The descriptions provide the fundamental basics for the functional and technical details discussed in later chapters, starting with abstract and objective definitions which are complemented with the specific interpretation applied in this thesis.

The definitions for architecture and (C-)ITS are complemented by other core terms and their meaning with which they are used in the subsequent chapters.

2.1. Architecture

Architectures are specified in various contexts: they occur in building construction as well as in the design of software systems. The term architecture in this thesis is first of all defined generically and then applied to the field of ITS and C-ITS. The ITS and C-ITS focused architecture aspects can be found in sections 2.2.4 and 2.2.6.8.
The descriptions in the subsequent chapters form the basis for the methodology developed in section 3.2. In the process of developing a method for the definition of an overall C-ITS architecture the original definitions were partially refined and detailed. Where this applies the reference to the continuative description is included.

2.1.1. Architecture definition

The term architecture is used in many different contexts. Searching for a definition leads to a huge number of results – and they are not all addressing the same aspects as the definitions are partially already dedicated to specific subject areas.

Starting with a very general outline, the **Oxford dictionary** [Stevenson, 2010] provides the following definitions for the term architecture:

- *The art or practice of designing and constructing buildings*
- *The style in which a building is designed and constructed, especially with regard to a specific period, place, or culture*
- *The complex or carefully designed structure of something*
- *The conceptual structure and logical organization of a computer or computer-based system.*

The definition shows that the term architecture is not only used in the world of building construction but in various other contexts where certain stable and durable structures are fundamental design elements of a system. Hence, the central idea from the Oxford dictionary definition which shall be reflected in this thesis' architecture definition, are the characteristics of being **structuring** and **design relevant**.

Another definition of architecture utilized in this thesis is given in **ISO 14813** [2006]. ISO 14813 is the core standard about ITS architecture developed within the standardization organizations CEN (European Committee for Standardization) and ISO (International Standardization Organization), it well summarizes the idea of what architecture is in its introduction:
'Architecture' can be defined as 'design; the way components fit together'. Architecture is implicit in any construction, be it of a physical entity (such as a building), an operational entity (such as a company or organisation), a system entity (such as a software system) or a business entity (such as a commercial business operation).
While it may be stated that every entity has an architecture, the particular architecture may be an explicit construction as a result of a deliberate design process or the implicit result of an unplanned series of events, or sometimes the combination of both.
Like the definition from the Oxford dictionary ISO 14813 as well mentions that architecture is occurring in different contexts but it is less specific about its attributes and only remarks that design is a characteristic epiphenomenon.

The **ISO 24010** Standard [2007] which deals with architecture descriptions provides as well a definition for architecture. ISO 24010 defines architecture with *fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution*. A detailed analysis of the definition is given by the ISO 42010 User Group [ISO/IEC/IEEE 42010 User Group, n.d.].

Research on additional architecture definitions showed that they either refer to existing definitions like the one from ISO 42010 or take up the core characteristics included in the other definitions mentioned above. One example is TOGAF (The Open Group Architecture Framework) [The Open Group, 2011b], which has a prominent role in the architecture description context.

Continuously reappearing in all definitions are the key elements 'design' and 'structure'. Architecture is a core facet of a system and ideally is incorporated from the early design process on. It provides a stable frame and structure throughout the whole development process and later lifetime of the system. It supports advancements and modifications and provides the necessary information to maintain interoperability.

Based on the definitions above the following definition for architecture will be used in the context of this document:
An **architecture** describes the structure of a system. It provides the framework for the system and summarizes its characteristics. Defining a system architecture is part of the design process.

The 'system' in the definition above will be an IT (Information Technology) system, in particular the architecture will be developed for systems that help to improve road traffic, so called Intelligent Transport Systems (details and definition in section 2.2.1).

2.1.2. Architecture and its facets

Now that the general scope of the term architecture and how it will be used in this thesis is tied down, the detailed aspects of architecture need to be scraped out. Most of the aspects are analyzed and described in detail in section 3.2, only the core elements are summarized here.

2.1.2.1. Levels of detail in architecture description

An architecture description can appear on a very high and abstract level, on which only general recommendations are given, or on a rather detailed level, on which every detail required for an implementation is recorded. Between both extremes exists a large number of nuances. Hence, architecture descriptions on different abstraction levels are possible. For this thesis three different levels are defined in detail in section 3.2.5:

- **Framework Architecture** – the most abstract architecture level which consists of policies and strategic guidelines addressing organizational, legal, operational, functional and technical aspects, completely technology agnostic
- **Reference Architecture** – a generic blueprint for domain specific implementations that comprises all specifications and standards which are required for interoperable instances
- **System Architecture** – the description of an actual implementation

The definitions are developed based on existing definitions and architectural descriptions when designing the architecture structure.

NOTE: The term System Architecture used for the architecture of the actual implementation is from a speech comprehension perspective misleading: Usually, the term 'system' implies a rather high and generic level of description. Historically the term 'System Architecture' was used for the implementation architecture in ITS and it became the conventional term for an architecture on this level. Therefore, the wording in this thesis follows the general linguistic usage in this subject area even though the general speech comprehension for 'system' is slightly different.

2.1.2.2. Perspectives and viewpoints of an architecture

Apart from the different levels of details an architecture might encompass descriptions of different perspectives on a system. The different perspectives are called **viewpoints**. Each viewpoint comprises the complete description of the system from a specific perspective. There is no generic set of viewpoints that is used for any architecture description, hence the viewpoints used in an architecture are architecture specific and might have different scopes in different fields. The viewpoints selected for an architecture description do not

need to cover all aspects of an architecture, an architecture focusing e.g. on functional aspects only comprises the respective viewpoints.
Section 3.2 identified a set of generic viewpoints that shall be used in this thesis' description of an architecture. They cover

- **organizational** – roles and responsibilities
- **functional** – business process, use cases, information structures, data models, interfaces
- **technical** – choice of technology

The detailed viewpoint definitions are summarized in section 3.3.2.

An architecture description covering almost all viewpoints is often called enterprise architecture. In extension to functional or technical focused architectures it comprises as well policy aspects, organizational structures and other non-technical viewpoints.

2.1.2.3. Domain in architecture context

In the context of architecture descriptions often the term domain occurs. Various sources provide different definitions for the term 'domain':
The **Oxford dictionary** [Stevenson, 2010] defines a domain as a *specified sphere of activity or knowledge*. In other contexts it is used for *subject areas, which are specialized content wise* or *the totality of knowledge in a whole field* [Wikipedia, 2016a].
Another definition is provided by the **Open Distributed Processing (ODP) standard** [ISO 10746-2, 1996] which is consulted in the approach in chapter 3. It says that *domains consist of a collection of managed objects that are grouped together for a special purpose*.

These definitions are already well in line with the definition used in the national German architecture discussions. The German architecture expert Hanfried Albrecht defined in his **position paper on the ITS Framework Architecture** [Albrecht, 2015] domain as *meta term that helps to delimitate a field in which knowledge on an object of reflection is applied.*
When using the term domain in ITS one can speak of an ITS domain. It is defined as delimitation of a field by an ITS interest (stakeholder) group by applying knowledge about ITS. The demarcation is depending on the interests of the stakeholders.

For the definition of domains used in this thesis the core attributes were extracted from the previously cited definitions, the resulting definition is: a **domain** delimitates a field of activity or knowledge. The elements of a domain together serve a special purpose. The boundaries of a domain are defined by the interests of the respective stakeholders.

Applying the definition to ITS and C-ITS allows for a large number of different domains. Examples are urban traffic, highway traffic, traffic light controlling, traffic management systems, cooperative ITS, passenger information systems, quality assurance in public transport and many others. The different domains are not fully separated and might be overlapping. Elements of an architecture in one domains might be reused in the architecture of

another domain.

NOTE: The term domain is as well used in other contexts:
The Oxford dictionary defines domain in computing as a distinct subset of the internet which addresses sharing a common suffix or under the control of a particular organization or individual.
Domain is colloquially used with a rather broad and general scope, examples in this context are 'automotive' or 'pharmacy'.
These interpretations are not applied here.

2.1.3. Modeling an architecture (architecture description language)

For the description and modeling of an architecture in the IT context various description and specification languages were developed. The idea is to formalize the description of a system to make it easy to understand for everyone who is familiar with the description language, to allow for reuse of already existing descriptions in other contexts and to enable comparison of different architecture descriptions. Partially, the description languages are standardized and continuously advanced based on new requirements.

A very popular and standardized description language in the IT context is **UML (Unified Modeling Language)**. UML was originally developed by The Open Group and was subject to standardization. The first version, UML 1.0, was originally published in 1997. Already 2 years later the further developments started that lead to UML 2.0. Currently, the version 2.4.1 is in use.
UML comes along with a large number (thirteen) of diagram types which are used to describe different aspects of a system. Each diagram type is suitable for a specific need or tailored to an explicit issue. The description language itself does not provide any guideline which diagrams shall be realized in which sequence, this is depending on the respective implementation.
A detailed description of UML including all diagrams and when and how to apply them is available in Rupp [2007]. The latest version of the UML description is available at the website of the Object Management Group [2015]. Related standards are ISO 19505-1 [2012] and ISO 19505-2 [2012].

Another popular description language is **ArchiMate**, established by The Open Group. ArchiMate was developed to support the formal description of an information system, organized in a way that supports reasoning about the structural and behavioral properties of the system and its evolution [The Open Group, 2012, p.1]. The goal of ArchiMate is to provide a uniform representation for diagrams, a graphical language, that supports the description of enterprise architectures. The ArchiMate description language is closely linked to the TOGAF standard [The Open Group, 2011b] which provides a methodology for the development of an enterprise architecture. TOGAF is analyzed as part of the methodological considerations in section 3.2.
Like UML ArchiMate provides a number of diagrams that allow to depict different aspects of a system. The diagrams themselves are structured according to the TOGAF architecture structure and are sorted in the abstraction layers Business, Application and Technology. Apart from that ArchiMate as well allows to include and reference diagrams from other

modelling languages like Business Process Modelling Language (BPMN) or UML [Velitchkov, 2011].
A detailed description of ArchiMate is given by the ArchiMate 2.0 Specification [The Open Group, 2012], practical advice in applying ArchiMate for architecture modeling is provided by the 'Mastering ArchiMate' Blog [Wierda, 2016].

Both description languages are used in this thesis, as each of them has specific benefits and advantages and combining the strength of both modelling languages allows to develop the best possible graphical description of an (enterprise) architecture.
ArchiMate is mainly used for the general and high-level descriptions of the system like the organizational structures, business processes and generic functional and technical structures. ArchiMate allows to model a full overview of the system including some more specific but still generic details of selected viewpoints and architecture aspects. UML is applied when more detailed and implementation specific descriptions are required like use case diagrams, sequence diagrams and others. The UML diagrams allow for very precise and unambiguous descriptions of system aspects. Another advantages of UML is the option of immediately transferring the diagrams into code for the implementation. Part of the ArchiMate modelling concept is to extend the ArchiMate diagrams by directly linking UML diagrams to its elements.
The described combination is used for the illustrations in the subsequent chapters and is recommended for any architecture model developed based on this approach.

2.1.3.1. Modeling architecture in ArchiMate

For the architecture descriptions of the Reference (chapter 7) and System Architecture (chapter 8) mainly the ArchiMate modeling language is used. The organizational viewpoint usually is described with elements from the business layer of Archimate, for the description of roles the element 'Business Role' is used. For the functional viewpoint elements both from the business and application layer are selected. The description of functional business processes is realized through 'Business Event' and 'Business Process' elements. When the descriptions needs to be more detailed, Archimate allows to link the business with the application layer. In this case, application layer elements are associated to the business layer elements, e.g. 'Application Components' are linked to business processes. Stepping down to the next layer as well involves that multiple application components are needed to describe one business process element. ArchiMate provides 'Application Services' to link the individual application components. The elements from the technical viewpoint are modeled with 'Nodes'.
The elements described above and used in the subsequent chapters are summarized in Figure 2.1.

2.1.4. Existing architecture frameworks and architecture models

The theoretical part of the methodology does not develop an overall C-ITS architecture (3.2) completely from scratch but first analyses and reuses existing architecture models. Several popular methods and models were selected for this approach, a slightly more detailed description of the core sources are provided in the subsequent subsections. Referen-

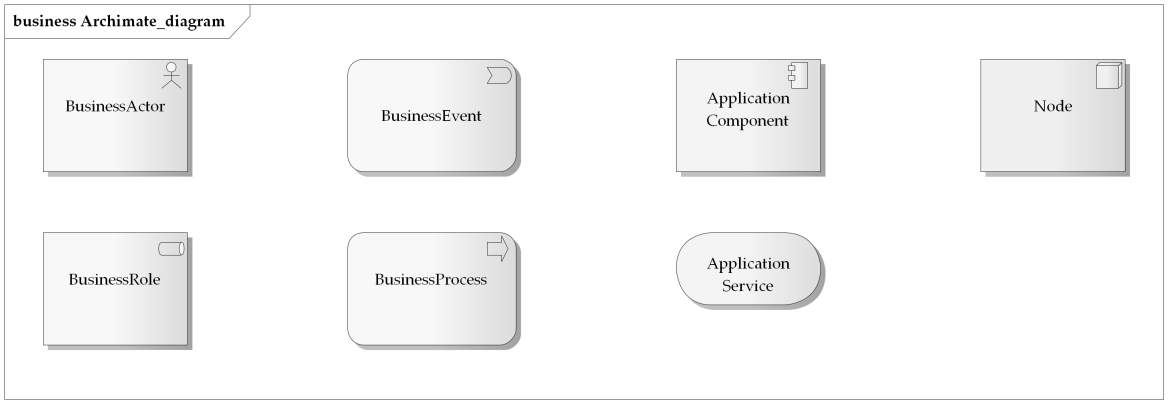

Figure 2.1.: Example for ArchiMate elements

ces and documents for further reading can be found in the respective subsections.

2.1.4.1. TOGAF

TOGAF is an enterprise architecture methodology and framework that was originally developed by The Open Group. The TOGAF architecture was first published in 1995 and is originally based on the US Department of Defense Technical Architecture Framework for Information Management [Department of Defense, 2010]. From then on it was continuously advanced by architecture experts and new versions are published regularly. The methodology is one of the most popular enterprise architecture standards and it is applied across different industries.
TOGAF provides a methodology to develop an architecture, the so called Architecture Development Method, and a framework, in which the developed artifacts can be classified, the Enterprise Continuum.
TOGAF is owned by The Open Group consortium and free of use. The current version is 9.1, a detailed description is available online [The Open Group, 2011b] and in the corresponding book [The Open Group, 2011a].

2.1.4.2. Zachman Framework

The Zachman Framework is a classification schema for architecture artefacts. It provides a framework to formally structure enterprise architectures and their viewpoints. The Zachman Framework was originally developed by John Zachman in 1978. Since then it was extended and formalized.
The Zachman Framework has a matrix structure and consists of a set of rows and columns. The rows comprise different viewpoints, starting on an abstract, high level going down to technical aspects. The individual rows are not independent, aspects from a higher row have implications on the lower row. Examples for rows are Business Model, System Model or Technology Model. The different columns have no specific attributes but contain fundamental questions and the respective answers form a description of the system concerning this specific aspect. Examples are 'What' – data; 'How' – process flow and functions; 'Who' – responsibility assignments.

The Zachman Framework does not provide a methodology to develop an enterprise architecture but only a structural framework for the different viewpoints and aspects of an architecture.
An overview sheet of the Zachman Framework is available online [Zachman, 1987].

2.1.4.3. Gartner

The Gartner approach was originally developed out of best practices in industry by several architecture experts. It comprises no specific methodology but a collection of various methodologies and their practical application. It is therefore closely linked to other architecture methods, the core value in this context are the Gartner experts who support the customer in applying enterprise architecture know-how to its company.
There is no detailed material or formal description of the Gartner approach available – usually experts are sent to the team that needs to develop the architecture, detailed descriptions are proprietary to companies that provide the Gartner architecture support. Some limited information is available in Bente et al. [2012] and Sessions [2007].

2.1.4.4. FGSV pyramid

The architecture task force (Arbeitsausschuss 3.1 Telematics) within the German FGSV (Forschungsgesellschaft für Straßen- und Verkehrswesen) developed an architecture model which was published in 2012 [FGSV AA 3.1.4, 2012] . Experts from different German ITS companies, research institutes and universities were involved in the design and specification process.
The FGSV architecture proposal addresses different levels of detail (Framework Architecture, Reference Architecture, System Architecture) and in each level different viewpoints. The viewpoints of one abstraction level (e.g. Reference Architecture) form a hierarchical pyramidal structure (see Figure 3.6) with the strategic (organizational) viewpoint at the top and the infrastructure (technical) viewpoint at the bottom. Inbetween are viewpoints called business process, information structures and technical services.
Practical application and implementation of the FGSV structure was done in the ITS framework architecture for public transport in Germany [Kieslich et al., 2013].

2.1.4.5. Open Distributed Processing

Open Distributed Processing (ODP) is a series of ISO standards initially published in 1998 ([ISO 10746-1, 1998]-[ISO 10746-4, 1998]). The ODP standards were developed by a joint initiative of several standardization organizations: ISO, IEC (International Electrotechnical Commission) and ITU-T (International Telecommunication Union - Telecommunication Standardization Sector).
The ODP standard mainly addresses architectures of distributed systems. The methodology has an object oriented approach which is used as well to delimit the system: internal (enterprise) objects are part of the system and are specifically set up as mechanism to enable or support the provision of a service via the considered system. External (enterprise) objects are involved in the system but not specifically set up.
ODP defines five different viewpoints, Enterprise, Technology, Information, Engineering,

Communication. Each of the viewpoints fully describes the system from the respective perspective. The scope of each viewpoint is described in detail in the standards. The viewpoints can be described in UML, details on the realization are described in ISO 19793 [2008]. An example for the practical application of the ODP standard are the Electronic Fee Collection (EFC) standardization activities in Europe [CEN 17573, 2009].

NOTE: Similar concepts like ODP are used in architectures developed for the US Department of Defense [2010] and the Concept of Operations for the use of ITS in the US [US Department of Transportation, 2011]. In both descriptions the initial concept described in the ODP standard was partially modified and adapted to the respective needs, mostly the viewpoints defined in ISO 10746 are preserved.

2.1.4.6. Standards

ISO 14813 [2006] is a multi-part standard that addresses different aspects. In this thesis only part 5 on 'Requirements for architecture description in ITS standards' is considered. A short summary of the individual parts can be found in an overview over ITS standards [Williams, 2008].

Part 1: ITS service domains, service groups and services

Part 2-4: not applicable to ITS – focus on TICS (Transport Information and Control Systems) = subset of ITS

Part 5: Requirements for architecture description in ITS standards

Part 6: Data presentation in Abstract Syntax Notation One (ASN.1)

ISO 42010 [2007] Systems and software engineering – Architecture description is the core standard about architecture structures of systems. It proposes a conceptual meta-model that consists of the core elements of an architecture, the model itself describes their relation. The meta-model is complemented by a generic description of best practices specified as requirements. ISO 42010 strongly influenced the definition of viewpoints in an architecture.

2.1.4.7. Other

Besides the architecture models detailed in the previous chapters there exist a number of other architecture models and frameworks. The description of TOGAF additionally refers to a large number of other Enterprise Architecture Frameworks e.g. C4ISR Architecture Framework, CORBA, Enterprise Architecture Planning, Federal Enterprise Architecture, Federal Enterprise Architecture Framework, ISO/IEC TR 14252:1996, NCR Enterprise Architecture Framework, SPIRIT Platform Blueprint Issue 3.0, TAFIM, TEAF [The Open Group, 2011a]. Various other sources provide additional lists of Enterprise Architecture Frameworks, e.g. Schekkerman [2006].

Those are not detailed here as they are not used in the subsequent methodology and because the architectures listed there are either overlapping with the already mentioned Enterprise Architecture Frameworks or are of minor importance because they address very subject-specific fields. Partially, they were only modifications of other existing Enterprise Architecture Frameworks.

2.2. Intelligent Transport Systems (ITS)

Before defining Intelligent Transport Systems in particular it is necessary to narrow down the definition of 'system': In general, the term system is used to *summarize a number of objects in a defined framework which have a relation with each other. The objects are as well called modules or components. The system boundary defines which components belong to a system. All other components are called the surrounding* [Kopacek and Zauner, 2004].

2.2.1. Definition ITS

Intelligent Transport Systems (or sometimes Intelligent TransportATION Systems, abbreviated with ITS) can be described with different definitions. Some prominent examples are presented here.

The **European ITS Directive** [Official Journal of the European Union, 2010] provides a definition for ITS, accordingly ITS are *systems in which information and communication technologies are applied in the field of road transport (including infrastructure, vehicles and users), in traffic and mobility management, as well as for interfaces with other modes of transport*.

Closely linked to the ITS Directive is the standardization in ITS. In the past the European and international standardization organizations developed standards in the field of ITS and therefore they developed as well corresponding definitions. **ISO** included a definition of ITS in their ITS Station Reference Architecture document [ISO 21217, 2009]. It defines ITS as *transport systems in which advanced information, communication, sensor and control technologies, including the internet, are applied to increase safety, sustainability, efficiency and comfort*. **ETSI** defines ITS with a strong link to communication and road transport: *Intelligent Transport Systems (ITS) include telematics and all types of communications in vehicles, between vehicles (e.g. car-to-car), and between vehicles and fixed locations (e.g. car-to-infrastructure)*. However, from the ETSI (European Telecommunications Standards Institute) perspective *ITS are not restricted to Road Transport – they also include the use of information and communication technologies (Information and Communication Technology (ICT)) for rail, water and air transport, including navigation systems* [ETSI - Intelligent Transport Systems, n.d.].

For the final definition of ITS used in this thesis mainly those three definitions are considered. The definition from the ITS Directive is the most relevant one in this context, as the scope of the work in the subsequent chapters focuses on ITS and C-ITS in Europe. Most of the considered ITS and C-ITS activities were initiated based on the European ITS Directive.

ITS is as well addressed in other regions e.g. the USA. There, the **US DOT (Department of Transport)** supports a large number of ITS activities. According to their definition ITS can be defined as the *application of advanced information and communications technology to surface transportation in order to achieve enhanced safety and mobility while reducing the environmental impact of transportation. The addition of wireless communications offers a powerful and transformative opportunity to establish transportation connectivity that further enables cooperative systems and dynamic data exchange using a broad range of advanced systems and technologies* [US DOT, 2011].

Apart from the cited definitions above there are definitions available from many other organizations worldwide. One prominent example is the PIARC handbook [World Road Association, 2005], which comprises a rather comprehensive description and definition of what ITS is.

Comparing those different definitions shows that common to all definitions is the intelligence of applications and services that enable the user to be better informed and hence travel safer and smarter. In general, ITS is not restricted to any specific field in transportation and traffic and includes the highway, urban, multimodal sector.
In this thesis the following definition of ITS is used: **Intelligent Transport Systems** are the application of information and communication technologies in road transport to increase safety, sustainability, efficiency and comfort. Communication is a core enabler for the improvements of ITS.

2.2.2. (Political) background on ITS in Europe

ITS is a prominent European topic and therefore addressed by the European Commission (EC). Within the organizational structure of the European Commission several DG (directorate general) deal with ITS. The European Commission mainly addresses ITS from a legislative and technology support and research perspective.

On the legislative side the ITS Action Plan needs to be mentioned. The **ITS Action Plan** was published by the European Commission in 2008 [Commission of the European Communities, 2008]. Its goal is to accelerate and coordinate the deployment of ITS in road transport in Europe. The Action Plan should help to make transport cleaner (greener), more efficient and more safe and secure. Therefore, it comprises six priority areas for action, for each of the priority areas a set of required actions and a corresponding schedule was identified. The priority action areas are 'Optimal use of road, traffic and travel data' (1), 'Continuity of traffic and freight management ITS services on European transport corridors and in conurbations' (2), 'Road safety and security' (3), 'Integration of the vehicle into the transport infrastructure' (4), 'Data security and protection, and liability issues' (5) and 'European ITS cooperation and coordination' (6). Details are available in the ITS Action Plan [Commission of the European Communities, 2008]. The proposed action areas and its corresponding actions are supposed to provide the framework for coherent and fast deployment of ITS in Europe.
The ITS Action Plan already includes the proposal for a directive which was developed in the following years. Goal of the directive was to support the harmonization and alignment of the inhomogeneous ITS landscape in Europe. It was supposed to enable a broader and coordinated uptake of ITS for roads and support the fast implementation of ITS through Europe.

The **Directive 2010/40/EU** (mentioned in the ITS Action Plan) was finally issued in 2010 [Official Journal of the European Union, 2010]. A directive is a legal act of the European Union which requires certain actions in the member states, how the requested goals are achieved is disposed to each member state. The ITS Directive demands specifications

for the six priority areas. The developed specifications (i.e. functional, technical, organizational or services provisions) shall address the compatibility, interoperability and continuity of ITS solutions across the European Union (EU). The specifications from the six priority actions are jointly addressed by the member states. The developed specifications are adopted by the EC, the member states have to make sure that they realize their implementations in accordance with the specifications. The specifications and other documents around the directive are available online [European Commission - Mobility and Transport, 2015].
NOTE: Part of the directive is as well a request to submit a national report on their ITS activities by 2011. Additionally, the member states had to provide a five year plan on their future activities. In 2014 a progress report was due. Some of the reports are publicly available and can be downloaded from the website of the EC [European Commission, 2016].

The ITS Action Plan and the European ITS Directive not only triggered political activities in the single member states of the EU. They were as well the basis for various technology support actions and research projects funded by the European Commission. Examples in the field of ITS are the TEMPO Program (2001-2006), which provided funding for regional but harmonized ITS deployment activities in Europe or the Trans-European Networks - Transport (TEN-T) work programme 2007-2013, which supported initiatives like EASY-WAY and the European ITS Platform (incl. several corridor deployment activities).

2.2.3. Legacy ITS

Both the ITS Action Plan as well as the ITS Directive appointed that there is a large inhomogeneous landscape of ITS applications in Europe. Many existing implementations fulfill the criteria and definitions of being ITS but they often implement different structures than those recently developed. One core differentiation criteria here is that usually the existing or so-called legacy ITS are implement as silos. The applications are designed in a way that they are only able to serve one specific purpose, multi-use is mostly not possible. In contrast, new ITS and their applications are often designed in a way in which they might be connected with other ITS (applications) so that single systems or their elements, modules or functions might serve multiple purposes and might be cooperative.
Most of the existing ITS implementations are part of legacy ITS. One of the goals of the architecture developed in this thesis is to integrate them. The developed approach will show that some of the applications only need minor modifications to transfer them to the current architecture design state in ITS.

2.2.4. Examples for ITS architectures (focus on Europe and Germany)

One of the requirements for the overall architecture developed in this thesis is the integration of existing architectures. Examining existing systems and applications (legacy ITS) shows that most of them have a more or less detailed description of their underlying architecture. This is called the ITS architecture.
Several prominent examples for ITS architectures of popular legacy ITS in Germany are analyzed in the BASt (Federal Highway Research Institute, Bundesanstalt für Straßenwesen) report F79 [Boltze and Krüger, 2011]. In the analysis particular features of an archi-

tecture were deconstructed for different existing systems and compared. From the results of this detailed analysis the most popular national ITS architectures are selected for the subsequent method. The list of selected ITS architectures can be found in section 3.2.4.2.2, detailed summaries for the different architectures are available in the report.
An overview of ITS architectures beyond Germany and Europe was conducted by Philipp Krüger [2013]. He already contributed to the work done in BASt F79 [Boltze and Krüger, 2011] and continued these activities, including a deepened investigation with a slightly broader scope.

2.2.5. Matrix report

Closely linked to ITS architectures is the Matrix report published by BASt in F97 [Lotz et al., 2012]. It does not develop or describe a specific ITS architecture but analyzed for a selected service (Hazardous Location Warning) a number of different ITS implementations and the respective ITS architectures. The systems selected for the comparison implement the service Hazardous Location Warning based on different technologies and different structures, the Matrix report therefore developed a generic structure to allow for a comparable analysis. Part of this structure was the analysis of the different architectures with regard to different viewpoints, essentially the organizational, functional and technical aspects. The method from the Matrix report was applied to selected ITS implementations what lead to comparable and transparent descriptions of the individual architectures.
Apart from the method for the structural analysis of ITS architectures the Matrix report supports the transformation of suchlike: the report already points out possible transitions from the silo structure of legacy ITS to the connected modular structure in ITS of today and the future. Details are available in 3.4.1.1 and in Lotz et al. [2012].

The Matrix report was developed in parallel to this thesis and is consulted and referenced repeatedly. Its results are taken as basis for developing a method for cooperative ITS architectures, they are advanced within the approach described in this thesis.

2.2.6. Cooperative ITS (C-ITS)

The field of ITS is very broad and can be subdivided into multiple more specific domains. Examples are 'green ITS' with a focus on sustainable and eco-friendly mobility or 'cooperative ITS' with a focus on communication enabled cooperation between entities. Focus of this thesis is on cooperative ITS.

2.2.6.1. Definition of C-ITS

The need for a definition of cooperative ITS was identified shortly after the mandate M/453 [European Commission - Enterprise and Industry Directorate General, 2009] for C-ITS was launched by the European Commission (details in 2.2.6.2). In the response to the mandate which was drafted by the standardization organizations CEN and ETSI [CEN and ETSI, 2010] a short definition of C-ITS reflecting their understanding was included. The definition is *Cooperative ITS: is a subset of overall ITS that communicates and shares information between ITS Stations to give advice or facilitate actions with the objective of improving*

safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems. At the time being this was sufficient and served its purpose but the standardization experts discovered when working on C-ITS standards that this is not adequate, therefore CEN and ISO (with contributions from ETSI experts) started to work on a more detailed definition of C-ITS – the standard ISO TR 17465-1 [2014]. The document is finished and published.
The main definition in TS 17465-1 originates from the Report to the Mandate M/453 and is complemented by some details which are supposed to increase the precision of the description. To avoid confusion and misinterpretation, a set of additional criteria complements the initial definition, examples for those criteria are a common reference architecture and the sharing of information between applications.
NOTE: ISO TR 17465-1 defines as well several other C-ITS related terms. Furthermore ISO TR 17465-1 provides some ideas on viewpoints which are called system perspectives that shall be covered when describing a C-ITS architecture. The perspectives are taken into account when developing the architecture framework.

Although the definitions from the mandate and in ISO TR 17465 are rather broad and open some people in the C-ITS community have a rather focused view on what C-ITS actually is. They only consider service implementations based on the ETSI ITS G5 (European profile for Intelligent Transport Systems operating in the 5 GHz frequency band) technology (802.11p WLAN, [ETSI 302 663, 2012]) to be cooperative. In general – and as well in this document – C-ITS is independent of the communication technology, the focus is on cooperation and interaction between entities and distributed implementation of services that requires communication and connectivity. For each individual cooperative service implementation the most suitable communication mode needs to be selected when realizing the different (external) communication interfaces of the service. Therefore, the range of communication technologies shall not be restricted to ETSI ITS G5 communication or cellular networks. Even services in which the individual modules are connected via internet are cooperative.
A much better differentiation criteria for C-ITS is the structure of actors that contribute to the implementation of a service. Multi-stakeholder service implementations automatically require that the different stakeholders are both connected and cooperative – otherwise the service might not be provided. Information needs to be exchanged between the different actors as no single stakeholder group is realizing the service by itself. The exchange of information in turn requires to establish communication links between the respective partners. Only if the partners cooperate with each other the communication is possible and successful – this affects both functional and technical aspects of the communication as well as economic aspects.

Based on the definitions and considerations above the following definition for C-ITS is used in this thesis:
Cooperative ITS: is a subset of overall ITS that communicates and shares information between ITS Stations to give advice or facilitate actions. Different stakeholders jointly implement ITS services with the support of communication with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems.
C-ITS is not limited to any specific domain in transportation.

2.2.6.2. (Political) background on C-ITS in Europe

C-ITS in Europe has its history both in the political activities on ITS driven by the European Commission (ITS Action Plan and ITS Directive) as well as in multiple funded European ITS and C-ITS projects. Both together significantly enabled the current maturity level C-ITS achieved and thereby facilitated the first deployment initiatives and decisions in Europe.

Closely linked to the ITS Action Plan and the ITS Directive is a standardization mandate, issued by the European Commission, shortly after the ITS Action Plan was published. The mandate M/453 [European Commission - Enterprise and Industry Directorate General, 2009] was directed to the European Standardization Organizations CEN, CENELEC (European Committee for Electrotechnical Standardization) and ETSI in 2009, subject were the standardization activities required for the implementation of C-ITS. The mandate M/453 was formally accepted by CEN and ETSI and in April 2010 they delivered the first joint report to the European Commission [CEN and ETSI, 2010]. The report included a table with the so called 'Minimum Set of Standards' – a list of standards identified by the two standardization organizations to be required for the successful implementation of C-ITS. The main categories were General, Testing, Applications, Facilities, Network and Transport, Access, Management and Security. The latter six categories reflect the structure of the ITS Station Reference Architecture standardized in ISO 21217 or ETSI 302 665 and include standards that detail these specific parts of the ITS Station Reference Architecture. The category 'General' includes high-level standards that were not assignable to any of the ITS Station Reference Architecture parts or Test Standards: Definitions and Terminology (e.g. TR 17465), the Organizational Architecture of C-ITS (ISO 17427), the Communication Reference Architecture (ISO 21217 or ETSI 302 665) and the Data Dictionary (ETSI 102 894-2). The category 'Testing' includes Test Standards required to test implementations of C-ITS.
From 2010 on CEN, ISO and ETSI started to develop the standards from the table, CEN and ISO were mainly responsible for application related standards, ETSI worked on the communication aspects. In July 2012 the mandate M/453 terminated. By then CEN, ISO and ETSI did develop and publish a large number of standards, a full overview of all the work done under the mandate M/453 is given in the final report [CEN / ISO and ETSI, 2013]. The standardization activities were partially funded by the European Commission, the standards resulting from mandate M/453 are an important contribution to the European C-ITS deployment activities.
Currently, discussions are ongoing on whether a second standardization mandate is required. Independent of this, the standardization organization continued to develop standards required for C-ITS deployment.

2.2.6.3. EU Projects on C-ITS

Besides the politically driven standardization activities various projects on C-ITS significantly contributed to the success story of C-ITS. The European Commission financially supported a large number of ideas around C-ITS through funding in various framework programs. The projects were developing the technology, proofed the technical feasibility and addressed various issues. But not only technical challenges were solved, some

had economic or legal aspects in focus, others mainly realized large-scale field operational tests to collect huge amounts of close to reality data and results. Some of the largest C-ITS projects in the past decades were:

- CVIS, COOPERS and SAFESPOT, three parallel implementation projects with focus on technology and proof of concept
- DriveC2X, bringing together a large number of national C-ITS activities, just recently closed successfully
- Coordination and support actions that made big contributions to standardization and dissemination of other projects' results: COMeSafety, COMeSafety2, CODECS

A summary and description of the mentioned projects as well as a list with additional C-ITS projects and field operational tests in Europe is available in the FOT-net Wiki [2011, Pages in category 'Cooperative Systems']

Most of the European projects had a work package dealing with project related architecture aspects and developed a project specific architecture. Though most of the projects considered architecture to be a necessary negligibility but actually focused on C-ITS technology or other C-ITS related aspects. The only project with a focus on architecture was FRAME (its predecessor KAREN) and the C-ITS successor eFrame.
The following sections provide some more information on prominent C-ITS projects considered in the approach of this thesis.

2.2.6.3.1. CVIS – Cooperative Vehicle-Infrastructure Systems

CVIS was one of the three large C-ITS projects in the 6th Framework Program running from 2006 to 2010. The project significantly contributed to the advancement of the C-ITS technology and analyzed various non-technical aspects like user acceptance, privacy, security and economical aspects. Part of the project were several test sites across Europe.
CVIS developed its own project architecture and was involved in the harmonization activities driven by COMeSafety.
Information and core documents are available from the Transport Research and Information Portal as the project website was closed down in the meantime [CVIS, n.d.].

2.2.6.3.2. COOPERS – Co-operative Networks for Intelligent Road Safety

COOPERS was like CVIS one of the three large C-ITS projects in the 6th Framework Program running as well from 2006 to 2010. Its objective was the C-ITS technology with a strong focus on safety related V2I (vehicle2infrastructure) services. The technical developments were tested at several European test sites in field operational tests.
COOPERS developed its own project architecture and contributed to the harmonization activities of COMeSafety.
Information and core documents are available from the Transport Research and Information Portal as the project website was closed down in the meantime [COOPERS, n.d.].

2.2.6.3.3. Safespot – Cooperative Systems for Road Safety

Safespot was the third of the three large C-ITS projects in the 6th Framework Program running from 2006 to 2010. Like the other two, CVIS and COOPERS, Safespot worked as well on the technical advancements of C-ITS which were demonstrated at several European test sites. The other targets of Safespot were non-technical aspects like organizational structures, business models and cost-benefit analysis.
Like the other two C-ITS projects Safespot developed its own project architecture and was involved in COMeSafety activities.
Information and core documents are available from the project website [Safespot, n.d.a] and the Transport Research and Information Portal [Safespot, n.d.b].

2.2.6.3.4. Drive C2X – DRIVing implementation and Evaluation of Car2X (C2X) communication technology in Europe

The project Drive C2X is the successor of the project Pre-Drive (2008-2010) and was funded in the 7th Framework Program running from 2011 to 2013. When Drive C2X started the C-ITS technology already achieved a comparatively mature level so the focus of Drive C2X was rather on the assessment of technology than on its advancement. Therefore, selected services were implemented and intensively tested on several European test sites, one of the main objectives was to do this in parallel in a harmonized and aligned environment to obtain comparable results under different conditions. Several national field operational tests participated in Drive C2X, e.g. simTD (Germany), DITCM (Netherlands), Score@F (France). Besides the technical aspects Drive C2X worked on business models and different crucial deployment factors of C-ITS.
Information and core documents are available from the project website [Drive C2X, n.d.a] and the Transport Research and Information Portal [Drive C2X, n.d.b].

2.2.6.3.5. COMeSafety – Communications for eSafety; COMeSafety2; CODECS

COMeSafety was a Coordination and Support Action in the 6th Framework Program of the European Commission running from 2006 to 2009. COMESafety supported the parallel running integrated projects CVIS, SafeSpot and COOPERS by working towards interoperable solutions. Therefore, COMeSafety developed a common European ITS communication architecture and thereby set the ground for interoperable systems. The architecture was standardized in CEN / ISO and ETSI. Apart from that COMeSafety was pushing the frequency allocation in the 5.9 GHz band.
Successors of COMeSafety are the projects COMeSafety2 (2011-2013, 7th Framework Program) and CODECS (2015-2018, Horizon2020). COMeSafety2 continued to contribute to standardization, international harmonization and supported the deployment discussions and activities in C-ITS. The CODECS project, which started recently, continued the harmonization activities, plays a major role in the joint deployment and will work on European standards' profiles for C-ITS [CODECS, n.d.].

2.2.6.3.6. FRAME (Framework Architecture Made for Europe) and eFrame (Extended Framework architecture for cooperative systems)

The development of a European ITS Framework architecture originally started with the project KAREN (1998-2000) and was later continued as FRAME project ([FRAME-NET, n.d.], [FRAME-S, n.d.], all funded by the European Commission). FRAME (FRAME-NET, FRAME-S) was running from 2001 to 2003 and maintained and advanced the architecture originally developed in KAREN. This incorporated as well the development of specific tools that should help users and stakeholders to customize their own architecture based on the generic European ITS Framework architecture.
Successor of FRAME was eFRAME (2008-2011), the C-ITS advancement of the FRAME project. eFRAME closely cooperated with the projects COOPERS, CVIS and Safespot. The three C-ITS technology focused projects provided the requirements (user needs) for the cooperative FRAME extensions. eFRAME provided an updated version of the FRAME tools and thereby showed that the transition of the FRAME results to C-ITS is possible.
Details on KAREN, FRAME and eFrame are available online [Frame, n.d.a].

2.2.6.4. National projects on C-ITS

C-ITS projects were not only funded by the European Commission but as well through the governments of the European countries. Some examples are: simTD (Germany), Score@F (France), DITCM (Netherlands), Testfeld Telematic (Austria). The following chapters provide a short summary of their scope.

2.2.6.4.1. simTD

simTD was a large German research project on C-ITS running from 2008 to 2013. The partners involved in the project implemented a large number of different services that improve road safety, traffic efficiency or provide value added services. The impact and benefits of the services were analyzed in a large-scale field operational test in the region around Frankfurt. simTD not only demonstrated the technical feasibility and maturity of the C-ITS technology but addressed as well many non-technical issues like legal aspects and business models.
The simTD test site and its technology were as well part of the Drive C2X project. After both projects were finalized the test site was closed down (equipment no longer active).
More details and documents are available online [simTD, n.d.].

2.2.6.4.2. UR:BAN

UR:BAN is a large German research project that developed advanced driver assistance and traffic management systems for cities. The project addressed three main fields with its subprojects Cognitive Assistance (driver assistance systems), Networked Traffic System (urban traffic management) and Human Factors in Traffic (human-machine interactions).
The project results were tested in test areas in three German cities, Duesseldorf, Braunschweig and Kassel.
More details and documents are available online [UR:BAN, n.d.].

2.2.6.4.3. Score@F

The French Score@F project implemented and tested a set of 13 safety-related C-ITS use cases in three French regions between 2010 and 2013. The services were tested and analyzed in a set of field operational tests. The Score@F activities are supposed to prepare a large-scale field operational test. Major results were the proof of technical feasibility and insights in various driver behaviors and acceptance aspects. Score@F was part of the Drive C2X project.
The C-ITS activities from Score@F are now continued in the SCOOP@F project. SCOOP@F is funded by the European Commission and is the French deployment pilot. More details are available online [SCORE@F, n.d.].

2.2.6.4.4. DITCM

DITCM is a large cooperation of partners from industry, government and research. On a test site close to Helmond different cooperative projects are implemented, examples are eCoMove or SPITS. DITCM was as well part of the Drive C2X project.
The C-ITS activities at the DITCM test site are now continued within the Dutch part of the C-ITS Corridor, projects on C-ITS architecture, security and other topics are launched and undertaken. Details are available on the DITCM website [DITCM, n.d.].

2.2.6.4.5. Testfeld Telematik

From 2011 until 2013 the project Testfeld Telematik was carried out in the Vienna region (Austria). Different services were implemented, tested and demonstrated by a consortium of 14 partners. The technical feasibility was shown as well as potential benefits for road traffic. One of the project's highlights certainly were the demonstrations during the ITS World Congress in 2012. More details on the project activities are available in the Testfeld Telematic flyer [Testfeld Telematik, 2012] and the final report [Testfeld Telematik, 2014].
The activities from the Testfeld Telematik are now continued with the ECo-AT project, the Austrian pre-development activities in the C-ITS Corridor. Details are available on the ECo-AT website [ECo-AT, n.d.].

2.2.6.5. Organizations involved in C-ITS (and ITS deployment)

Apart from the legislative activities of the European Commission and their financial support of research and standardization projects a number of other organizations deal with C-ITS and its deployment. Most of the road transport related stakeholder groups and organizations like CEDR (Association of road directors and road authorities), ASECAP (Association of toll road operators), Polis (Association of cities and regions in Europe) or C2C-CC (Car2Car Communication Consortium) have at least some expert group, task force or subgroup that deals with C-ITS.

CEDR [CEDR, 2016] is the association of road directors and road authorities, a non-profit association which represents the road directors of Europe. This association includes 27 countries, and one of the core missions is the involvement in EU-wide initiatives on matters concerning road transport.

ASECAP [ASECAP, 2016] is the association of toll road operators, it has members from 21 countries. One of the missions of the organization is to exchange best practices on operation of their infrastructure including improved traffic management with the goal of better services for their users and enhanced safety.
Polis [POLIS, n.d.] is the association of cities and regions in Europe. They work together to develop innovative technologies in their field of responsibility, Polis serves for ITS members as a platform to exchange experiences and know-how.
In all three organizations C-ITS is only one out of many topics which are discussed.

Slightly standing out of the preceding list is the C2C-CC [Car2Car Communication Consortium, n.d.]. The C2C-CC is a consortium of mainly vehicle manufacturers and their suppliers but as well some research institutes and other ITS related companies. In contrast to the other aforementioned associations the C2C-CC has a strong focus on the C-ITS technology with a limitation to the communication over ITS G5 (short-range communication). This slightly changed recently (now including as well long-range communication) and the C2C-CC starts to discuss as well automated driving issues. The C2C-CC plays an important role in the deployment of C-ITS as the members of the organization were the first ones that agreed amongst each other on a Memorandum of Understanding (MoU) for the deployment of C-ITS [Car2Car Communication Consortium, 2011].

Apart from the stakeholder group specific organizations, that deal with C-ITS topics from the perspective of their members, as well an umbrella organization was formed. The Amsterdam Group [Amsterdam Group, n.d.] connects CEDR, ASECAP, C2C-CC and Polis and focuses on the deployment of C-ITS. The members of the Amsterdam Group meet regularly and exchange experiences on deployment activities of their members. Those belonging to the 'front runners' in C-ITS deployment inform about recent activities and share specifications with the 'follow-ups' to allow for a harmonized deployment of C-ITS in Europe. The Amsterdam Group has several sub groups that deal with specific topics, e.g. functional specification (service descriptions and profile documents), security issues, business models. The results are published through white papers which serve as basis for standards. Determined by its role in European deployment the Amsterdam Group has a close link to the European deployment initiatives like the C-ITS Corridor, Scoop@F and others.

2.2.6.6. European deployment activities

Courtesy of the large number of funded national and European projects and field operational tests is the advancement of this technology for C-ITS. Recently several of the projects proved the maturity of the technology, projects more and more not only address technology related aspects but tackle deployment related research questions. Those are usually grounded in non-technical fields and have an economic or legal background, the project partners identify and evaluate potential business cases and deal with privacy and security questions. Although some C-ITS projects are still running and research on this topic continues there are as well some stakeholder groups that identified sufficient arguments to start deployment of C-ITS. They are as well called 'front runners' as those will be involved in the first deployments of the C-ITS technologies and they will make the first experiences

with day-to-day operation of the results achieved in the projects and field operational tests.

The first group for deployment was formed by Germany, Austria and the Netherlands in 2012 when the ministries of transport in the three countries agreed to deploy C-ITS in a corridor through their countries. This initiative is called **C-ITS Corridor**. The three countries work in close cooperation with industry (Automotive Industry – mainly driven by the German part of the to the C-ITS Corridor –, Roadside equipment manufacturers – mainly driven by the Austrian part – and Nomadic device industry – mainly driven by the Dutch part) to deploy C-ITS services . More background information and details are given in section 8.1 and on the official website of the C-ITS Corridor [Cooperative ITS Corridor, n.d.].

Another European deployment project is **SCOOP@F**, the successor of Score@F. Scoop@F is funded by the European Commission and deploys C-ITS services in different French regions. The deployment initiative calls itself a pilot, as they still have a strong focus on research and field operational test but in large-scale close to real deployment dimensions. There is close collaboration between Scoop@F and the C-ITS Corridor and specifications are exchanged and harmonized to later ensure European interoperability of the deployed services. This work is done on the platform that the Amsterdam Group provides.

Additionally, deployment activities are under preparation in Hungary and the Czech Republic. Here, the Amsterdam Group serves as well as organization for exchanging experiences and specifications.

2.2.6.7. Non-European C-ITS activities

C-ITS is not only a European topic, it is addressed in many projects and initiatives worldwide and partially there are already services deployed. These activities are somewhat based on different starting and legal situations and therefore cannot be completely conveyed to Europe. The following chapters give a short overview of the regional deployment activities but do not dive into details as the non-European activities are not the scope of this thesis. More detailed descriptions and additional information are available in Platte [2014] and with a focus on architectures in Krüger et al. [2013].

2.2.6.7.1. USA

The C-ITS activities in the USA started already many years ago. Like in Europe the government funded several projects on ITS and C-ITS and the US experts significantly contributed to the evolvement of the technology. In those projects often internationally operating vehicle manufacturers were involved so that the technology transfer between the USA and Europe was well ensured. Focus of the American projects are mostly safety applications based on vehicle-to-vehicle communication, the infrastructure side is only partially involved.
Some of the most important US C-ITS projects and initiatives are: CAMP / VSC3, Model Safety Deployment Project, Safety Pilot, VII. Those are complemented by field operational tests in the Connected Vehicle Testbeds in seven regions amongst them the very prominent

Michigan Testbed.

The US DOT announced in the past that they will make a decision on the deployment of C-ITS in light vehicles by 2013 based on the project results, mainly the Safety Pilot. The available options were to start with the deployment right immediately, initiate further research activities and start to prepare deployment or to stop the C-ITS activities. The US DOT did decide to continue the research activities. A large national field operational test was launched called the South-East Michigan testbed.
A similar decision was announced for heavy vehicles for 2015, but research activities in preparation for this decision are currently still ongoing.

In parallel, the US DOT funded a project to develop an architecture which they called 'Concept of Operations'. The basis for the developed architecture is the structure of viewpoints proposed by the DoD (Department of Defense Architecture) [2010] architecture.
The descriptions provided in the public deliverables are already rather specific for certain (selected) use cases. The structure applied for the description of the architecture is highly in line with the concept of ODP [ISO 10746-1, 1998]. Therefore, the results fit quite well to what is developed in this thesis.
Characteristic for the description of the Concept of Operations is its strong focus on security and privacy aspects.

A more detailed description of the American situation can be found in Platte [2014].

2.2.6.7.2. Japan

Japan is one of the countries that already started to deploy C-ITS several years ago. The technology is there referred to as 'Smartway' and has similar goals like in the other regions: making transportation safer and more efficient by implementing cooperative technologies. C-ITS is seen as key element to realize automated driving (target date: 2020). The Japanese C-ITS deployment is mainly driven by the government and its ministries and is realized based on mobile devices in vehicles. From a technical perspective the Japanese C-ITS implementation is slightly different from the ones in Europe and the US as it makes use of a different frequency spectrum.

Unfortunately most information on the Japanese activities is only available in Japanese and therefore of limited use to the European C-ITS experts. Japan developed a large number of national standards to ensure interoperability of the nation-wide implementations. They are as well in Japanese and therefore European C-ITS projects and pilots have only restricted benefit from these documents.

Some more detailed information on Japanese C-ITS activities is available in Platte [2014].

2.2.6.7.3. Korea

Korea is as well rather active in C-ITS, their main C-ITS research and deployment activities are called 'Smart Highways', a set of different projects that started in 2006. The individual

projects address different traffic related topics like adverse weather conditions, real-time traffic information, safety and tolling. The different cooperative services are implemented in a test region close to Seoul [Business Korea, 2013; Korea Expressway Corporation, 2013]. Unfortunately most information is only available in Korean and therefore of limited use to the European C-ITS experts.

2.2.6.8. C-ITS architectures

Deployment of C-ITS just started recently therefore a complete and approved architecture for systems applying this technology does not yet exist. The different projects mentioned in section 2.2.6.3 partially developed project specific architectures. (A broader overview and analysis is given as part of the methodology, the overview is in Tables B.3 and B.4.) But usually those architecture descriptions are limited to the scope and needs of the project i.e. not all levels and views as they are identified in this thesis, are addressed. Additionally, the project architectures were often no longer maintained and updated after the project was finalized so that they do not reflect the latest technological findings. Hence, only useful elements are available but so far no complete and up-to-date architecture for C-ITS exists.
The recently started deployment initiatives therefore have to develop their own C-ITS architecture. In the C-ITS Corridor the architecture is one of the core topics and addressed within its own project group. The architecture is developed with close link to the methodology established in this thesis. The latest result of applying the methodology is described in chapter 8.

2.3. Other details, definitions, terms

2.3.1. General definitions from architecture context

In the reference documents used for the development of the method for defining an overall C-ITS architecture as well as in the resulting method itself various architecture related terms are applied. The following terms are frequently used and therefore explained here.

2.3.1.1. Model

The Oxford dictionary provides the following definition for model: *A thing used as an example to follow or imitate*. In this thesis the term model is used in the context of architecture. The description of the overall C-ITS architecture is not started from scratch but existing architecture models are analyzed in terms of their re-usability for the C-ITS architecture. Generic architecture descriptions (partially from a different context) are used as an example that is (to some extent) imitated. For details see section 3.2.

2.3.1.2. Role

The term role is used in the context of organizational architectures. It was defined in ISO 17427 [2013], the standard is as well considered in the description of the organizational

viewpoint for the overall C-ITS architecture. The definition in ISO 17427 was updated recently and formulated more precisely. The new definition is:
A role identifies a behavior to be associated with a person or organizational unit. A role is described by tasks, competences and responsibilities.
The definition of role uses another two terms which are defined as follows: Behavior is a *collection of actions with a set of constraints on when they may occur* [ISO 10746-2, 1996] and action is *something which happens* [ISO 10746-2, 1996].

2.3.1.3. Actor

Closely linked to the term role is the term actor. It is as well defined in ISO 17427:
An actor is a *user playing a coherent set of roles when interacting with the system within a particular use case* [ISO 24014-1, 2007]
The term actor occurs mainly in the context of practically applying generic organizational architectures, i.e. the abstract roles are assigned to persons, organizations or entities.

2.3.1.4. Stakeholder

Not completely overlapping with actor is the stakeholder, it is defined as *individual or organization having a right, share, claim or interest in a system or in ITS possession of characteristics that meet their needs and expectations* [ISO 12207, 2008].
The difference between actor and stakeholder is their involvement in the implementation and operation of a system. Characteristic for the actor is its active involvement. A stakeholder might be an actor as well but could also be passive and outside the operational processes of a system.

2.3.1.5. System

In general, the term 'system' is applied to *summarize a number of objects in a defined framework which have a relation with each other. The objects are as well called modules or components. The system boundary defines which components belong to a system. All other components are called the surrounding* [Kopacek and Zauner, 2004].
Especially in the context of the different architecture levels the term 'system' refers to the real implementation, an actually existing combination of modules and components that is in operation.

2.3.1.6. Object

ISO 10746-2 [1996] defines object as a *model of an entity. An object is characterized by its behaviour and, dually, by its state. An object is distinct from any other object. An object is encapsulated, i.e. any change in its state can only occur as a result of an internal action or as a result of an interaction with its environment*.

2.4. General description of Top Down and Bottom Up Approach

Top Down and Bottom Up Approach are two complementary strategies which are in use in different contexts e.g. they are applied in scientific theories. Each approach has specific characteristics which are utilized to assemble information, unlock correlations and commonalities and develop generic system designs. Several parts of this document make use of the Top Down and Bottom Up approach: They are used to develop the framework for the architecture description and later to detail and complete this description in the Reference Architecture. Here a general description of Top Down and Bottom Up Approach is given, the more specific application (customization) is described in section 3.2.

2.4.1. Top Down Approach

The Top Down Approach is relating to a hierarchical structure or process that progresses from a large, basic unit to smaller, detailed subunits. The large, basic unit usually describes an abstract, often conceptual and more general level. An organized proceeding is applied to come to the detailed and specific level.
Practically carrying out the approach implies that in each step the results from the previous higher (generic) level are picked up and further detailed until the desired level of detail is achieved. This means, that the resulting detailed description is always closely linked with the original high level description. Example applications can be found in information processing.

2.4.2. Bottom Up Approach

The Bottom Up Approach is the reverse counterpart to the Top Down Approach. It begins with details and works up to the conceptual level, i.e. it is progressing from small or subordinate units to larger or more universal units, as in an organization or process.
In practice this might be applied by taking a (large) number of detailed descriptions, generalizing them and developing an abstract description.

2.4.3. Combination of Top Down and Bottom Up Approach

In this thesis a combination of Top Down and Bottom Up Approach is used. That is, not only each approach is applied separately but the results of both are actually merged together: The Top Down Approach is applied when developing the architecture from abstract (theoretical) models to details, developing generic structures for the overall C-ITS architecture out of existing abstract methods. The Bottom Up Approach is applied when generalizing the detailed, practical descriptions of actually realized systems to abstract structures. At some point the results of both approaches ideally meet, this is denoted as merge of both approaches. The result – here – is the general description of the overall C-ITS architecture. Merging both approaches additionally can be used as reciprocal proof: As stated before the results of both approaches ideally meet at some point, actually striking this point serves as confirmation for the successful application of both concepts. The figurative description can be found in Figure 3.2.

3. Method to describe an architecture for C-ITS – Approach

The **objective** of this part of the document is to describe the complete approach that is used to define the overall architecture for C-ITS. Based on this description

- the frame structure for an overall architecture is developed and
- the abstract elements of the overall architecture are detailed

The method for the description of an overall architecture for C-ITS starts with the explanation of the generic approach that runs through the whole document. It describes shortly the individual steps that will be taken to finally result in an overall architecture for C-ITS (section 3.1).
The focus of the remaining sections of this chapter are on the description of the theoretical aspects of the approach. Section 3.2 describes the analysis which leads to the abstract structure of the overall architecture. Section 3.3 picks up the results from section 3.2 and fills the developed structure with abstract descriptions of the individual aspects consulting again the basic material already used in section 3.2. In section 3.4 the hitherto developed architecture is complemented by additional requirements for C-ITS like the integration of legacy ITS and the future extensibility. The results of all these examinations are subsumed in section 3.5.

3.1. Approach for the definition of an overall C-ITS architecture

Figure 3.1 gives a graphical representation of the complete approach to describe the overall architecture for C-ITS. It consists of three major building blocks, the theoretical method, its practical application to achieve a generic overall architecture description and finally the practical realization with an example architecture.

In the **first part**, the theoretical background for architectures will be analyzed with the goal to first develop a frame structure for the subsequent descriptions (light grey box in Figure 3.1). Basis for this structure are various sources: theoretical methodical background, practical implementation examples and C-ITS specific requirements. The analysis and combination is described in detail in section 3.2. Result of these activities will be a **theoretical frame structure**.
In the **second part** the previously defined frame structure is further augmented with specific descriptions of the individual aspects. Section 3.3 provides the procedure how to expand the initial descriptions – the presented recipe is generic and might as well be applied in a different non (C-)ITS related context. Section 3.4 complements the C-ITS specific

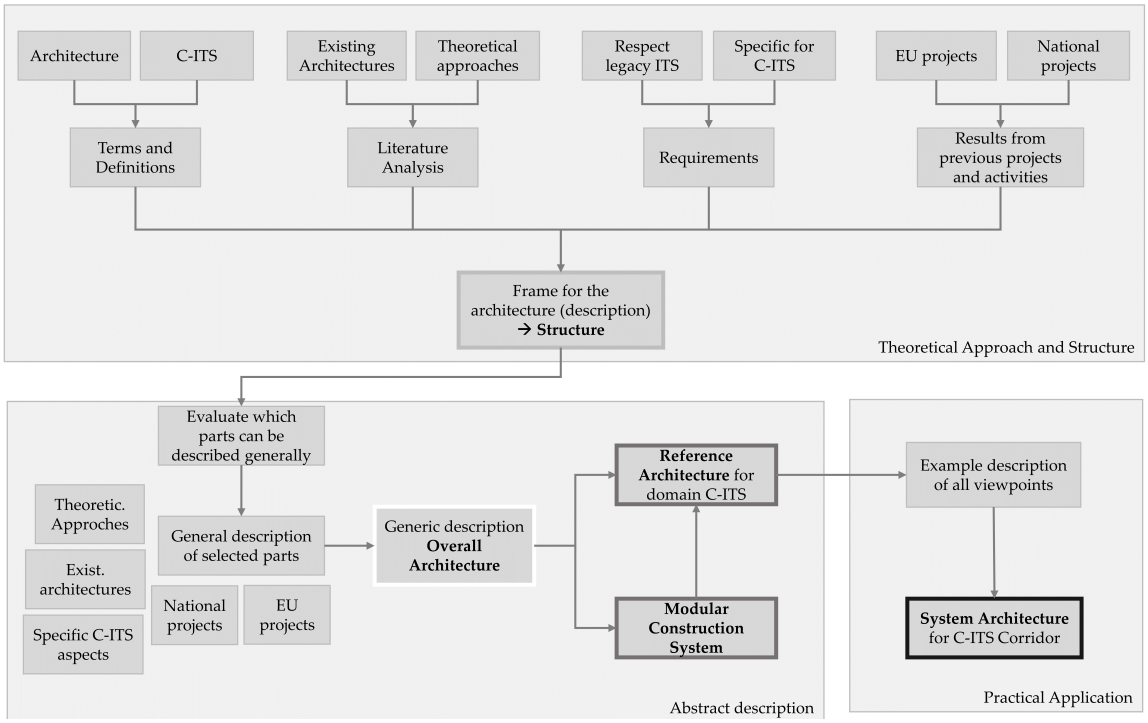

Figure 3.1.: Graphical representation of approach applied

requirements and thereby completes the list of aspects to be considered in the generic overall C-ITS architecture frame structure (section 3.5). These results of the second part end in a theoretical description of the architecture (white box in Figure 3.1) called abstract **overall architecture description**, it is described in detail in chapter 4. The overall architecture is the basis for more detailed descriptions of its elements. One is the **Modular Construction System** detailed in chapter 5, the other the **Reference Architecture** described in chapter 7 (dark grey boxes in Figure 3.1). The Reference Architecture in this document is developed specifically for C-ITS – but the approach itself is designed in a way that it might as well be used to develop other Reference Architectures – hence the resulting architecture is the practical validation of the theoretical thoughts from part 1 and 2. The Reference Architecture comes along with a Modular Construction System. This covers at least the scope of the Reference Architecture but might even have a wider scope (see Figure 4.1). The dark grey boxes are substitutional for various Reference Architectures and elements in a large comprehensive Modular Construction System.
For the practical verification of these theoretical activities a **third part** is included in Figure 3.1. There, the results of the two previous parts are applied in a real world example: The Reference Architecture and its Modular Construction System are mapped to a specific example, a **system architecture** (black box in Figure 3.1). This aspect is addressed in chapter 8.

3.2. Approach Part 1 – Frame structure for overall architecture

The **objective** of this part of the approach is to provide a frame structure for the description of the overall architecture. The frame structure shall provide guidance when describing the overall architecture. The corresponding details can be found in sections 3.3 to 3.5.
NOTE: This part will only develop the frame structure – this does not include detailing the elements of the developed structure.

3.2.1. General structure of an architecture

General considerations lead to the following rough idea of how to structure an overall architecture commonly:
An architecture description may address different **levels** of abstraction – the description could be either very concrete, close to a potential realization (implementation) OR on the other hand very general, rather providing a common guideline for architectures in a specific domain. Additionally, all nuances between those two extreme points are possible. The architecture on any specific level always includes an exhaustive description of the system. Summarizing this, an architecture description could address anything between general and specific – the individual levels represent different shades and each of them comprises complete descriptions of the system.
A system (and its architecture) can be described through a set of **viewpoints (layers)**. They structure an architecture description on a specific level. Different viewpoints (layers) focus on different aspects of a system, this can be on the one side high-level strategic aspects (e.g. strategies, policies, goals, organizational structures) and on the other side rather low-level technical aspects (e.g. hardware settings). Viewpoints usually exist on all architecture levels – depending on the level they might not be developed and defined in detail, especially if they cover rather technical aspects. Summarizing this, an architecture description on a specific level can be substructured into a number of viewpoints or layers that describe different aspects of this specific architecture level of a system.
Combining both core aspects results in a structure that will consist of different perpendicular levels and viewpoints (layers), the aspired frame structure result will be a matrix. The elements of this matrix formed through levels and layers will be identified and described in the recapitulatory section 3.2.6.
NOTE: In the methodical part (chapter 3) both the terms 'viewpoint' and 'layer' are used to describe the substructure within one abstraction level. They are applied in a completely interchangeable way: In the beginning when the frame structure is still rather abstract mainly the term 'layer' is used. With the solidification of the final architecture structure the term 'viewpoint' is favored.

3.2.2. General description of applied approach

The frame structure of the overall architecture is worked out in a two-part process that consists of the development of a theoretical procedure followed by the practical application of its result.
Basis both for the theoretical and practical part are the Top Down and Bottom Up Approach (defined in detail in chapter 2). A schematic description is depicted in Figure 3.2. The Top Down part will contribute with literature based research and analysis that in-

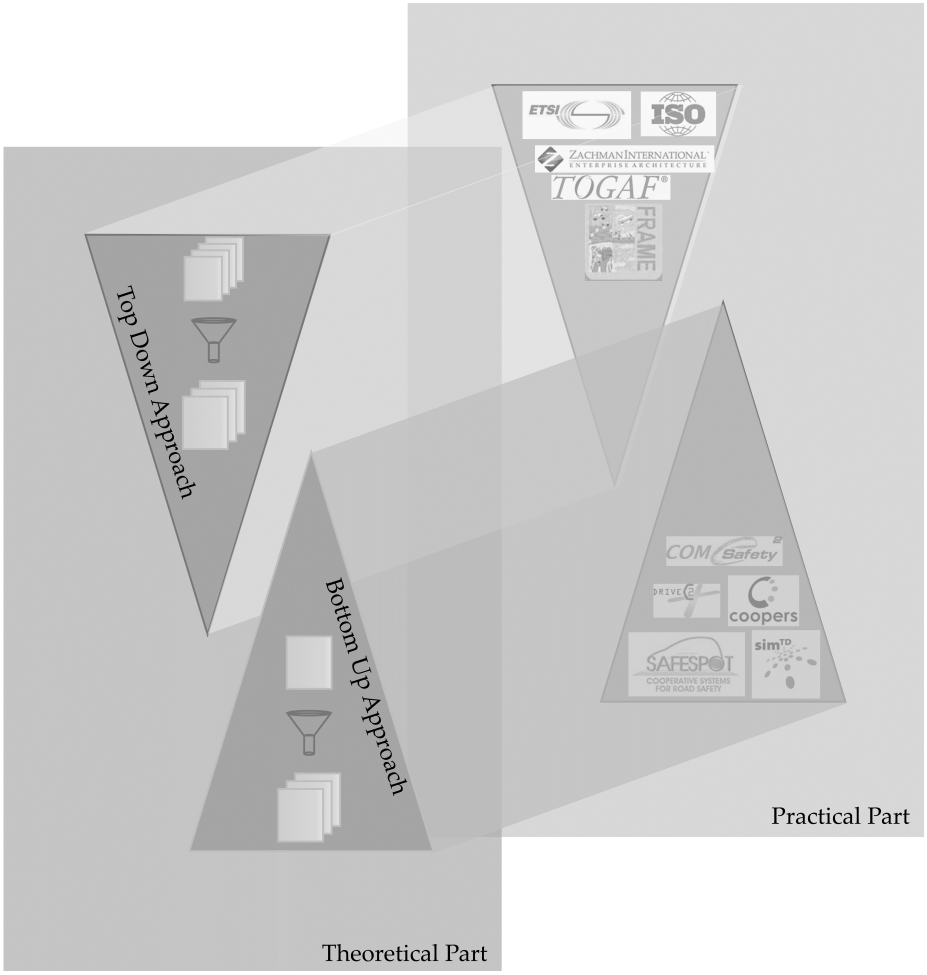

Figure 3.2.: Theoretical (left) and practical (right) process to determine frame structure of overall architecture based on Top Down Approach and Bottom Up Approach

cludes theoretical approaches, architecture models and papers on this topic. The Bottom Up part will provide an evaluation of results from previous projects and activities (including their practical implementations) as well as the analysis of architectures for legacy ITS (already deployed systems).

In the theoretical part, an abstract procedure on how to link Top Down and Bottom Up Approach to derive the frame structure is developed, including a detailed description of the general steps that need to be taken (see left side of Figure 3.2 and section 3.2.3). For the practical part various real-world candidates are fed into this abstract workflow description and are evaluated along the previously described process steps (see right side of Figure 3.2 and section 3.2.4).

NOTE: Scope of this document is Europe, and especially Germany. Therefore, the Bottom Up Approach focuses only on existing systems in Europe which are still in operation. Activities in the rest of the world (mainly US and Japan) are not considered here. This constriction is not applied to the Top Down Approach, high-level architectures from other regions might bring valuable input

to the respective part of the approach. Main goal of the Bottom Up Approach is to ensure that the developed frame structure is not only theoretical but designed in a way that existing and currently operational architectures and their concepts are reflected and in the future might be integrated in the developed frame structure.

3.2.3. Theoretical considerations

The theoretical part describes abstractly the method with its steps that is used to identify the frame structure. The practical application of these considerations take place in section 3.2.4. Like previously stated the method both for the theoretical and practical part will consist of two parts, a Top Down (3.2.3.1) and Bottom Up Approach (3.2.3.2).

3.2.3.1. Top Down Approach

Focus of the Top Down part is a literature analysis. Its goal is to identify a suitable theoretical architecture model that can be used to cover both the **levels** and **layers** aspect as it was previously described (3.2.1). Therefore, in a selection process suitable theoretical architecture models are identified. (A schematic graphical sketch of the process and its individual steps is provided in Figure 3.3.) The selection is twofold – first architecture models that cover full system descriptions (enterprise architectures) and provide a methodology to describe an overall architecture are extracted (Selection Process I in Figure 3.3). In a second step it is evaluated how much those architecture models already cover C-ITS specific characteristics (Selection Process II in Figure 3.3). For both selection steps suitable criteria are identified in the theoretical part.

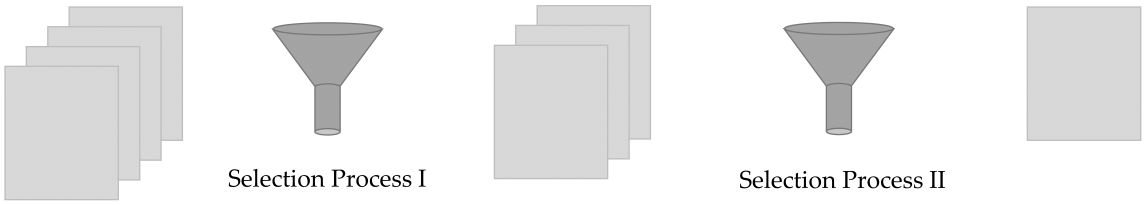

Figure 3.3.: Graphical representation of Top Down architecture model selection process.

In detail, the following steps will be executed:

Step 1: Identify theoretical architecture models

Step 2: Identify the requirements to select for criteria 'enterprise' and 'method(ology)', define selection process and criteria, undertake the selection
Result: selected architecture model(s)

Step 3: Identify the requirements to select for 'C-ITS', define selection process and criteria, undertake the selection
Result: selected architecture model(s),

Step 4: Derive levels and layers from selected architecture models and denominate missing parts based on C-ITS selection process

3.2.3.1.1. Step 1 – Identify theoretical architecture models

Searching for Enterprise Architecture models leads to a large number of potential candidates. Numerous experts published books with descriptions about existing enterprise architecture models and their view on what are the best ones. This already shows the importance of the following step that focuses on the selection of suitable models and the need to clearly define strict selection criteria to significantly reduce the number of discussed models. Step 1 compiles an overview of existing architecture models.

3.2.3.1.2. Step 2 – Evaluation and selection process I

The first selection process is supposed to identify those candidates that actually provide an enterprise architecture methodology. For the evaluation, the two terms ('enterprise' and 'methodology') and their scope are defined. The selected definitions are used to derive the evaluation criteria and requirements for the subsequent selection process, details are described in Appendix A.1. For each candidate the strengths and weaknesses with respect to the identified evaluation criteria are fleshed out. The candidates, which are in line with the scope of the definitions, are selected for the second part of the selection process.

3.2.3.1.3. Step 3 – Selection process II

The candidates selected in the previous step are taken and are now analyzed with focus on C-ITS. Therefore, first C-ITS is characterized and the requirements and criteria are derived like in the previous step, details are described in Appendix A.2.
The Selection Process II then takes the characteristics of C-ITS and the criteria without a specific reference to C-ITS or enterprise architecture models and analyses how the single candidates selected in the previous step fulfill those criteria and characteristics. Again, this evaluation is done through an analysis of strengths and weaknesses for these specific characteristics. The candidate that best fulfills the requirements is finally selected.

3.2.3.1.4. Step 4 – Derive levels and layers from selected architecture models

The finally selected candidate(s) is (are) used to identify which levels and layers are used – these results will serve as input for the description of the frame structure. It is assumed that none of the available candidates is able to completely implement all the characteristics and criteria. Therefore, this step additionally identifies missing parts based on the C-ITS selection process. These aspects are detailed in the second part of the approach (section 3.3) and are required for a complete description of the abstract architecture.

3.2.3.2. Bottom Up Approach

Focus of the bottom up part is an analysis of already existing ITS and C-ITS architectures. The goal is to identify the requirements from existing architectures in terms of **levels** and **layers** that need to be covered in a future frame structure. This is done in a multi-stage process.

In detail, the following steps will be executed:

Step 1: Identify existing definitions of levels and layers

Step 2: Identify candidates of existing ITS and if available C-ITS architectures

Step 3 Analyze candidates with regard to their frame structure

Step 4: Derive levels and layers from existing ITS and C-ITS architectures

3.2.3.2.1. Step 1 – Identify existing definitions of levels and layers

There are already papers available that analyzed and / or summarize the frame structures used in existing ITS architectures. Partially, they include abstract and general definitions as well as frame structure descriptions. This step collects the existing definitions and descriptions and checks whether they can be used as a basis for the definition of levels and layers in the present document.

3.2.3.2.2. Step 2 – Identify candidates of existing (C-)ITS architectures

This step identifies existing (C-)ITS architectures that are potential candidates for the following steps of the bottom up approach. Partially this analysis superimposes on existing documents analyzing the current situation.

3.2.3.2.3. Step 3 – Analyze candidates with regard to their frame structure

The candidates identified in the previous step are thoroughly analyzed. Basis for this analysis are the following aspects which in parts are derived from those already addressed in the report 'Recommendations for the Development and Maintenance of National ITS Architectures' [Krüger et al., 2013]:

- what level is addressed
- what layers are addressed
  - specific details beyond organizational, functional, technical
- where is it applied (reference implementation, real-life example)
- special requirements that need to be considered in the overall architecture

The first two aspects from the list will allow to classify the respective architecture and sort it into the general architecture structures from the first thoughts in section 3.2.1. The criterion of where it is applied helps to integrate it in the diverse structure of ITS architectures. The aspects of being in use and location of implementation support considerations on both the temporal and spatial applicability.
The results of this analysis finally are consolidated, so that a conclusion is possible on how to deal with the candidates when drafting the overall architecture and decide which requirements a candidate brings in need to be considered (and where).

3.2.3.2.4. Step 4 – Derive levels and layers from existing ITS and C-ITS architectures

Finally, a consolidated view on the **levels** and **layers** used in existing ITS and C-ITS architectures can be derived. Later this is taken into account when combining the results of the Top Down and Bottom Up Approach.

3.2.4. Practical application of theoretical considerations

The practical application of the approach defined in the previous section leads to the frame structure for the overall architecture. Therefore, the steps identified in the previous section are successively executed incorporating the selection criteria identified in the theoretical part (3.2.3). The practical application of the previously defined approach in this section concludes the part 1 of the approach discussed in this document.

3.2.4.1. Top Down Approach

The steps already described and detailed in section 3.2.3.1 are applied in the following subsections.

3.2.4.1.1. Step 1 – Identify theoretical architecture models

The following theoretical architecture models were selected as potential candidates because they

- define themselves to be enterprise architecture models
- are frequently applied and used in different fields
- are self-contained models and not the customization or deduction of other architecture models

NOTE: Popular models that are expected to be considered but actually do not fulfill the basic criteria above are included in the list for completeness. Reasons for excluding them can be found in the short subsumption at the end of the selection in section 3.2.4.1.2. A short description including references on where to find more information on the individual enterprise architecture frameworks can be found in chapter 2.

The list of candidates basically can be split up into two different categories. One part consists of best-practice and de-facto standard models, the other of actually standardized architecture frameworks.

Popular models of the first category, the best-practice and de-facto standard models for enterprise architectures [Bente et al., 2012], are

- Zachman Framework [Zachman, 1987]
- TOGAF [The Open Group, 2011b]
- Gartner [Bente et al., 2012, page 118]

They are widely applied across various industries and for different scopes. Details are available in section 2.1.4.
The models address different aspects of an enterprise architecture, Zachman Framework provides a structure and frame for the various elements of an architecture, TOGAF not only provides a structure but as well a method to develop the different elements of an architecture. Gartner is developed by several established consulting companies and consolidates a number of best practices for enterprise architectures.

Architecture models were not only developed by expert groups. Standardization bodies provide as well guidelines to describe the architecture of a system. This includes standards that generally describe the architecture for whole systems (e.g. ODP-RM [ISO 10746-1, 1998], ISO 42010 [2007]) as well as only specific parts ([ETSI 302 665, 2010] – Communication Architecture, [ISO 21217, 2009] – CALM Standards). For the analysis in this part only those that address the system in its full complexity are considered. Standards addressing only distinct parts or viewpoints are considered in the description of the specific viewpoint in section 3.3.
The following standards are incorporated here

- ISO 42010 [2007] Systems and software engineering – Architecture description: the core architecture standard developed by ISO providing general guidelines for the development of architectures (equivalent is IEEE 1471 [2000])
- ISO 10746 [1998] Information technology – Open Distributed Processing – Reference Model: Architecture: Core architecture standard for distributed systems
- ISO 14813 [2006] Intelligent transport systems – Reference model architecture(s) for the ITS sector: architecture standard specific for ITS

Additionally, architecture standards for specific domains exist or are under development. They are not included in this analysis.

So far not listed but from some experts considered as THE enterprise architecture framework for C-ITS is FRAME. FRAME considers itself to provide the European ITS framework architecture. Therefore, the following steps of the approach shall include and evaluate this architecture description.

3.2.4.1.2. Step 2 – Selection process I

Evaluating the strengths and weaknesses of the candidates identified in the previous step with the criteria developed in the theoretical procedure (3.2.3.1.2) results in Table A.1. Based on this evaluation the following candidates will not be considered in the next step:
Zachman Framework is excluded in this step because it does not really provide an approach to develop an architecture structure or individual viewpoints but only a grid in which one can sort the architecture elements that are already there. Additionally, Zachman Framework allows to identify the still missing parts of an architecture but it does not give any advice or procedure on how to develop the missing links. To cover these aspects, it is necessary to return to other approaches that offer these procedures. Therefore, the

Zachman Framework rather serves as complement to other architecture methodologies. It is excluded in this step but still should be considered in the more specific description of the architecture in section 3.3 as its strengths certainly lie in the mature and practically approved generic structure.
Gartner Framework is excluded in this step. Although Gartner is rather famous and frequently mentioned in the context of enterprise architecture it is not a methodology of its own but rather stands for guided implementations of customized existing architecture frameworks.
ISO 42010 is excluded in this step. The standard provides an abstract description of aspects that need to be considered when designing an architecture including a conceptual model of an architectural description. The conceptual model depicted in Figure 3.4 is extensive and provides important structural aspects for an architecture. Therefore, the meta-model from ISO 42010 will be considered in the more specific description of the architecture in section 3.3.
Regarding the procedure to develop an architecture, the standard only gives a brief list of steps that need to be taken when designing an architecture according to the framework described in the standard. ISO 42010 is very generic and leaves most of the aspects to the user and does not give any advices and procedures. In combination with a more detailed guidebook ISO 42010 might be a valuable source. In this context it is seen as the source of basic principles that need to be followed when developing an architecture – though it is not capable of supporting the design process.
ISO 14813 is excluded in this step. The standard provides a valuable description of different viewpoints but like ISO 42010 lacks a detailed description of a methodology how to apply the standard to develop an architecture. Nevertheless, the standard shall be considered in later steps as the aspects on viewpoints might serve as input to design a complete list of viewpoints in the modification phase of the finally selected model.

3.2.4.1.3. Step 3 – Selection process II

Evaluating the strengths and weaknesses of the candidates remaining from the previous step with the second set of criteria developed in the theoretical procedure (3.2.3.1.3) leads to the results summarized in Table A.2.
FRAME is excluded in this step because it does not ensure that different versions or implementations of the architecture model are interoperable. FRAME allows to modify its structure to the regional users needs. Unfortunately, the changes made to the structure for this modifications lead to the loss of compatibility of the different framework instances. One key aspect of C-ITS will be that there will be a growing number of various individual implementations before a single architecture might be mandated for all implementations. Though interoperability between different implementations is required as especially the mobile ITS Stations in the C-ITS context get in touch with different regional implementations.
For Germany the FGSV analyzed the possibility to develop the national German ITS architecture based on the structures propose by FRAME [FGSV AA 3.1.4, 2012]. They mainly criticized that FRAME only uses an implicit business process and that its details are not transparent to the user, that the functions in FRAME are not completely designed in a modular way so that they only can be reused partially, that FRAME already provides a

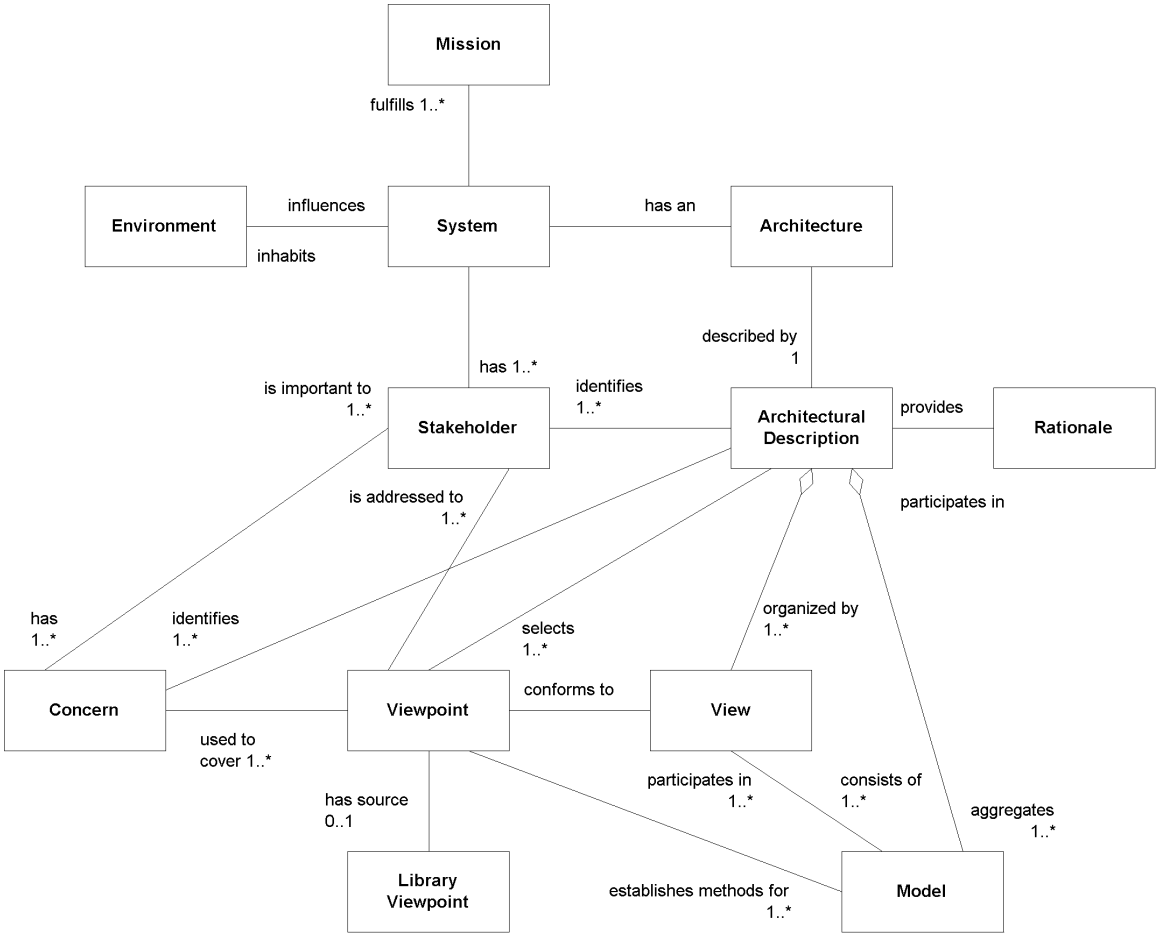

Figure 3.4.: ISO 42010 Conceptual Model of architectural description [2007]

fixed assignment of modules to technical subsystems what leads to a loss of flexibility and that the data model and data structures do not conform to the current state of the art.
Although FRAME is excluded in this step for the reasons described above its general concept shall be considered in the description of the overall architecture. FRAME with its first attempts on creating an architecture model with modular structures from which the real systems can be constructed like out of a toolbox is a rather crucial aspect that will be picked up (in 3.2.6 and section 4.1) and refined (in section 5.1).
ISO 10746 is excluded in this step because the architecture model does not include different levels of abstraction which will be needed in this context. Though ISO 10746 provides very valuable input for the description of viewpoints, these aspects shall be included in the subsequent discussions (3.3) although ISO 10746 is not selected here.

TOGAF finally is selected as core methodology for designing the framework for a C-ITS architecture methodology. Though TOGAF was not explicitly applied to C-ITS so far the selection process carved out several reasons for selecting TOGAF amongst which are the ap-

plicability to distributed systems (without a specific focus on the characteristics of C-ITS) and the interoperability of different realizations of the TOGAF methodology.
Like previously stated valuable aspects from other analyzed methodologies – partially not addressed in the selected methodology (TOGAF) – will be incorporated when designing the C-ITS architecture methodology.

3.2.4.1.4. Step 4 – Derive levels and layers from selected architecture models and denominate missing parts based on C-ITS selection process

The selected candidate provides valuable contributions to the definition of the different architecture levels and layers. TOGAF (9.1) [The Open Group, 2011b] defined a so called Enterprise Continuum that allows to classify architectures and artifacts into categories ranging from generic 'Foundation Architectures' to organization-specific Architectures.
The Enterprise Continuum provides a multi-dimensional structure which is depicted in Figure 3.5.

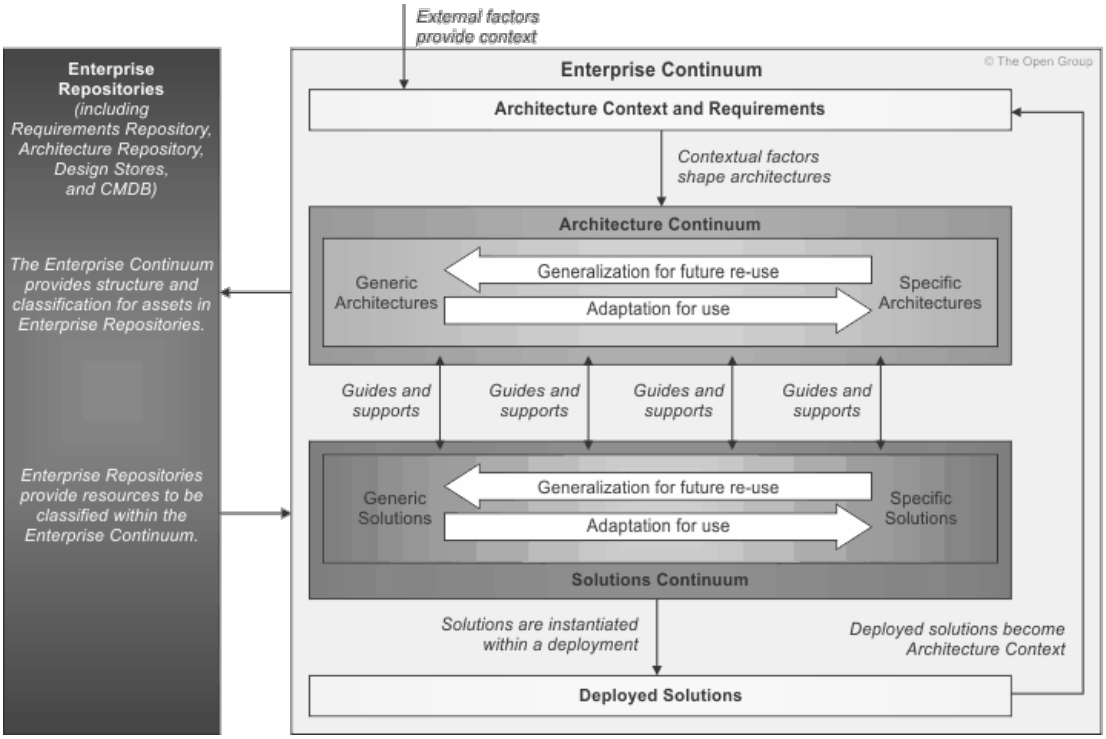

Figure 3.5.: TOGAF 9.1 Enterprise Continuum [The Open Group, 2011b]

The Enterprise Continuum in TOGAF consists of three levels: The **Enterprise Continuum** itself, the **Architecture Continuum**, and the **Solution Continuum**. The Enterprise Continuum consists of contextual assets used to develop architectures, such as policies, standards, strategic initiatives, organizational structures, and enterprise-level capabilities. That is, the Enterprise Continuum describes the high-level aspects of the addressed architecture. The Architecture Continuum consists of architectures, architectural building blocks, and architectural models, that are relevant to the task of constructing an organization-specific

architecture. The Solution Continuum provides a consistent way to describe and understand the implementation of the assets defined in the Architecture Continuum.

Aligning this structure provided by the TOGAF Enterprise Continuum with the initial assumption on the architecture structure described in section 3.2.1 shows a clear accordance. The TOGAF methodology provides different abstraction levels for the description of the architecture – the different levels are well in line with the ones originally assumed in section 3.2.1. Other candidates from the previous selection process do not explicitly address different architecture levels and therefore cannot contribute to this aspect. Partially, the abstract description (e.g. the standard itself or the description of the methodology) and its actual adaptation to a specific situation can be considered as different architecture levels.

Besides the different levels covered by the Enterprise Continuum TOGAF addresses four different 'architecture domains':

- Business Architecture – defines the business strategy, governance, organization, and key business processes
- Data Architecture – describes the structure of an organization's logical and physical data assets and data management resources
- Application Architecture – provides a blueprint for the individual applications to be deployed, their interactions, and their relationships to the core business processes of the organization
- Technology Architecture – describes the logical software and hardware capabilities that are required to support the deployment of business, data, and application services. This includes IT infrastructure, middleware, networks, communications, processing, standards, etc.

Those so called architecture domains correspond to viewpoints in other architecture descriptions. Matching these with viewpoints – e.g. from ISO 10746 or FRAME – illustrates that, though different terms are used and the cut varies, in general the same aspects are addressed. This is in line with the definition in ISO 24010 that allows for an architecture specific number of viewpoints. In general, the architectures consist of a strategic, high-level, **organizational** viewpoint (e.g. Business in TOGAF, Enterprise in ODP), a **functional** oriented viewpoint (e.g. Application Architecture and Data in TOGAF, Functional Viewpoint in FRAME) and a rather **technical** viewpoint (e.g. Technology Viewpoint in FRAME, ODP and TOGAF).

Specific C-ITS aspects are not covered yet and need to be developed specifically for the C-ITS architecture methodology based on C-ITS requirements. The selected framework provides the toolbox to customize existing artifacts to the respective needs.

3.2.4.2. Bottom Up Approach

The steps identified in section 3.2.3.2 are applied in the following subsections.

3.2.4.2.1. Step 1 – Existing definitions for levels and layers

There exist already definitions for structuring ITS architectures. Partially, these are new, independent definitions, partially the descriptions summarize existing definitions.
Already in 2007 Busch, Keller, Riegelhuth and Schnittger published a paper [Busch et al., 2007] in which they discussed the need for a national ITS architecture for Germany. As key success factors for sustainable ITS systems they identified the need for architectures on different levels – Framework Architecture, Reference Architecture and System Architecture as well as a national overall concept are mentioned as required core elements. The authors define **Framework Architecture** as a *strategic guideline that encloses organizational, legal, operational and technical elements*.
Reference Architecture includes *general organizational agreements, generic interface definitions and abstract component descriptions and describes an architecture for generic services*. Therefore, it usually *serves as a blueprint for the more concrete implementation of such a generic service*.
System Architecture is defined by the authors as *precise description of functional relationships between different components*.
Additionally the authors identified the need for a so called **national ITS vision** that describes the political strategies and corresponding tasks using telematic systems.
The paper already names the aspects **organizational**, **functional** and **technical** as eminent elements of a framework architecture. A detailed description of those terms is not given in the paper.

The definitions from the previously mentioned paper were picked up by Dr. Philip Krüger when analyzing the ITS architecture situation in Germany, Europe and worldwide in detail [Krüger et al., 2013]. He further developed the existing definitions and added definitions that he needed to fully cover the scope of his work.
National ITS Vision (Nationales IVS Leitbild): *The National ITS Vision represents a high-level, long-term oriented and political strategy for the use of ITS. It should be a commitment for ITS which encompasses the aspirations of all stakeholders including the users. It also illustrates the aims as well as the expected benefits of using ITS. Furthermore, the National ITS Vision will be substantiated in a framework plan which comprises specifications regarding roles, responsibilities, as well as general specifications for measures and a timeline for the implementation.*
Framework Architecture (IVS Rahmenarchitektur): *The Framework Architecture is based on the national ITS Vision as well as on the framework plan. It is more concrete than the ITS Vision but still technology-independent. The Framework Architecture contains functional (equivalent: logical), physical, and organizational aspects, which aims to ensure interoperability on the level of the Reference Architecture, but also has to provide flexibility for the detailed implementation of ITS in specific projects.*
Overall Architecture (IVS Gesamtarchitektur): *When defining a Framework Architecture on the level of operators or local authorities the term Overall Architecture is used which correspondingly comprises the content of the Framework Architecture.*
Reference Architecture (IVS Referenzarchitektur): *The Reference Architecture specifies the Framework Architecture for one ITS-related function, e. g. traffic signal control systems, and the Reference Architecture is used as a blueprint for implementing this function. The Reference Architecture comprises all specifications and, if necessary, also standards to ensure integrated ITS implementations.*

System Architecture (IVS Systemarchitektur): *When defining a Reference Architecture on the level of operators or local authorities, the term System Architecture is used which correspondingly comprises the content of the Reference Architecture.*
In the description of the individual national ITS architecture activities Dr. Philip Krüger makes as well use of the partitioning of individual architecture levels into **organizational**, **functional** and **technical**. Definitions and delineation of those layers against each other are not given in his document.

Definitions for different architecture levels are as well provided in the German FGSV guidelines on the development of an ITS architecture for Germany [Busch et al., 2004].

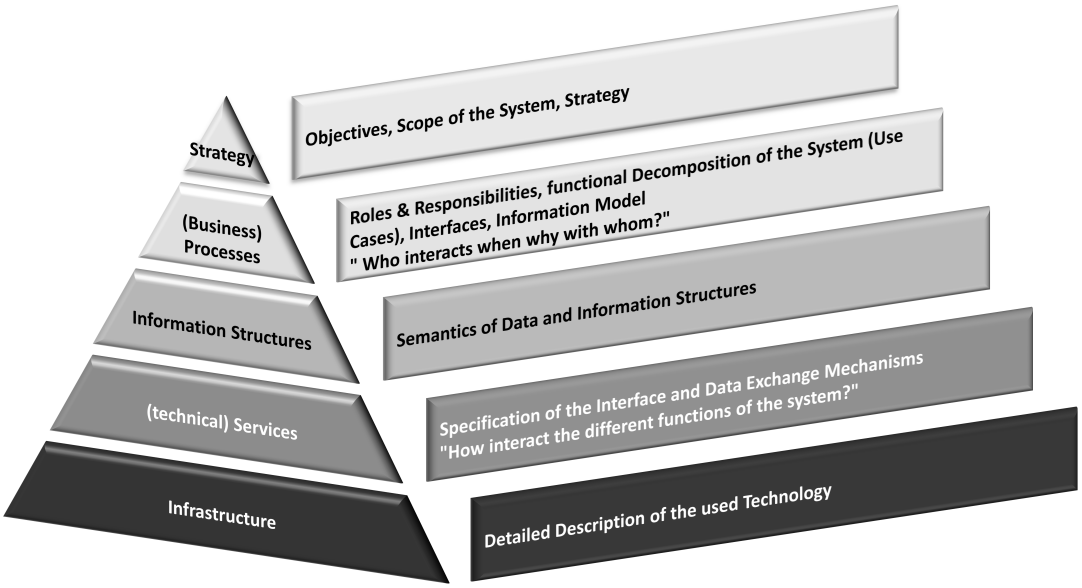

Figure 3.6.: ITS Pyramid from FGSV Paper: Developing an ITS Architecture for Germany [FGSV AA 3.1.4, 2012]

Framework Architecture provides the implementation framework for the realization of strategies and objectives of ITS as a whole.
Reference Architecture concretizes the Framework Architecture for a specific domain.
System Architecture (in the paper: **architecture of a real system**) describes the actual implementation on the last concretion level. The descriptions of the previous concretion levels (Framework Architecture and Reference Architecture) are adapted to the respective implementation situation.
Viewpoints are addressed in the pyramid description and reappear on every architecture level. The pyramid consists of the viewpoints **strategy**, (business) **processes**, **information structures**, (technical) **services** and **infrastructure** (details see Figure 3.6).

Definitions for ITS from a standardization viewpoint are given in ISO 14813-5 [2006]. The standard does not distinguish between different architecture levels and therefore only de-

fined the **ITS architecture** as *non specified system design for a family of functionally different ITS systems, interconnected to operate in consort, it is the non specified system design for a family of functionally different systems, interconnected to operate in harmony*.
Additionally, the document provides a list of viewpoints which are defined as follows:
Organizational (architecture): *description which identifies how the organization(s)-specific requirements will be met*.
Functional (architecture): *aspect of a 'logical','process oriented' decomposition of an overall ITS architecture the functional architecture provides an arrangement of functions and their sub-functions and interfaces (internal and external) that defines the execution sequencing, conditions for control or data flow, and the performance requirements to satisfy the requirements baseline*.
Additionally, the following viewpoints and sub-architectures are mentioned:
Conceptual architecture: *high level abstract architecture that defines overall principles and objectives of a system or entity which provides an overall description of a system incorporating operational concepts and user requirements, together with its known inter-relationships with other systems*
Logical architecture: *shall describe the nature of the system based on the information, control or functions and it describes the interrelations of these aspects; the logical architecture is independent of any hardware focus or software*
Physical (application) architecture: *allocation of the logical architecture to physical entities but not relating to the deployment of equipment*.
Communications architecture: *description of the media and medium standards and protocols used to support and communicate through the system*

3.2.4.2.2. Step 2 – Candidates of existing ITS and if available C-ITS architectures

Focusing on ITS in Germany and Europe a large number of already existing architectures can be considered. A detailed analysis of the situation was done in the BASt report 'Internationale und nationale Ansätze für Telematik-Leitbilder und ITS-Architekturen im Straßenverkehr' [Boltze and Krüger, 2011]. In the report the authors present a detailed overview of the current telematic landscape and ITS architectures in Germany and Europe and analyzed a large number of (legacy) ITS architectures in detail.
The work done within this BASt project is the basis for this part of the approach, the identification and selection of suitable candidate architectures. The descriptions of the BASt report were updated recently by Dr. Philip Krüger [2013].
Focus of both reports were architectures of existing ITS implementations in Germany, so called legacy ITS. Legacy ITS is defined as systems that are already implemented today using existing ITS architectures. The reports' list includes the following candidates from the field of transportation and traffic:

- Leaflet for the furnishing of traffic control centers and sub-centers, Merkblatt für die Ausstattung von Verkehrsrechnerzentralen und Unterzentralen (MARZ)
- Technical Terms of Delivery for Road Stations, Technische Lieferbedingungen für Streckenstationen (TLS)
- Association of users of the uniform central computer software for traffic management systems, Verein der Nutzer der einheitlichen Rechnerzentralensoftware für

Verkehrsleitsysteme (NERZ)

- Mobility Data Marketplace, Mobilitätsdatenmarktplatz (MDM)
- Architecture for public transport from Association of German Transport Companies, Verband Deutscher Verkehrsunternehmen (VDV)-Kernapplikation
- Continuous electronic timetable information, Durchgängige ELektronische FahrplanInformation (DELFI)
- Open Communication Interface for road Traffic control systems (OCIT)
- Open Traffic System (OTS)
- Framework directive for the traffic information service, Rahmenrichtlinie für den Verkehrswarndienst (RVWD)

A short description of the listed systems including references to additional information and links can be found in the PhD of Dr. Philip Krüger [2013].
The architectures from the list above will be considered as candidates for the Bottom Up Approach.

The currently ongoing work on a national German Framework Architecture is addressing a slightly different abstraction level. Experts were invited to discuss the topic and first attempts were undertaken to define the scope of such a Framework Architecture. One core requirement will be that the developed Framework Architecture will incorporate already existing Reference Architectures (e.g. those listed above: MARZ, TLS, others). The results of this expert group is of high relevance for this work – but as the work just started shortly results cannot yet be included here.

Apart from existing ITS architectures and the activities on a national German Framework Architecture another field that needs to be considered in terms of existing architectures is C-ITS. C-ITS currently is under development, therefore no deployed systems and their architectures are available so far. Though, various projects developed prototype-like systems with corresponding architectures. Various research projects are funded by the government (national or on EU level) to support the development of new technologies for the market. Often, such projects form the basis for future implementations, the concepts and structures are tested extensively in the project, experience is gained and the consolidated results are (partially) transferred into standardization and future implementations. One good example is the core result of the COMeSafety project: the project developed the C-ITS Communication architecture which is standardized in ETSI EN 302 665 and was implemented in many other research projects.
Focus of this document is C-ITS, therefore at least major architecture results from the following C-ITS projects will be included in the analysis:

- simTD
- Safespot
- CVIS

- COOPERS
- DRIVEC2X
- COMESafety2
- FRAME

A short description of the projects and their scope can be found in sections 2.2.6.3 and 2.2.6.4.

3.2.4.2.3. Step 3 – Analyze candidates

All of the candidates from section 3.2.4.2.2 – both from ITS and C-ITS – were analyzed based on a set of questions (partially adopted from Boltze and Krüger [2011]):

- what level is addressed (Framework Architecture, Reference Architecture, System Architecture)
- what layers are addressed (Organizational, Functional, Technical or others)
- details beyond organizational, functional, technical (more specific)
- where is it applied (reference implementation, real-life example)
- special requirements that need to be considered in the overall architecture

For the application of the questions on the ITS architectures listed in section 3.2.4.2.2 the existing architecture analysis [Boltze and Krüger, 2011; Krüger et al., 2013] was considered. Results are gathered in Tables B.1 to B.4. The analysis of the ITS architectures is kept rather brief as details for the individual architecture candidates can be extracted from the BASt report [Boltze and Krüger, 2011] and its update [Krüger et al., 2013]. Tables B.1 and B.2 only summarize these reports and emphasize certain aspects.
Tables B.3 and B.4 for the C-ITS architecture are slightly more detailed and are complemented by Appendix B.2, where additional information can be found that is the basis for the results in Tables B.3 and B.4 as the ITS analysis in the BASt report and its continuation did not cover C-ITS architectures.

Evaluating the results in Tables B.1 to B.4 leads to the following core conclusions:

- Currently, there are almost no framework architectures available.
- The analyzed architectures (both for ITS and C-ITS) are mainly from the level of the Reference or System Architecture.
- Most of the architectures already give a description of different viewpoints, the focus of most descriptions is on the functional viewpoint.
- Rarely any architecture really describes the organizational viewpoint in detail.
- Descriptions of the organizational viewpoint only vaguely describe possible actors involved but give no full picture of all stakeholders involved in the operation of a specific system

- There is a strong focus on communication aspects and architectures.
- Rarely any architecture description gives a clear description which levels and layers are addressed.
- Often, different levels are covered within one architecture description (especially Reference Architecture and System Architecture)
- Often different layers / viewpoints are covered within one description (especially functional and technical)

Summarized altogether the existing architectures might provide valuable contributions to the descriptions of the frame structure of the overall C-ITS architecture but there are as well some gaps which are not yet filled by them.

3.2.4.2.4. Step 4 – Derive frame structure

The analysis of existing definitions showed that different papers already deal with definitions of the level and viewpoint aspects – they developed similar definitions for Framework Architecture, Reference Architecture, System Architecture, and the core viewpoints organizational, functional and technical. This is complemented by the results of the analysis of existing architectures. The analyzed architectures cover not all levels and layers but in general reflect the originally proposed architecture structure and therefore might provide valuable contributions to selected topics in the subsequent chapters.

Based on the previous analysis of existing definitions, real world ITS and C-ITS project architectures the following levels and viewpoints can be derived as a result of the Bottom Up Approach:
The **level** structure in the definitions is addressed through three different units: the Framework Architecture, Reference Architecture and System Architecture. Those terms are not used in a consistent way in the different architectures and often are not even defined. Therefore, architectures describing implementations are of no avail for deriving a definition for the different levels. The definition for the levels based on a merge of the paper definitions in section 3.2.4.2.1 is
Framework Architecture: Strategic guideline that addresses organizational, legal, operational, functional and technical aspects. It ensures interoperability on the level of the Reference Architectures and at the same time enables flexibility for the implementation of ITS. The Framework Architecture is completely technology independent.
Reference Architecture: Generic description of organizational agreements, interfaces and components for a specific domain. It usually serves as a blueprint for more concrete implementations of the services in the specific domain. The Reference Architecture comprises all specifications and standards needed to ensure interoperability between instantiations of this Reference Architecture's implementations.
System Architecture: Architecture of the actual implementation that includes precise descriptions of functional relationships between different components.

The **layer / viewpoints** structure is subject to a similar issue like the level structure. The

analyzed architecture definitions do not provide definitions and the actual descriptions rather mix the different viewpoints. Therefore – like for the levels – the available definitions (3.2.4.2.1) are merged and aligned with the descriptions of the project and implementation architectures.
Organizational: Roles, responsibilities and relationships within the system. The organizational viewpoint might include more high-level aspects like strategies, goals and objectives.
Functional: Functional decomposition of the system, services implemented, including the underlying processes, interfaces, information structure, data model
Technical: Choice of technology in the system.
The functional viewpoint actually covers a large number of different aspects. This can be seen e.g. in the FGSV definition (see Figure 3.6). This level of detail is not reflected in these general definitions as usually the architectures consider the general term 'functional' to subsume the different aspects.

3.2.5. Summary of results from approach part 1

Goal of this first part of the approach (described in the introduction to section 3.2) was to develop a frame structure for the architecture (see Figure 3.1 – light grey box). Therefore, two different approaches were applied – one starting from theoretical architecture methods and descriptions (Top Down Approach), the other starting from projects and practical real-world implementations (Bottom Up approach). Already before starting both approaches a hypothesis on the structuring concepts of an architecture was formulated that included levels and layers / viewpoints. Both approaches were applied to validate – and where necessary complete – these assumptions. The results along the original hypothesis are summarized in the following paragraphs.

3.2.5.1. Level – Framework Architecture

The Framework Architecture describes the most abstract level. It consists of policies and strategic guidelines which address organizational, legal, operational, functional and technical aspects. It is completely technology agnostic.
NOTE: Comparable to the Enterprise Continuum in TOGAF

3.2.5.2. Level – Reference Architecture

The Reference Architecture provides a generic blueprint for domain specific implementations. It comprises all specifications and standards which are required for interoperable instances.
NOTE: Comparable to the Architecture Continuum in TOGAF

3.2.5.3. Level – System Architecture

The System Architecture describes the actual implementation.
NOTE: Comparable to the Solution Continuum in TOGAF

3.2.5.4. Cross references between levels

The Bottom Up Approach identified links between the different individual levels. The **Framework Architecture** is closely linked with the **Reference Architecture**. The Reference Architecture realizes and details the requirements set by the policies and strategic guidelines of the Framework Architecture. Interoperability between different Reference Architectures is enabled by the Framework Architecture.
The **Reference Architecture** is closely linked with the **System Architecture**. The Reference Architecture provides options (similar to a toolbox) for different System Architectures, the standards and specifications named in the Reference Architecture ensure the interoperability on this level.

3.2.5.5. Viewpoint – Organizational

The organizational viewpoint is from the abstraction level on the top position. It may include the description of strategies, goals and objectives, as well as the definition of roles and responsibilities.

3.2.5.6. Viewpoint – Functional

The functional viewpoint deals with various aspects of the functional decomposition of the system and depending on system specific requirements might be sub-divided into several viewpoints. It may describe business processes and use cases, the corresponding information structure and data model as well as required interfaces including communication aspects and protocols.

3.2.5.7. Viewpoint – Technical

The technical viewpoint is from the abstraction level on the lowest position. It describes the choice of technology in the system i.e. the hard- and software architecture.

3.2.5.8. Cross references between viewpoints

The individual layers (viewpoints) described in the previous chapters shall not be viewed isolated. Although each viewpoint provides a complete description of the system from this specific viewpoint perspective there is a strong link between the individual viewpoints. Design decisions in one viewpoint have implications on the design of other viewpoints. The link between the different viewpoints is depicted in Figure 3.7.
The **organizational viewpoint** describes strategies, goals and objectives which are reflected in the other viewpoints. More precisely, the organizational viewpoint includes the description of the organizational architecture consisting of a set of roles and responsibilities. Not only is for each role a set of responsibilities identified, the responsibilities are all linked to specific actions. Those in turn represent elements of a business process or use case – which are part of the functional viewpoint.
The **functional viewpoint** describes the business processes and use cases – which comprise individual elements, the previously mentioned actions. Those elements are linked through interfaces, which are described by a corresponding architecture, including communication

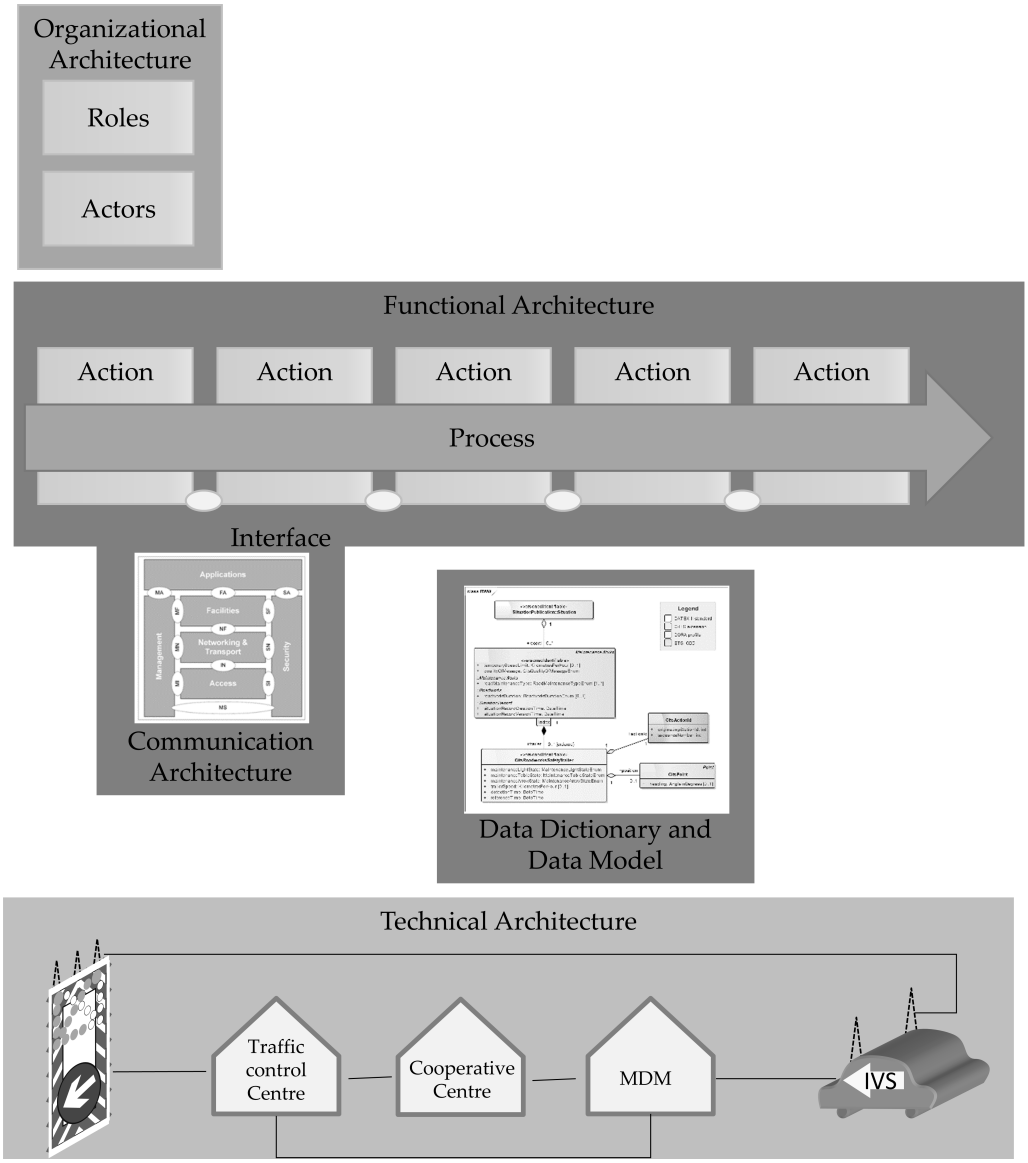

Figure 3.7.: Link between different viewpoints in architecture

aspects and protocols. In turn those are realized based on information structures and data models. The design of these aspects has implications on the technical implementation – what is in the scope of the technical viewpoint.
Finally, the **technical viewpoint** describes on which hardware element which software – realizing the functionalities previously described – is implemented.

3.2.6. Conclusion on generic structure for overall architecture

Besides the results already described in the previous chapter the Bottom Up Approach showed that the different viewpoints might be implemented on different levels i.e. that each viewpoint may be described on different levels of abstraction. For example, the organizational architecture may be described strategically and abstract (Framework Architecture), it may be defined generically, so that it may be applied in different domains or regions (Reference Architecture) and it may be very concrete including the denomination of actors that are involved in the implementation of a specific organizational architecture.
Merging this last finding with the already described structure of levels and viewpoints leads to the conclusion that for the frame structure of a C-ITS architecture a matrix structure best represents this actual situation (see Table 3.1).

		Layers		
		Organizational	**Functional**	**Technical**
Levels	**Framework Architecture**			
	Reference Architecture			
	System Architecture			

Table 3.1.: Resulting architecture structure based on results and conclusions of applied approach

The matrix structure allows to have in the same context both different levels of abstraction and different viewpoints. Additionally, it complies with the derived results that different abstraction levels may be reflected within a viewpoint.
In total it provides a powerful frame and scope for the overall architecture of C-ITS addressing all the relevant aspects.

The frame structure identified in this chapter and summarized in Table 3.1 coincides with available considerations and definitions on architecture structures e.g. from Busch et al. [2007]. Hence, the results of this chapter not only confirm other existing architectural structures but additionally provide a detailed analysis and description of their theoretical background.

The following paragraphs and therefore the next steps in the process will deal with filling the structure from Table 3.1. This will be done based on the methodology and approaches applied in this chapter.

3.3. Approach Part 2 – Blueprint description of elements within frame structure

The first part of the approach (see section 3.2) identified the scope and structure of the C-ITS architecture. Based on the same methodology like the one used to carve out the architecture structure itself now the frame structure will be filled with content. The specifications developed in this second part are still on a rather abstract level – the practical details will follow in the third part.
Before actually applying the Top Down and Bottom Up Approach to detail the different elements in the frame structure it needs to be decided whether all parts of the frame structure shall be detailed on an abstract level or only some of them. The decision will be based on the original definitions of the individual elements (see section 3.2.5) in combination with the objectives of part 2.
Hence, the following aspects are addressed in this part:

- evaluation which parts of the overall architecture shall be detailed on an abstract level
- application of Top Down and Bottom Up Approach on the selected parts to develop an extensive abstract description

Together with the aspects identified in sections 3.4 and 3.5 this will result in a blueprint like description that is used in chapter 4 to actually describe the overall architecture.

3.3.1. Selection of architecture elements for the generic description

The analysis in the previous chapter lead to a matrix like structure for the scope of the overall C-ITS architecture (see Table 3.1). It consists of three different levels (Framework Architecture, Reference Architecture and System Architecture) where each of the levels comprises three different viewpoints (organizational, functional and technical). Both the different levels and layers are linked with each other: The levels represent different degrees of abstraction and detailing starting with a very abstract description in the Framework Architecture to a detailed, implementation specific description in the System Architecture. The layers cover different viewpoints or perspectives of an architecture.
These results will later (in the third part) form the basis for the practical application. Examining closely the scope and definitions of the individual elements of levels and layers reveals that not all elements in the resulting matrix structure describing the overall C-ITS architecture are destined to be described on an abstract level. Therefore, those elements where such a description is appropriate are selected in this part.

First of all it is assumed that such a selection takes place on the levels and not the layers / viewpoints. The degree of abstraction within the matrix runs along the 'level' dimension – the viewpoints differ not in level of abstraction but perspectives addressed.
Therefore, focus and basis of the selection are the definitions of the different levels, the corresponding interpretation and the transfer to C-ITS.
The **Framework Architecture** describes the most abstract level and consists of policies and strategic guidelines which address different aspects and viewpoints. In general, it only

includes a rough description of what should be covered by the more detailed description in the Reference Architecture and System Architecture. Apart from that, the Framework Architecture is completely technology agnostic.
Applying this general description of Framework Architecture to C-ITS reveals that a C-ITS Framework Architecture itself would not be independent and self-contained compared to an ITS Framework Architecture. C-ITS is closely linked to ITS, basically can be seen as a specific subset of ITS bringing in new technology specific innovations and improvements. Accordingly, a close link between the Framework Architectures of ITS and C-ITS exists. It is assumed that no specific C-ITS Framework Architecture exists and the ITS Framework Architecture is taken as basis.
The ITS Framework Architecture for Germany currently is developed in the project team 'PG IVS Rahmenarchitektur' under the lead of BASt. The Framework Architecture itself is not further detailed in this document and can be obtained through BASt as soon as it is published.

The **Reference Architecture** provides a generic blueprint for domain specific system implementations (= System Architectures). It comprises all specifications and standards which are required for interoperable instances. Different domains may have different Reference Architectures, the Reference Architectures of multiple domains together provide a valuable pool of generic and abstract modules which might be reused, even domain spanning, in the corresponding architectures if they are sufficiently generic. Therefore, an abstract description of the individual viewpoints of the Reference Architecture, reflecting the domain specific characteristics, is needed.

The **System Architecture** describes in detail the actual implementation. It is derived from the Reference Architecture and is very context specific. Usually, only few instances of such an architecture exist, therefore no general description of the individual viewpoints on this level is required. Additionally, the System Architecture has a very close link to the (superordinate) Reference Architecture – abstractly describing the Reference Architecture therefore has strong implications on the corresponding System Architecture(s).

Hence, the following subsections will deepen on a Reference Architecture abstraction level the description of viewpoints from section 3.2.5. Therefore, the respective definitions are picked up and complemented by valuable aspects from the theoretical models that were discarded during the selection process (see section 3.2.4).

3.3.2. Approach to specify the individual viewpoints in detail

In the first part (section 3.2), a multi-stage selection process was applied to identify the different levels and layers. Various elements from the starting pool of theoretical and practical models were discarded by the methodology although they comprehended at least partially valuable aspects and concepts. Therefore, before actually detailing the three core viewpoints / layers in an architecture description, the first task is to consolidate the derived viewpoint specification from part 1 with specific aspects of the excluded models. Those combined with C-ITS specific requirements should lead to a complete but abstract description of the individual viewpoints of the overall C-ITS architecture.

Basis for the detailing of the identified viewpoints are the results from part 1 of the methodology, the organizational, functional and technical viewpoint. Thereupon built, the descriptions of the non-selected viewpoint aspects from other models are matched with those three viewpoints. This was done by comparing the generic description of the core viewpoints resulting out of part 1 (section 3.2.5) with the original viewpoint descriptions from the discarded architecture models and then assigning the discarded viewpoints to the most suitable core viewpoints. The result is depicted in Figure 3.8.

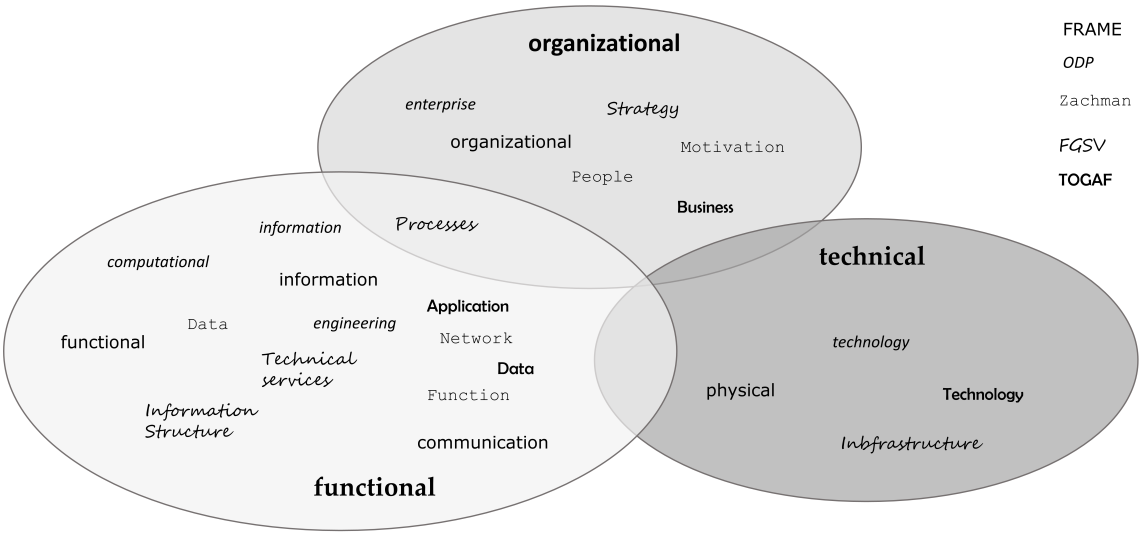

Figure 3.8.: Result of assigning previously excluded aspects on viewpoints / layers to the selected layers / viewpoints

The three core viewpoints identified in part 1 are each represented by a bubble (Figure 3.8). The previous analysis already showed that the three viewpoints cannot be clearly separated – this is illustrated with the overlapping bubbles. The viewpoints from the models discarded in part 1 are each assigned to one of the three core viewpoints and therefore written in the corresponding bubble. The different discarded models are illustrated with different fonts.
The mapping to the three core viewpoints shows that they in fact represent much more depth and complexity than expressed by the original single model based description. Partially, it was difficult to clearly assign a viewpoint to only one bubble – this is closely linked with the overlapping core viewpoints and their respective bubbles. Hence, some viewpoints are assigned to the overlapping area.

Summarizing the results depicted in Figure 3.8 the additional assignment of the discarded models leads to a more detailed paraphrase of the initial viewpoints: The organizational viewpoint may include – besides the description of **organizational** structures, roles and responsibilities – the description of the overall (business) strategy and policies, goals of the enterprise addressed in the architecture as well as the motivation for such an architecture.

Especially the **functional** viewpoint subsumes a comparatively large number of different aspects. There are – on a rather high level – the functions, applications, processes, and use case descriptions followed by information structures used for the semantic description of the system, information and data models. And last but not least the rather communication and network oriented aspects, including various interfaces. The scope of the **technical** viewpoint is complemented by infrastructure and physical aspects like the hardware in use mentioned in viewpoint descriptions of non-selected models.

This extended diagram of the three core viewpoints will serve as a solid basis in the following detailed theoretical analysis and completion of the viewpoint descriptions.
The subsequent chapters develop for each viewpoint based on the Top Down and Bottom Up Approach a more detailed viewpoint definition including a short guidance on how to actually specify the respective viewpoint in a Reference Architecture. In practice this guidance is applied for C-ITS in chapter 7 but it might as well be transferred to any other Reference Architecture.

3.3.2.1. Organizational Viewpoint

The organizational viewpoint is the top layer and most abstract description of a system. To detail this viewpoint the previously excluded methodologies (section 3.2.4) will be examined closely as they might provide additional and valuable input for a more precise description. Organizational aspects are deduced from those methodologies, both from the theoretical (Top Down Approach) as well as the practical (Bottom Up Approach) perspective.

3.3.2.1.1. Organizational Viewpoints – Top Down Approach

Valuable input for the Top Down Approach is provided by different theoretical architecture models. The **ODP** standard ISO 10746 [1998] calls the organizational viewpoint 'enterprise viewpoint', which does not only allow for a description of strategies and policies but as well the different roles, responsibilities and organizational cross references. ODP provides definitions for key aspects of an organizational architecture amongst others are the definition for roles, responsibilities and actors. Those definitions are used in this document (detailed definitions see chapter 2).
Besides those definitions ODP does only provide a very abstract concept of an organizational (enterprise) viewpoint which states the need for policies and rules, roles, their link to responsibilities as well as relationships between roles (e.g. through contracts). Example applications are given in the Annex of the standard. Another practical application of the ODP standard is the Electronic Fee Collection Architecture Standard ISO / CEN 17573 [2010]. The ODP standard itself does not name any roles. No methodology for the development of an organizational viewpoint is provided.

Rather problem oriented is the abstract description of roles in **ITIL (IT Infrastructure Library)** v3 [ITIL, n.d.]. ITIL is used in practice for IT service management in various businesses and provides guidelines, best practices and support for the deployment and operation phase. This includes business processes, organizational structures and tools.

One aspect described in ITIL is a set of roles, covering the whole value chain from developing a service strategy, service design, service transition, service operation to service improvement. The roles which are part of ITIL are arranged in the aforementioned groups [Kempter and Kempter, 2016]. In CEN/ISO 17427 [2013] the different roles of ITIL were analyzed with regard to C-ITS and a subset was selected for the organizational viewpoint described in the standard. Additionally, some roles were merged and restructured to better reflect the requirements of C-ITS. (For details see Appendix D.)

Although **TOGAF** was selected for the definition of the frame structure of the overall architecture and was the basis for including organizational aspects as a separate viewpoint, no detailed blueprint for an organizational viewpoint is included. Nevertheless, TOGAF provides as part of the model the so-called Architecture Development Method (ADM) [The Open Group, 2011b, Part II ADM] which provides a tested and repeatable process for developing architectures. The method bases on an iterative multi-phase cycle. By running through the various phases an architecture framework and architecture content is developed and defined. Each phase in the cycle consists of the same sequence of steps which are processed with focus on the topic addressed in the respective phase of the ADM cycle. In phase B of the ADM cycle the business architecture is developed. It starts with a so-called baseline description that should as much as possible depend on existing architecture descriptions for the considered system. Depending upon the available material either in a top down or bottom up process the business processes are identified. Therefore a structured analysis, a use case analysis and process modeling might be undertaken to describe the business abstractly in the corresponding models, structures and processes. Additionally, actors, roles, objectives, functions and other aspects of a business architecture are identified and analyzed. (A detailed description is available in the TOGAF book [The Open Group, 2011b, chapter 8].)

The German **FGSV** architecture is similar to the concepts described in TOGAF. Organizational aspects like policies, strategies, roles and responsibilities are covered in two different viewpoints: 'strategy' and '(business) processes'. The 'strategy' viewpoint describes the scope of the system, its objectives and strategy. The '(business) processes' comprise the roles and responsibilities. Additionally, the '(business) process' viewpoint describes the functional decomposition of the system, interfaces and the information model, this part of the viewpoint in fact overlaps with the functional viewpoint (see next section 3.3.2.2) and is not considered to be relevant for the organizational viewpoint.
Though various organizational aspects are covered in the two viewpoints no detailed explanation or approach to develop a description of those aspects is provided.

3.3.2.1.2. Organizational Viewpoints – Bottom Up Approach

In contrary, for the Bottom Up Approach the results of various C-ITS projects are considered. An organizational architecture was part of the work program of the **SafeSpot** Project. In fact, two deliverables with a preliminary and final organizational architecture [Manfredi et al., 2008, 2010] were developed.
The SafeSpot approach mainly bases on a methodology already applied in ARTIST, the national Italian ITS Reference Architecture [Isola, 2003]. ARTIST derives the organizational

architecture from the functionalities needed to develop and deploy the considered system – including deployment, procurement, legal framework and implementation aspects. The approach bases on an analysis of value chains of different services, functionalities are grouped to so-called macro-functionalities which are attributed to stakeholders as homogenous 'packages' [Manfredi et al., 2008]. SafeSpot identified through this process a set of roles (according to the SafeSpot definition of a 'role'[1]), their detailed description including the whole approach can be found in in D6.3.1 [Manfredi et al., 2008] and D6.3.2 [Manfredi et al., 2010]).
Additionally, organizational schemes for different scenarios and business models were developed by the project. Examples for generic and service specific organizational schemes are depicted in the final Safespot organizational architecture [Manfredi et al., 2010]. The generic process for the identification of roles developed in SafeSpot may be applied to other scenarios. Therefore, both the approach as well as the results (generic roles) shall be picked up in the description of the organizational viewpoint of the C-ITS Reference Architecture (see section 7.1.3).

The **FRAME** project did not develop an abstract organizational viewpoint but provides in its framework a large number of potential actors involved in ITS and C-ITS. A detailed description of all actors can be found in D15 part 6 [Bossom et al., 2011, Table 1], the visualization of the system and its involved actors is provided in the FRAME Browsing Tool [Frame, 2011].
The set of actors itself does not allow to derive any organizational structures including roles and responsibilities but it may be useful to check the results from applying the organizational viewpoint against FRAME. Therefore, this huge conglomeration shall come to use when the basic organizational structure (section 7.1) is developed and a validation is outstanding.

As can be seen from the overview in Tables B.3 and B.4 no other existing architecture from the Bottom Up Approach provides a detailed description of the organizational viewpoint that needs to be considered. The listed examples only slightly touch the underlying organizational structures.

The theoretical analysis of organizational architectures of existing projects and initiatives is complemented by a **Bottom Up analysis of selected service's processes**, the individual process steps and the corresponding actors. This complementing activity is deduced from the approach applied in Safespot and a detailed description can be found in Appendix D. It starts with the description of the underlying processes of a selected service. The detailed process description is used to identify different tasks and actions that arise during the operation of the selected services. In parallel, actors involved in the process and its steps are identified. Based on the assignment of actors, actions and tasks are grouped and bundled logically. On the other side possible structures for the different tasks and actions are derived from the task and action assignments of real implementations. Both results together are used to identify the maximum number of required interfaces within a process

[1] definition in D6.3.2 [Manfredi et al., 2010]: role is a set of homogeneous functionalities that need to be performed in order to realize the system

i.e. the maximum number of action or task bundles that might occur in the implementation of the selected service. This structure is the basis for the definition of roles – they now need to be named and described, responsibilities (deduced from the original tasks and actions) are assigned. The resulting roles and responsibilities can be matched with theoretical organizational structures to fine-tune the list of roles.
This analysis provides additional input for the detailing of the organizational viewpoint as it provides a potential structure of roles and responsibilities based on a specific service. (This procedure was developed as part of the Standard ISO 17427 [2013] that describes the organizational architecture for C-ITS.)

3.3.2.1.3. Results and Conclusion Organizational Viewpoint

The additional aspects from other architecture methodologies and projects which were not selected for the frame structure in section 3.2.4 finally provide a valuable contribution to a deepened and more precise definition of the organizational viewpoint. The non-selected theoretical methods help to focus the scope of this viewpoint's description. Additionally, a closer analysis of the results from the Bottom Up Approach projects, which were excluded in the previous step, showed that they will provide a valuable basis for the concluding validation and verification of the practical methodology application's results.

Finally, merging the results of this part with the definitions from the previous part leads to the following more precise definition of the **organizational viewpoint scope**: The organizational viewpoint describes the strategic goals and objectives as well as the rules and policies applicable in the system. In line with this business focused orientation the organizational viewpoint describes the roles and responsibilities for the system, comprising not only the individual roles but as well the link between the different roles. Methodologies like ODP additionally allow to focus the organizational viewpoint on C-ITS itself by clearly setting the system boundaries (for details see [ISO 17427, 2013]).

The theoretical methodologies from the Top Down Approach are only capable of providing the scope and boundary conditions for the viewpoint description. More practical guidance is provided from the Bottom Up Approach. In short, the following steps are taken to develop an organizational viewpoint:

1. The strategic goals, objectives, rules and policies are defined by the stakeholders and responsible persons from the strategic and political level

2. The roles and responsibilities are identified through the Bottom Up Approach and afterwards are cross checked with the results from various existing projects

A detailed description of the practical application of these steps can be found in section 7.1.

3.3.2.2. Functional Viewpoint

The functional viewpoint is rather multi-layered as it subsumes a large number of different aspects. Again, like for the organizational viewpoint, the previously excluded methodologies might provide valuable input for a more precise description of this viewpoint.

3.3.2.2.1. Functional Viewpoints – Top Down Approach

Several viewpoints from **ODP** [ISO 10746-1, 1998] can be subsumed under the term 'functional'. In detail the Information, Computational and Engineering Viewpoint provide aspects that fit into the functional description of a system.
Within the **Information Viewpoint** the semantics of information and information processing are described. It consists of a set of information objects, their relationships and behavior. The information viewpoint ensures that all components in a system share a common understanding of the information they communicate when they interact [ISO 10746-1, 1998] and that every component has the same interpretation of the item, no matter how the items are handled. The description of the information objects in the Information Viewpoint is independent of the way the information processing functions are implemented.
The **Computational Viewpoint** describes the functional decomposition that enables distribution of the system into objects which interact at interfaces. It is concerned with the distribution of processing. The computational viewpoint decomposes the system into objects performing individual functions and interacting at well defined interfaces [ISO 10746-1, 1998]. The viewpoint description provides various interface types which can be characterized by their signature, behavior and environmental contract. ('when and why do objects interact' [ISO 10746-1, 1998])
The **Engineering Viewpoint** describes functions and mechanisms required to support distributed interactions between objects in the system. It focuses on the way object interaction is achieved and on the resources needed to do so [ISO 10746-1, 1998]. Concepts for describing the infrastructure required to support the distribution are included, amongst others the required rules for structuring communication channels between objects. Summing this up, the Engineering Viewpoint provides a description of how the system's processing is distributed. ('how do objects interact' [ISO 10746-1, 1998])
According to the ODP standard the Information Viewpoint can be mapped to the Computational Viewpoint and the Computational Viewpoint can be mapped to the Engineering Viewpoint. A detailed example can be found in the standard [ISO 10746-1, 1998], additionally the UML4ODP standard [ISO 19793, 2008] provides a useful description of the mapping with a focus on how to model this in UML.

Similar like ODP the **FGSV** methodology provides several pyramid layers that can be subsumed under the functional viewpoint (complete picture of the pyramid see Figure 3.6). In the FGSV paper they are called (Business) Processes, Information Structure and (Technical) Services. The (business) process layer of the FGSV pyramid was already mentioned in the context of the organizational viewpoint as it is providing aspects that fit in both viewpoints. The rather functional aspects of the **(business) process layer** are the functional decomposition of the system into use cases, interfaces and the underlying information model. The **information structure layer** covers the semantics of data and the information structures. The **(technical) services layer** describes interfaces and data exchange mechanisms.
Like for the organizational viewpoint no detailed description or approach to develop a description of the functional aspects covered in parts of the (business) process, the information structure and (technical) services layer are available.

TOGAF, the original blueprint for the scope of the different viewpoints, originally provides aspects for the functional viewpoint, Applications and Data architecture view. The **Application architecture view** addresses the concerns of system and software engineers responsible for developing and integrating the various application software components of the system [The Open Group, 2011b, chapter 11] and is developed in the phase C of the ADM[2]. It is developed based on the business architecture view which corresponds to the organizational viewpoint in this document (see section 3.3.2.1). For the Application Viewpoint the applications (or services) of the system are analyzed. Therefore, a list of all services is developed, it is checked whether it is necessary to detail, merge or split up services and then an architecture is developed which relates the services to business services, business functions, data and processes. As next step different relations are identified in matrixes and diagrams are developed e.g. for communication or use cases. Like for the organizational viewpoint TOGAF does not provide any final blueprint but this approach.
The other TOGAF viewpoint that fits into the definition of 'functional' from the previous chapter is the **Data architecture viewpoint** [The Open Group, 2011b, chapter 10]. It addresses the concerns of database designers and administrators, and system engineers responsible for developing and integrating the various database components of the system. Like the Application architecture this viewpoint is developed in the ADM phase C and therefore follows the same steps – only the content developed within the steps is different and focuses on data models.

3.3.2.2.2. Functional Viewpoints – Bottom Up Approach

The functional viewpoint is frequently addressed in project architectures. Therefore, a huge basis exists for the Bottom Up part of the approach. Details will not be completely repeated here – only the common denominators and core aspects are quoted.

FRAME provides three viewpoints that actually provide functional descriptions of the system, the functional, information and communication viewpoint. In FRAME the **functional viewpoint** consist of functions (services) that create the ITS Application or Service [Jesty and Bossom, 2010]. The functional architecture [Bossom et al., 2009] is based on user needs which were derived from the stakeholder aspirations as a first step when modeling the FRAME architecture. The user needs are used to identify the required services whereas each individual service might be split up into further details for the description of the functional viewpoint. The FRAME Browsing Tool [Frame, 2011] provides a large set of both user needs and corresponding services, including their subdivision in smaller elements and details. The FRAME Browsing Tool comprises as well Cooperative Services which were developed in close cooperation with the projects CVIS, SafeSpot and Coopers. Unfortunately the selected services no longer match the currently discussed Day 1 Applications in C-ITS (see section 7.2.2).
Apart from the functions, data flows are part of the FRAME functional viewpoint, they link the individual functions with each other and with the actors. The FRAME Browsing Tool already provides a static mesh of data flows between FRAME specific functions. Rather technical is the **communication viewpoint** that comprises the requirements for communication between physical units in each location [Jesty and Bossom, 2010]. It describes the

[2] description of all eight phases of the ADM can be found in [The Open Group, 2011b,a]

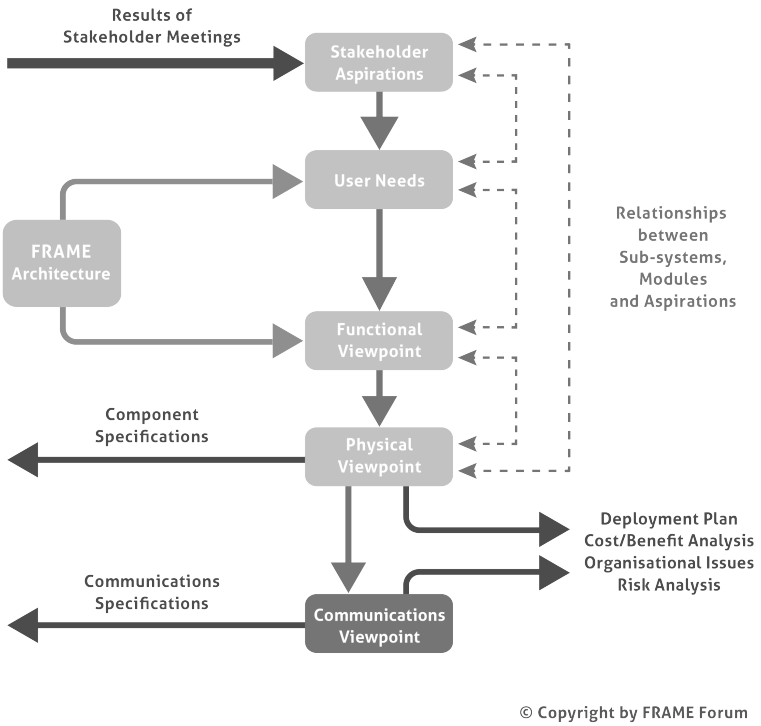

Figure 3.9.: FRAME architecture development process [Frame, n.d.b]

communication links needed to support the exchange of information between different parts of the system via physical data flows (which are described in the physical architecture). FRAME provides a detailed analysis for a selection of services in D3.2 [KAREN, 2000b]. The results of the analysis include a collection of requirements and characteristics of the physical communication channel for individual communication links. The document concludes with a short summary on existing data exchange standards.
There are links between the individual viewpoints similar to what was described for ODP and the FGSV pyramid. FRAME provides a specific architecture design process (Figure 3.9) that originally starts from user needs (not covered by a viewpoint of its own), then describes the functional viewpoint, from which the physical viewpoint is derived (see description of the Technical Viewpoint (3.3.2.3)) which in turn is the basis for the Communication Viewpoint.
One viewpoint that is only rarely mentioned in the context of FRAME is the **Information viewpoint**, it defines the information that is used, its attributes and relationships [Jesty and Bossom, 2010]. The Information Viewpoint is not included in the 'classical' FRAME process diagram for the development of an architecture (Figure 3.9) but was mentioned by the FRAME developers to be eminent for a complete architecture description [Jesty and Bossom, 2010].
Apart from the FRAME Browsing Tool, which provides demonstrative visualizations of the services and functions, their structure as well as the underlying data flows and physical structure, FRAME additionally developed the so called FRAME Selection Tool [Frame, 2012] which allows the user to feed the tool with its own requirements and tailor the FRAME structure specific to its own needs. If necessary it is as well possible to include new requirements, functions, data flows and information objects. Unfortunately the concept behind FRAME was not designed in a way that modified or extended versions of the basic FRAME architecture are still interoperable. Changes to the pre-set structure provided by the Selection Tool require modifications of the hard-coded architecture structure being the basis of the Selection Tool.

One core functional architecture description developed by the three C-ITS projects CVIS, Safespot, COOPERS in close cooperation with the experts working on FRAME and the COMeSafety project was standardized in ISO / CEN and ETSI: The **Communication Reference Architecture** for ITS ([ISO 21217, 2009] and [ETSI 302 665, 2010], both standards are consistent). The standardized Communication Reference Architecture is the basis for the description of communication in C-ITS, though the possible communication technologies are not solely C-ITS focused. Core element in the standard is the so-called ITS Station, a functional entity specified by the ITS Station Reference Architecture [ETSI 302 665, 2010, Definitions]. The standard describes for this ITS Station a communication stack with four horizontal and two vertical layers (see Figure 3.10). Its different elements can easily be mapped to the ISO OSI (Open System Interconnection) Stack [ISO / IEC 7498-1, 1996].
Each element in the ITS Station Reference Architecture can be described by various other standards. Some examples are given in the standard itself (see Figure 3.11)
The architecture structure from the standard was implemented in various C-ITS projects, elements from within the layers were developed, implemented, improved and standardized. A lot of this work was done under the umbrella of the standardization mandate M/453 ([European Commission - Enterprise and Industry Directorate General, 2009] han-

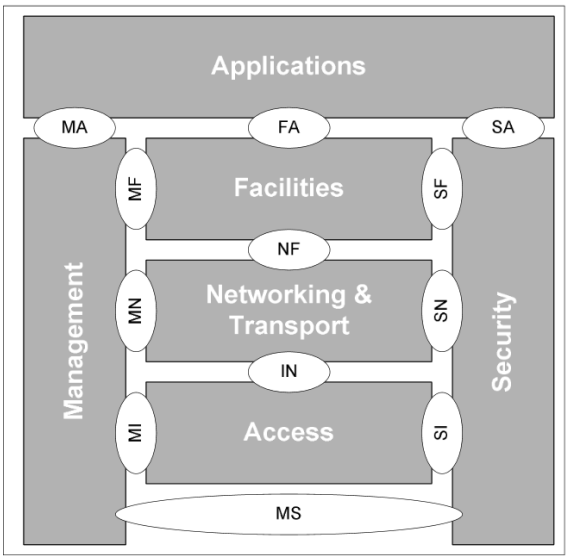

Figure 3.10.: ETSI EN 302 665 Communication Architecture – ITS Station Reference Architecture [ETSI 302 665, 2010]

dled by CEN and ETSI, details on results in the final report to the mandate from CEN and ETSI [CEN / ISO and ETSI, 2013]). Some very prominent examples are:

- Application layer: Basic Set of Applications [ETSI 102 637-1, 2010], various application standards
- Facilities layer: Cooperative Awareness Basic Service [ETSI 302 637-2, 2014], Decentralized Environmental Notification Basic Service [ETSI 302 637-3, 2014], Local Dynamic Map [ETSI 102 863, 2011], Common Data Dictionary [ETSI 102 894-2, 2013]
- Networking & Transport Layer: GeoNetworking Protocol series [ETSI 102 636-1, 2010], [ETSI 102 636-2, 2010]
- Access Layer: European Profile on ITS G5 [ETSI 202 663, 2009], CEN / ISO Dedicated Short Range Communication (DSCR) (e.g. [CEN 12834, 2003; CEN 12795, 2003; CEN 12253, 2004])
- Management Layer: Congestion Management [ETSI 102 687, 2011]
- Security Layer: Security Architecture [ETSI 102 940, 2012]

As can be seen from the examples above the ITS Station architecture provides a frame for many different aspects of an ITS architecture, therefore the standard has actually a rather prominent role in C-ITS. Though it is named Communication Reference Architecture the examples embedded in the frame (see list above) show that the scope of ETSI TS 302 665 is definitively broader than communication only: e.g. the application layer comprises standards that actually describe different services and applications (functions), the facility layer includes the data dictionary.

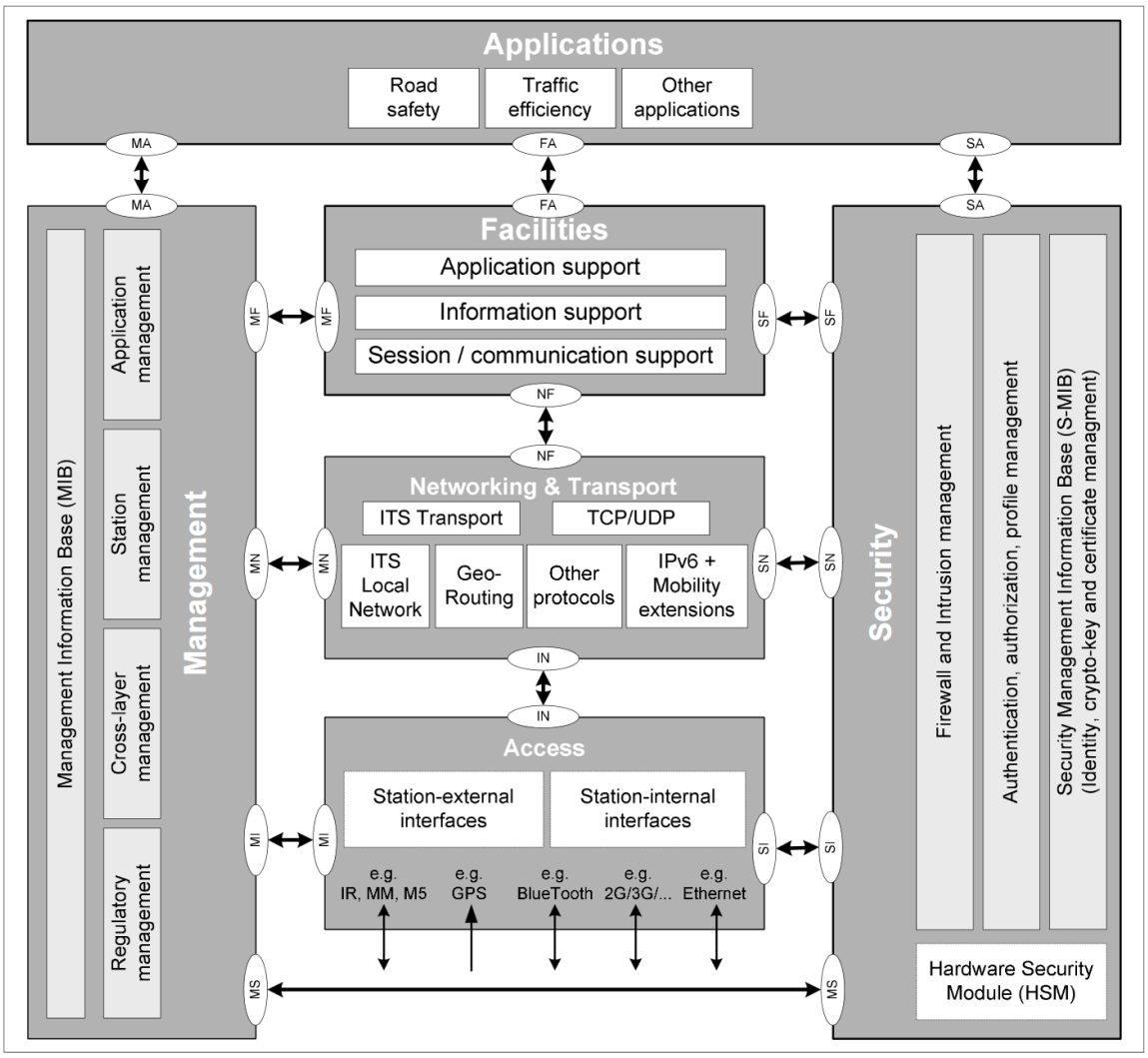

Figure 3.11.: Example elements of the ITS Station Reference Architecture [ETSI 302 665, 2010]

Besides the aspects discussed in the Communication Reference Architecture, another core element of the functional architecture that is used in different project architectures is the **Common Data Dictionary** for C-ITS [ETSI 102 894-2, 2013] specified by ETSI. The Common Data Dictionary (CDD) includes the data model for various C-ITS applications and therefore matches the principles of the TOGAF Data architecture or the ODP Information viewpoint. The CDD is basis for the standards which are part of the Communication Reference Architecture, e.g. the Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM) standards. Both are elements of the Facility layer and specify the corresponding C-ITS messages based on the CDD.

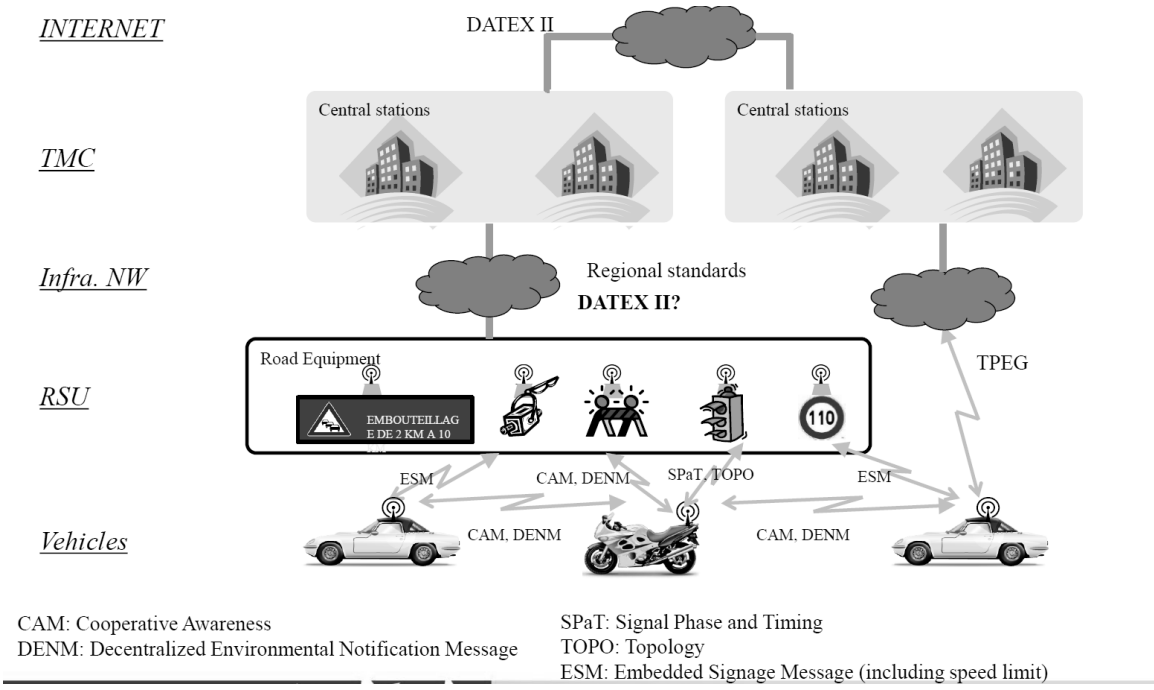

Figure 3.12.: Need for harmonization of data dictionaries [Lin, 2012]

Apart from the ETSI CDD other data dictionaries and data models do exist in ITS: DATEX (Data exchange specifications for traffic management and information) II [CEN 16157-4, 2014] is widely used by road operators for communication between traffic control centres. TPEG (Traffic and travel information via transport protocol experts group) (ISO 18234 [2013] and 21219 [2014] series) provides a data dictionary for traffic information services. Activities were started by the European EASYWAY project to harmonize the DATEX II and TPEG data dictionaries as both worlds are getting closer to each other. Interoperability was first demonstrated at the ITS Europe Congress in Lyon in 2011 [Lin, 2012]. Similar activities probably will become necessary in the future for the C-ITS CDD: on the one hand, the road operator and service provider will in the future transmit its information not only in the already existing DATEX II and TPEG messages but as well as C-ITS messages (CAM, DENM, in the future additional message formats) (Figure 3.12 – RDS-TMC (Radio Data System -

Traffic Message Channel) and RSU (Road Side Unit) level). On the other hand, the vehicle or user will receive messages in multiple formats based on different data dictionaries (Figure 3.12 – vehicle level). To prevent conflicts caused by contradicting information aligned data dictionaries are an important prerequisite.
If no harmonization takes place at least an agreement on how to map the structures from one data dictionary to the other needs to be made to allow for system boundary transition and interoperability when the different systems operate in the same area and target the same user.

3.3.2.2.3. Results and Conclusion Functional Viewpoint

The analysis from sections 3.3.2.2.1 and 3.3.2.2.2 shows that though discarded in the previous steps again the other methodologies and project architectures can contribute to an improved description of a viewpoint. The discarded results from the previous step both supported sharpening the scope as well as helped to describe the functional viewpoint in a level of detail as it is needed for the description of the Reference Architecture.

The advanced analysis of both the abstract descriptions from ODP, TOGAF the FGSV methodology and the results from projects and practical implementations like FRAME and the Communication Reference Architecture allow to structure the aspects of the functional viewpoint (Figure 3.13). An abstract description includes a set of modules which are linked with each other through a number of interfaces (upper part of Figure 3.13). Examples are addressed both by FRAME and the Application layer of the Communication Reference Architecture. When actually realizing this abstract description and therefore becoming more system specific additionally both a data model and a communication architecture will be part of the functional descriptions (lower part of Figure 3.13). Examples for data models are those developed for C-ITS (Common Data Dictionary), TPEG or other domains, examples for the communication architecture are covered by the lower layers of the Communication Reference Architecture.

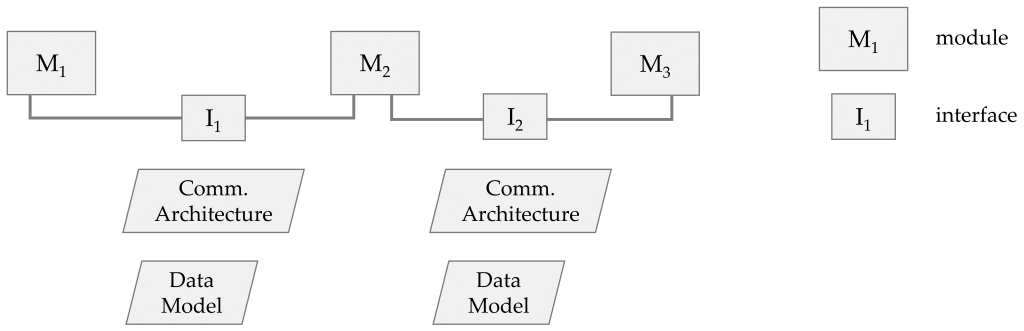

Figure 3.13.: Elements of functional viewpoint

Finally, merging the results of this part with the definitions from the previous part leads to the following more precise definition of the **functional viewpoint scope**. The functional viewpoint describes for a selection of services the corresponding business processes and use cases. Additionally, the corresponding information structure and data model are

defined and described. The services are split into appropriate modules and sub-services which are linked through interfaces, both are described within the functional viewpoint. For the link between these components communication plays an eminent role, therefore a communication architecture comprising various communication aspects like data models, protocols and access media are defined.

Again, the practical advice for the description of the functional viewpoint is mainly deduced from the Bottom Up Approach. The theoretical architecture models mainly helped in the definition of the scope, the architectures developed in the projects give ideas on the structure that later might serve as a blueprint and provide examples and possible options. Therefore, the following steps will be taken to define the functional viewpoint:

1. Services, for which the architecture description shall be realized, are identified

2. Use cases and processes for these services are modeled and described, partially this might include the description of business processes. As soon as the services are specified they are split up into a set of modules. Those modules are intensely analyzed on potentials for merging or further split up.

3. The required data model is described – including the information that is exchanged between entities and the format that is used.

4. Relevant interfaces in the processes are identified, interfaces are described, including all communication aspects

For the functional viewpoint a large number of standards are available, some of them were named in the Bottom Up Approach. Where possible those standards should be used as a basis, profiles on top of those standards shall be developed. This mainly applies for the communication aspects.
Interfaces are crucial for interoperability. In case that new interfaces are identified it needs to be checked whether it is appropriate to standardize those interfaces to ensure interoperability.
Regarding the data model it shall be analyzed whether it is possible to modify and extend existing data models. If possible, no new independent data model shall be developed.

A detailed description of the practical application of these results can be found in section 7.2.

3.3.2.3. Technical Viewpoint

The technical viewpoint closes the gap from the theoretical architecture description to the real-world implementation of the architecture. The approach for the identification of the frame structure only resulted in a short description of the viewpoint, again, like for the organizational and functional viewpoint, the previously excluded methodologies will be analyzed in detail to see whether they might provide valuable input for a more precise description of this viewpoint.

3.3.2.3.1. Technical Viewpoints – Top Down Approach

ODP provides one viewpoint that matches the Technical viewpoint in this document, the **Technology Viewpoint**. According to ISO 10746 it is defined as the choice of technology to support system distribution. It describes the implementation of the ODP system in terms of a configuration of technology objects representing the hardware and software components of the implementation [ISO 10746-1, 1998]. It therefore provides the link between the other viewpoint specifications (Enterprise, Information, Computational, Engineering) and the implementation.

In the **FGSV** pyramid only one layer corresponds to the technical viewpoint, the Infrastructure layer. The **infrastructure layer** incorporates a detailed description of the technology used for the implementation of an architecture and therefore describes similar aspects like the Technology Viewpoint of ODP.

TOGAF comprises as well a Technology Viewpoint called **technology architecture** which address the concerns of acquirers (procurement personnel responsible for acquiring the commercial off-the-shelf software and hardware to be included in the system), operations staff, system administrators, and system managers [The Open Group, 2011a]. The technology architecture is like the other architectures of TOGAF developed within the ADM cycle. Phase D addresses only this specific aspect with the same procedures like the other phases. For the technology architecture it is determined which logical technology components are needed to meet the requirements of the business, application and data architecture, functionalities are assigned to existing and new components including a spatial assignment where to deploy them. (More details are available in the TOGAF book [The Open Group, 2011a, chapter 12].)

3.3.2.3.2. Technical Viewpoints – Bottom Up Approach

FRAME defines a physical viewpoint which corresponds with this document's definition of the technical viewpoint. It defines the location of functions together with the data that flows between those locations [Jesty and Bossom, 2010]. An only very general description of the background for a physical architecture of FRAME can be found in D3.3 [KAREN, 2000a]. The Browsing Tool does not address the physical architecture – when actually designing a system's architecture with the FRAME Selection Tool [Frame, 2012] it is possible to develop a physical viewpoint. The tool allows to generate physical components and assign the corresponding functionalities and services.

Other known C-ITS and ITS projects do not provide an abstract description of the technical aspects and are therefore not considered here.
The design of the technical viewpoint is heavily depending on the descriptions from the superior viewpoints and the requirements and boundary conditions set by the stakeholders actually implementing the system. Therefore, a general description is rather difficult and usually needs to be individually tailored to the results of the other viewpoints to be valuable for an individual project.

3.3.2.3.3. Results and Conclusion Technical Viewpoint

Merging the results of the two previous chapters on the technical viewpoint with the definitions from the previous part (section 3.2.5) leads to the following more precise definition of the **technical viewpoint scope**. The technical viewpoint describes the choice of technology (hard- and software) for the deployment of services and functionalities of the system. Existing technology is taken into account and integrated.

The description of the technical viewpoint is mainly deduced from the detailed TOGAF description – for the technical viewpoint the Bottom Up Approach does not provide much input.

1. Services that should be deployed and their requirements on technology components are identified
2. Existing technology components are identified
3. The required technology architecture is described by assigning services and functionalities to technology components based on service requirements

The technical viewpoint is already rather implementation specific. Requirements for the deployment of a system and its services might be regional specific and can be affected by various aspects like architectures of already existing systems, services and technology structures, organizational structures in a country or region, results of cost-benefit analysis for different implementation variations, or strategic and political decisions.

A detailed description of the practical application of these results can be found in section 7.3.

3.3.3. Conclusions on viewpoint detailing and complementing aspects

The frame structure developed in the previous chapter provides a solid structure and basis for the description of an overall architecture. Before actually diving into the details and applying the frame structure to a specific example, this chapter did identify which parts of the frame structure are useful to be detailed. The analysis first revealed, that this evaluation should focus on the levels and not the layers, as they describe the different abstraction levels of an architecture. Taking into account ongoing activities and the placement and consideration of the overall context resulted in the decision to refer to the 'Rahmenarchitektur' activities in Germany for the Framework Architecture, focus on the Reference Architecture in terms of the abstract description and use the System Architecture as practical example to validate the results of the theoretical and abstract Reference Architecture description.

So far, the viewpoints (layers) identified in the frame structure were not yet described in detail and in general. Therefore, this part of the approach made use of existing project results, documents and standards from the first part to develop a blueprint for the description of those viewpoints. The re-analysis of the material helped to develop improved viewpoint descriptions which now will serve as the basis for the abstract description of the Reference Architecture.

The detailed characterization of the viewpoints shows that there are actually more facets required to cover all aspects of an architecture. For a short illustrative excursus, the single viewpoints are regarded as vertical elements in the description of the architecture abstraction level (c.f. Table 3.1). The single vertical elements are not organized like silos, there are certain perpendicular horizontal aspects, also known as cross-cutting issues. They are composed of a small subset of the single viewpoints and range through all the vertical viewpoints. Often, the horizontal aspects are only sparsely addressed in the viewpoint descriptions, nevertheless they are highly important when designing an architecture. The most prominent examples are IT-Security, privacy and (data) quality along the whole value chain.
For the **IT-Security** aspects in an architecture it is important to start the description as early as possible to minimize the impacts on the architecture concept and structure at a later point in time. Some of the viewpoints already touch the security aspects, e.g. the communication reference architecture addressed in the functional viewpoint (3.3.2.2) already includes this as a transverse aspect. Though IT-Security is more than only securing communications (like described in the communication reference architecture). IT-Security has organizational impacts as it requires its own roles and responsibilities, there are functional aspects, as there are specific security processes and activities, structures and components and technical aspects in terms of hardware requirements. Summarizing this leads to the conclusion, that not only the requirements from IT-Security need to be passed to those that design the overall architecture. In parallel, a detailed security architecture needs to be developed and described. This is not focus of this thesis. Valuable contributions to this topic are available in ETSI 102 940 [2012].
Another horizontal topic is the **privacy** of the user. Privacy is of high importance and has big implications on the acceptance of a system. And like for the IT-Security the requirements of privacy might have an impact on how the architecture of the system is formed. Therefore, as well those requirements need to be fixed as early as possible ('privacy by design', [Hustinx, 2010]) so that they can be considered in the architecture design phase.
IT-Security and Privacy are linked tightly. The conceptual and implementation decisions in both fields are depending on each other.
The third horizontal aspect is **quality**. Quality is important across all viewpoints and along the whole value chain. It has severe implications on the acceptance of a service and the intensity as well as frequency of use. In sequential processes like the value chain it is important that a high level of quality is aspired right from the beginning on and that appropriate actions are taken to ensure an adequate quality. Quality in traffic information is addressed in different European projects and organisations (e.g.TISA [TISA, n.d.], EIP project [EIP, n.d.]). Recently they started various activities to identify how to measure quality and to develop mechanisms to improve quality in traffic information services.
The mentioned aspects are picked up again in the extension of the architecture frame structure, example modules are appointed in the description of the Reference Architecture.

3.4. Domain specific aspects complementing the theoretical approach

The first and second part of the approach developed (based on the Top Down and Bottom Up Approach) a detailed frame structure as well as a detailed description on how to actually model the different aspects of the overall architecture. Partially, the methodology used for defining those aspects already incorporated specific aspects and characteristics of C-ITS when selecting the basis for the analysis. Nevertheless, before actually applying the results of part 1 and 2 on the overall architecture and especially the Reference Architecture for the domain C-ITS it is necessary to have a closer look on some other requirements for the overall C-ITS architecture which were already mentioned right in the beginning but not yet in focus so far. Those were:

- the developed architecture shall incorporate existing (legacy) ITS systems and their services, functionalities, technologies and architectures
- the developed architecture should enable the integration of new, future technologies without fundamental changes of the architecture itself

Hence, the following objectives are addressed in this part:

- evaluation of results from existing analysis on structures in ITS architectures and their implementation
- deduction of implications on architecture structure to enable
  - consolidation with legacy ITS
  - future extensibility with additional services, technologies etc.

The respective aspects are not addressed through the Top Down and Bottom Up Approach but are covered by a separate methodology.

3.4.1. Integration of legacy ITS

The integration of various legacy ITS architectures in the structures developed in part 1 and 2 first of all requires a detailed analysis of those systems to identify structural commonalities. A huge contribution to this activity is made by the work that was done in the so called Matrix report [Lotz et al., 2012]. The methodology as well as its results described in the report are the fundamental basis for handling the integration of legacy ITS requirement. The conclusions are reflected in the proposed migration concept for legacy ITS (3.4.1.2).

3.4.1.1. Analysis of legacy ITS – The Matrix report

The Matrix report [Lotz et al., 2012] developed by BASt did a thorough analysis of different ITS service implementations in Germany. Therefore, the report selected one representative ITS service as example: traffic information with hazard location warning. The traffic information service on hazard location warning informs the driver about relevant hazardous

spots on his route, like black ice or oil spill. Already today multiple implementations of such a traffic information service exist in parallel in different domains.
Although it appears to be cheaper and simpler to implement the service only in one single domain the currently followed approach of multiple implementations in different domains has severe benefits: this approach is per definition redundant, what increases its fail-safeness. Additionally it allows the road operator (or service provider) to get in touch with the user through various channels, as not every user has the same media available. Therefore, the architectural consolidation of the different implementation variations is a core task and challenge in traffic management. The fusion is supposed to set aside the currently existing silos and realize the transformation to cooperative ITS.
Based on the example of the traffic information service on hazard location warning the Reference Architectures of the different domains that provide this service were analyzed. The domains discussed in the report were legacy ITS with classical roadside telematics services, traffic information services (public and private), autonomous vehicle systems, and different implementation variations of cooperative ITS. Each of the domains focuses on a specific technology to realize the selected service. By force of historical circumstances distinct and independent architectures were developed for the individual domains.

The Matrix report describes for the selected service in all individual domains the organizational, functional and technical processes. Therefore a general structure originally developed by the organization TISA (Traveller Information Services Association) was used, the so-called TISA value chain [TISA Executive Office, 2012]. The value chain describes the necessary steps from the detection of the original event to the final presentation to the end user, including the main process steps 'Detection', 'Evaluation' and 'Presentation'.
NOTE: The terms 'Detection', 'Evaluation' and 'Presentation' are used here with their IT related meanings: Detection comprises all aspects of gathering information e.g. induction loops, video detection, floating car data (Input). Evaluation comprises all aspects of evaluation and information processing (Process). Presentation comprises all aspects of making the results available to the receiver e.g. presentation on variable message signs, on the radio or Human Machine Interface (HMI) as well as providing the results as new input to other systems (Output). In IT this principle is also knows as IPO model: Input-Process-Output.

The real-world implementations of the selected service traffic information on hazard location in the different domains were mapped to the abstracted TISA value chain to obtain comparable descriptions of the organizational, functional and technical aspects (example see Figure 3.14, all descriptions in Lotz et al. [2012]). The individual descriptions comprise summaries of the single process steps, the corresponding responsible actor as well as a short description of the interfaces between the process steps with the utilized communication media as well as the implemented protocol standard.

The standardized descriptions of the individual implementations in the different domains finally were aligned and transferred in a single matrix like overview for better comparability of the individual aspects (see Figure 3.15).

The results summarized in Figure 3.15 show the different options determined in the analysis of the different implementations of the traffic information service road hazard warning

2.1 ITS option: Road Traffic Management

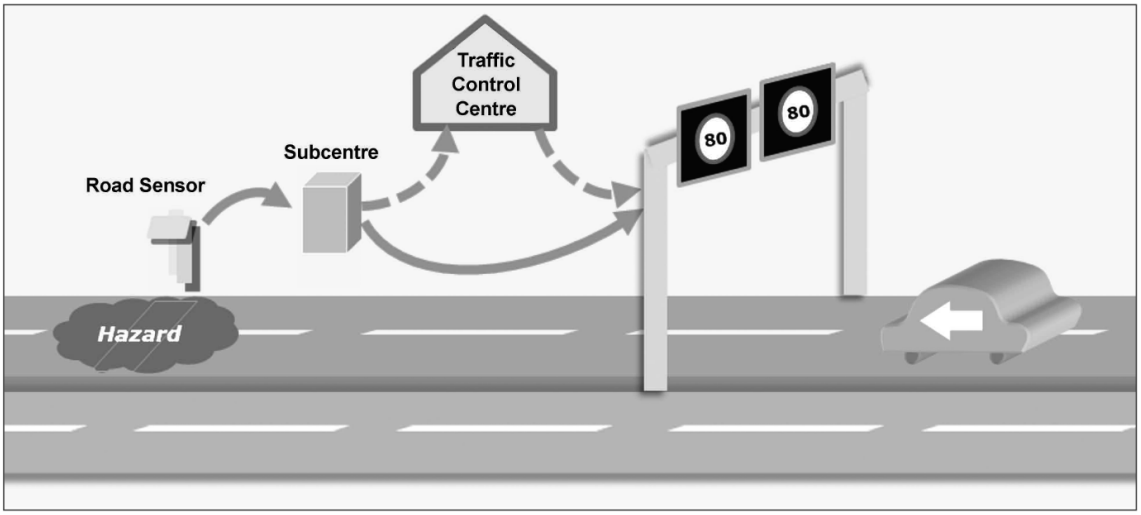

Fig. 3: Simplified sketch of the ITS system variant Road Traffic Management

	Detection	Evaluation	Presentation
Description	The road sensor detects the hazardous situation.	An evaluation takes place in the subcenter that directly sends commands to the display. A way of communication via the traffic control centre is also intended for surveillance or special circuits.	The dynamic traffic sign displays the result to the driver.
Responsible	Road operator	Road operator	Road operator

Communication bearer	Copper cable, in exceptional cases cellular network	Fiber optic cable, partly copper cable
Data protocol standard	TLS (Technical Terms of Delivery for Road Stations) Partly European standards	TLS (Technical Terms of Delivery for Road Stations) No European standards

Figure 3.14.: Example from Matrix report – description of organizational, functional and technical process for classical traffic management – other examples in the BASt report [Lotz et al., 2012]

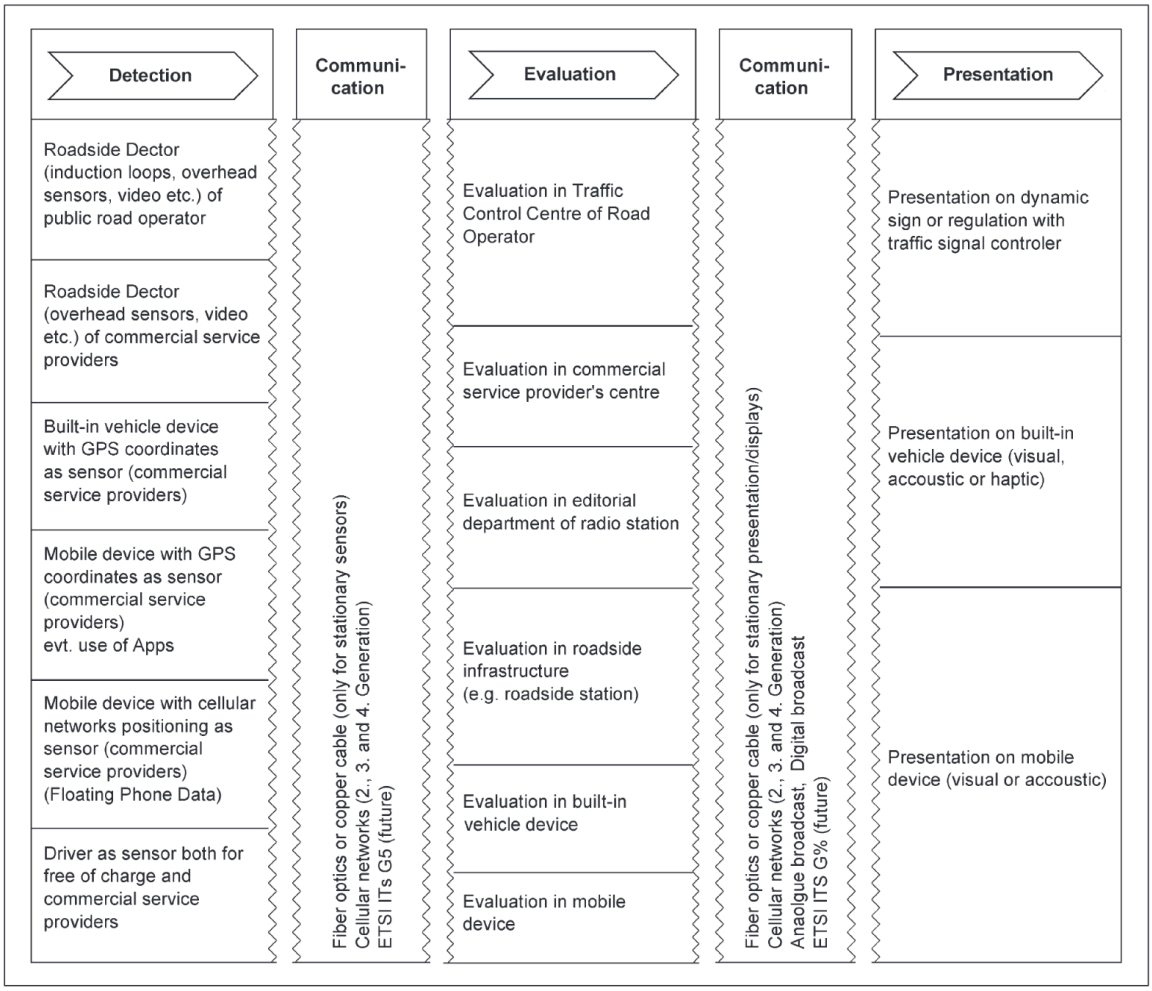

Fig. 11: Matrix of ITS system components

Figure 3.15.: Summary of results from Matrix report [Lotz et al., 2012]

(example in Figure 3.14). The structure of the results in Figure 3.15 is predetermined by the structure and elements of the TISA value chain. Both for the individual process steps (Detection, Evaluation, Presentation) as well as the communication between the steps a large variety of options is used in the different implementations. (Organizational aspects originally described as a separate element in the individual descriptions (see Figure 3.14) were merged with the descriptions of the process steps (Figure 3.15)).
Having a closer look on the results in Figure 3.15, the summary shows as well, that partially different domains already make use of similar organizational, functional and technical elements – without actually sharing them but implementing them in multiple instantiations, each in a different domain. Example for this is the evaluation of the raw data – on an abstract and general level it only differs in the responsible actors. (Though individual algorithms might be in use by the different actors, the product of the evaluation step, e.g. decision that the raw data describes a hazardous location, is the same.)
Advancing this finding leads to the conclusion that a more efficient implementation with the same variety of individual systems, addressing the same service, should make use of synergies coming from shared use of individual modules and interfaces.

Beyond that, single modules and interfaces in such a synergetic structure can be replaced and updated more easily – and not only for one specific implementation. This might reduce costs and facilitate the up-to-date-ness of the system as a whole.
In addition, the previous conclusion in combination with the matrix representation evidently leads to the finding, that there might be much more options for cooperation and sharing of modules between different domains than already implemented nowadays. The result may be new organizational, functional and technical structures to realize the respective service.

Therefore, the core conclusion from the matrix report transferred to this thesis regarding integration of legacy ITS is that a **modular design** of modules and interfaces would be beneficial. It enables a large variety of options for integrating existing systems and technologies and additionally allows for a huge number of new combinations of the modular elements – supporting the development and implementation of new services.

3.4.1.2. Migration concept for legacy ITS

The conclusion from the Matrix report [Lotz et al., 2012] that most of the legacy ITS analyzed in the report already can be subdivided into modular elements is an essential finding that shall be considered when providing a proposal for a migration concept for legacy ITS.

The partition of legacy ITS resulting in suitable modules is the first step for integrating those systems in the (new) overall C-ITS architecture. The partition in this context respects the proposed structures and interfaces of the (new) overall architecture. Applying this subdivision to the legacy ITS architecture leads to modules which easily can be integrated into the new architecture.

Besides the adjustment of the legacy ITS architecture to the new overall architecture it is as well possible that in an early design phase of the new overall architecture the existing

structures and interfaces from legacy ITS are considered and included in the new architecture description. Usually, new systems are developed based on existing systems – hence it partially makes sense that core architectural characteristics are adopted. In this case migration from a legacy ITS architecture, which is transformed to a modular structure, to the new overall architecture is even easier.

3.4.2. Enabling future extensions

Another core requirement for the overall architecture of C-ITS was the capability to incorporate new services and technologies in the future without substantially modifying the structure of the original architecture. This might include the replacement of existing technologies due to innovation cycles like it is known from cellular network communication (2G, 3G, 4G and 5G coming soon). Possible are as well completely new services, addressing new challenges of traffic management. Or only small modifications or extensions of existing services – which is comparable to an update in case that a service is operated independently but might have more implications in a connected environment of shared components. The selected underlying concept for the design of the overall architecture should permit and facilitate all these modifications.

Taking up the concept of the Matrix report [Lotz et al., 2012] with the analysis of different existing domains based on the TISA value chain and transferring this to future technological extensions and new services leads to the conclusion that the same structure or concept will enable the replacement and extension of modules and elements.
The design will need to be flexible enough to facilitate the provision of new interfaces and elements (modules) along the whole value chain. That could be:

- new actors / stakeholders getting involved, taking over new roles and responsibilities coming along with the technological changes
- new data sources (based on new detection options and technologies),
- new services (based on existing sources, using existing presentation mechanisms but providing new functionalities) and algorithms,
- new presentation modes (e.g. through new technologies),
- new communication technologies to link the individual elements (new generation of existing technologies or completely new technologies),

All these aspects require known and standardized interfaces for all viewpoints (organizational, functional, technical) and a modular structure as general basis that allows for fast and smooth transition between different system generations. Therefore, the conclusions from the previous section (3.4.1) fit well for the requirements of future extensibility and only need to be complemented by the need for standardized interfaces.

3.4.3. Conclusions on integration of supplementary aspects

Both requirements, the integration of legacy ITS and enabling future extensions, bring additional demands to the overall architecture design and structure decision. They do not

require to completely restructure the high-level frame structure and the description of the viewpoints defined in the previous parts can as well be preserved. Therefore, no severe conflicts with the so far developed results are provoked. But nevertheless expansions of the frame structure are necessary: the concepts identified in part 1 (3.2) and 2 (3.3), the frame structure with its different levels and various viewpoints, needs to implement a modular structure within its design framework to enable the flexibility demanded by the C-ITS specific requirements. This will be realized with slight extensions of the existing structure, the details are described in the consecutive chapters. In parallel, existing architectures need to be transferred into the modular structure. That this is possible was discussed in section 3.4.1. For new modules and interfaces the modular structure is set as key design requirement.

3.5. Summary and Conclusion on approach and complementing requirements

The results of part 1 and 2 together form the theoretical method that is used to describe the overall architecture for C-ITS.
First, part 1 (3.2) developed a frame structure that should be used as scaffold for the description of the overall architecture. Core result was a matrix structure with three different levels (Framework Architecture, Reference Architecture, System Architecture) that address different levels of abstraction when describing an architecture and three perpendicular viewpoints that describe different aspects of a system in the respective level.
Based on that, the part 2 (3.3) identified which aspects of the matrix structure should be detailed for the description of the overall architecture and which elements of the frame structure shall be particularized. The results especially of the latter task lead to a good foundation for the abstract description of the Reference Architecture and the thereof deduced System Architecture.
Apart from resulting in those tangible outcomes which are a valuable basis for the following chapters the analysis carried out in sections 3.2 and 3.3 is as well an important contribution to the so far fragmentary and sparse work-up and description of the theoretical background behind the concept of the overall (C-)ITS architecture.

Right from the beginning, the scope of the overall architecture was not exclusively C-ITS specific as one core requirement is the successful integration of legacy ITS. This is reflected in the overall architecture, as the result will be an ITS architecture that allows to use C-ITS as a technology but still is able to consider other future technologies without fundamental changes in the architecture itself. Combining this requirement with the variety of features, services, technologies and architectures presented and analyzed in part 1 and 2 was discussed in the third part (3.4) and leads to the following conclusions:
To enable the flexibility addressed by the concept of C-ITS, the transformation of legacy ITS to a modular structure is crucial. This allows to re-use existing modules and components and easily integrate new technologies and modules – across all three viewpoints. Currently, the overall architecture does not explicitly take this into account because the description of the frame structure and the viewpoints is still that abstract that it might be used for different cases of application. Bringing in the requirements and boundary conditions addressed in the third part of this chapter (3.4) leads to this slightly shifted scope that will deeply influence the description of the overall architecture. The resulting abstract overall architecture description in chapter 4 takes up exactly these characteristics and transforms them into advancements of the structure presented in this chapter. This requires that the so far discussed matrix structures are cracked and extended to enable future developments described in the chapter on the overall architecture. This revolution on the level of the overall architecture finally finds expression in the practical transfer of the theoretical approach to the Reference and System Architecture.

4. Overall Architecture for C-ITS – Abstract description

The approach developed and applied in the previous chapter (3) lead to a basic architecture frame structure. In addition, some relevant points were identified that need to be embellished in order to obtain a complete overall architecture for C-ITS. More precisely, the matrix structure with levels and viewpoints developed in the previous chapter shall be the basis for the architecture description. The description itself then shall have a modular structure as underlying concept, and, resulting out of this requirement, an additional element in the architecture is required, the Modular Construction System.
Based on these key results, this part of the document will summarize the results of the approach executed in the previous chapter resulting in an abstract description of the overall architecture including the new element 'Modular Construction System'.

4.1. General structure of overall architecture

The general design as well as a more detailed description of the individual elements of the overall architecture structure were identified, defined and detailed in sections 3.2 and 3.3. This was complemented by additional requirements that need to be fulfilled by a C-ITS specific architecture structure (section 3.4). Both of those general results are now picked up and the general structure is adapted according to these additional requirements. The following core aspects are addressed in these results and need to be taken into account for the resulting overall architecture for C-ITS:

- The architecture consists of different **levels** (Framework Architecture, Reference Architecture and System Architecture) which represent different degrees of abstraction within the overall architecture. The Framework Architecture is the highest abstraction level amongst the three of them, it subsumes the Reference Architectures of different domains. The Reference Architectures provide domain-specific but still generic architecture descriptions which are later further detailed when a system is actually implemented. The corresponding architecture for a real world implementation is called System Architecture.

- Each level in the overall architecture consists of different layers or **viewpoints**. In this document the three generic viewpoints organizational, functional and technical are considered. A detailed description of the individual viewpoints is developed in the second part of the approach (section 3.3).

- The structural concept of the architecture shall be **modular** to fulfill the flexibility requirements regarding integration of legacy ITS and future technologies.

4.2. Extension of structural architecture concept

The aspect of modularity mentioned in the last item of the previous list has implications on the structure of the architecture across all levels and layers i.e. it will be visible from Framework Architecture to System Architecture and within the different viewpoints. Due to the scope of the different architecture levels the modularity has its biggest influence on the structural concept of the Reference Architecture: the Framework Architecture only provides a generic and abstract description, the System Architecture is already very implementation specific so that modularity only has limited opportunities to unfold. The Reference Architecture in turn provides the blueprint description for a whole domain. Domains might be partially overlapping (see chapter 2), hence individual modules might be assigned to Reference Architectures in different domains.
Advancing the idea of reusing modules in different contexts in turn implies, that in case a new Reference Architecture shall be developed, a kind of pool needs to be available in which all available modules are listed or registered to ensure that newly developed Reference Architectures reuse as many modules as possible and not duplicate existing modules. Otherwise, the idea of easily producing new features and functionalities based on existing modules by recombining them, marginally upgrading them or adding new modules, is not ensured.
Currently, the frame structure does not provide any structural element for such a pool therefore the concept for the overall C-ITS architecture is extended by a collecting toolbox, the **Modular Construction System**. It is a key element in the overall architecture as it comprises the complete collection of all modules that are used in the Reference Architectures of the different domains.

4.3. Derived structure of overall C-ITS architecture

Based on those requirements the initial architecture structure like it is described in section 3.2.6 finally resulting in the matrix structure from Table 3.1 is adapted and slightly modified. The updated abstract description of the architecture structure is depicted in Figure 4.1.
Like in the previous schema with the matrix structure the different levels of an architecture are arranged in a hierarchical way, this is simply transferred to the graphical representation in Figure 4.1. According to the structure developed in the previous chapter this results in the Framework Architecture being at the top, followed by one or more Reference Architecture(s) which abstractly describe(s) the architecture for different domains covered by the Framework Architecture. Finally, the Reference Architecture is compiled into implementation specific System Architectures which are actually implemented in real world scenarios. In the present thesis the Framework Architecture is addressing ITS, the subordinate Reference Architectures involve particular domains within ITS, examples are C-ITS, urban ITS, traffic information and many others. According to the definition in section 2.1.2.3 domains might be partially overlapping i.e. they are partially implementing identical functionalities in different contexts or for different purposes. This characteristic is picked up in the concept of the Modular Construction System, which is introduced as new element in Figure 4.1.

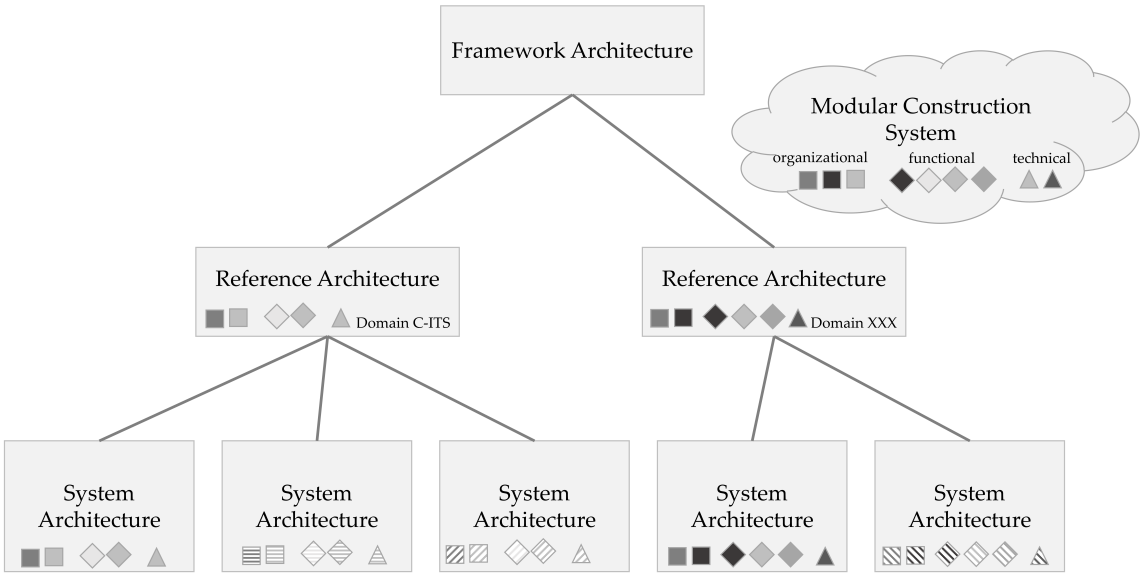

Figure 4.1.: Overall architecture – general structure

In each of the architecture levels three core viewpoints (organizational, functional and technical) are present, each viewpoint comprises several aspects, options for the individual parts are mentioned in Figure 3.8. The three core viewpoints are coded by different shapes in Figure 4.1, organizational elements are coded with squares, functional elements with diamonds and technical elements with triangles, the subdivision of the viewpoints in smaller elements is depicted with shapes colored in different shades of grey.

The requirement regarding a modular structure identified previously implies the need for an additional element in the overall architecture that is called Modular Construction System (see Figure 4.1), a toolbox that accommodates all the different modules and components from which one can choose when actually designing an architecture. The Modular Construction System reflects as well the viewpoint structure and therefore the shape-coding applied on the viewpoints matches the one in the Modular Construction System. As the Modular Construction System collects all possible modules which are occurring in the corresponding References Architectures a large number of shapes in different shades of grey are part of the tool box.

For the new architecture element, the Modular Construction System, a suitable position within the overall architecture has to be identified. Only few elements in the Modular Construction System are domain specific, in general they are independent of the domain and are implemented in various different domains. Correlating this with the level structure of the overall architecture, the Modular Construction System may be located on top of the Reference Architecture. In turn, this may imply that the Modular Construction System should be integrated in the Framework Architecture. But on the other hand, the modules actually only follow and implement the policies stated in the Framework Architecture and are on a Reference Architecture level of detail. This is the reason for installing the Modular

Construction System between the Framework and Reference Architecture.

4.4. Summary and Conclusion

The present chapter consolidated the results from chapter 3 and developed further the initial and abstract frame to a suitable structure in which all results and requirements on an overall C-ITS architecture can be embedded (Figure 4.1). The generated structure extends the results from chapter 3 and entails a new element within the generic architecture structure, the Modular Construction System, to realize the previously identified characteristics and requirements. The placement of the new element within the hierarchy of the overall architecture was discussed and its internal structure was analyzed and detailed.

Based on the structure (Figure 4.1) the subsequent chapters will describe the different elements of the overall architecture. Chapter 5 provides more details on the Modular Construction System, its internal structure and the general description of its elements (modules). This is complemented by an insight into the huge Modular Construction System through the description of a sample subset of the new architectural element. Chapter 7 contains the description of the C-ITS Reference Architecture, it is developed based on the approach and its conclusions from chapter 3. Finally, the overall architecture description is completed by a sample application of the Reference Architecture from chapter 7, the C-ITS Corridor System Architecture (chapter 8).

5. Modular Construction System

The description of the overall architecture (chapter 4) includes the 'Modular Construction System' as a new element which is needed to completely satisfy the requirements on an overall architecture. This chapter describes the new element, that subsumes all modular elements of the Reference Architecture, in detail.
Section 5.1 explains which aspects are addressed by the Modular Construction System as new structural architecture element. Then, section 5.2 provides a detailed and comprehensive view of the Modular Construction System itself and its sub-elements. After that a template for the description of its parts is presented in section 5.3 that should help to gather, structure and depict the complexity of each component, given the fact that the Modular Construction System as a whole is hard to capture. Section 5.4 gives a detailed sample description of one selected element, complemented by a list of further candidates for a Modular Construction System in section 5.5.

5.1. Modular architecture structures

The theoretical paper study (section 3.2) revealed that a close link between the Framework Architecture and Reference Architecture is missing, under a Framework Architecture several Reference Architectures for different domains can exist (see as well Figure 4.1). Partially, those individual domains are overlapping as they make use of the same elements and functionalities. Usually, this does not affect the complete architecture with all its viewpoints and components but parts of it. To avoid duplication of elements used in the different Reference Architectures, it is therefore proposed to use a modular structure within the viewpoints of the Reference Architecture. This allows multiple domains to integrate the same modules in their specific Reference Architecture.

In general, an architecture with a modular structure has various advantages. One of them was already mentioned before, it is the fact that the same functionalities do not need to be developed multiple times. Within a modular structure all domains can access the same module and implement profiles or instances of the module.
Even if modules are not reused in Reference Architectures of different domains the partition of a service into modules has the advantage, that in case that a module is outdated, it can be easily replaced by a new module (respecting the same interfaces and providing comparable functionalities) without touching the service as a whole. Such a situation might occur e.g. when technologies are outdated and need to be replaced with the latest version or a completely different technology. If the service is already in a modular structure the efforts for such updates are minimized.
One of the prerequisites to enable the flexibilities of implementing the same modules in different domains, or easily replacing modules, are standardized interfaces. As additional

benefit the standardized interfaces enlarge the community of experts able to contribute to the pool of modules, so technology is improved much faster. The results are accessible for many stakeholders.

The analysis of already implemented Reference and System Architectures in the Matrix report [Lotz et al., 2012] revealed that even existing systems might be partitioned into modules. Currently, the analyzed implementations duplicate the different functionalities because they were developed independently and without an underlying modular concept. This results in so-called silos: the individual systems are monolithic, concordant features are not shared. However, according to the results of the Matrix report a transition into a modular structure – with all its benefits – would be possible and therefore even would allow for an integration of legacy ITS elements into such a modular concept.

5.2. Internal structure of the Modular Construction System

The idea of reusing modules in different domains and contexts influences the original structure of the overall architecture as it was described in section 3.2.5 and Table 3.1 and lead to an additional structural element that is called Modular Construction System. It basically is a database that provides the modules for all potential Reference Architectures implemented under a defined Framework Architecture that covers various domains. The integration of the Modular Construction System in the overall architecture is described in detail in 4.2.
Through the Modular Construction Systems new implementations or restructured old implementations might now share their modules with each other. When a new Reference Architecture is developed or existing Reference Architectures are updated suitable matching modules are identified in the Modular Construction System based on the respective requirements. Like that monolithic silos in the field of ITS will disappear.

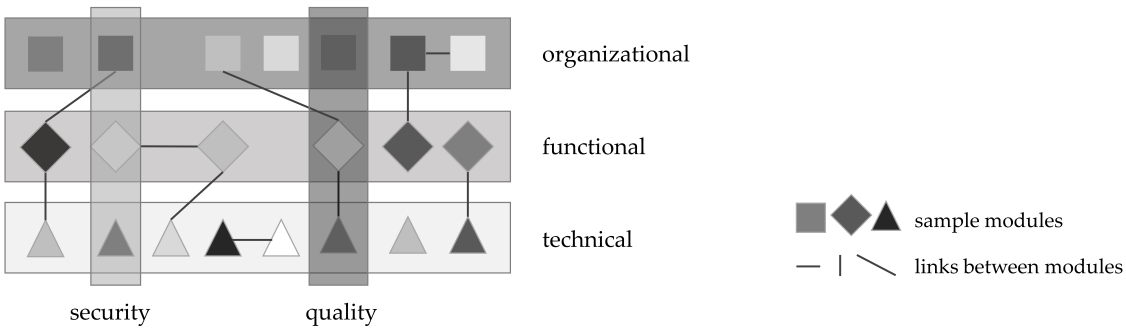

Figure 5.1.: Exemplary internal structure of Modular Construction System

The elements of the Modular Construction System can be placed in a generic structure which is depicted in Figure 5.1.
The individual modules cover different aspects and viewpoints, they are represented with different shapes. The viewpoint is selected as one of the structuring elements, therefore

they are organized into organizational, functional and technical aspects. In Figure 5.1 each of the three viewpoints is delimited by a horizontal block, the corresponding modules are coded by a similar shape, the description on the right side indicates the type of viewpoint. Basis for the assignment of modules to viewpoints in the Modular Construction System is their correspondence to viewpoints in the Reference Architecture descriptions. A more detailed description of the different viewpoints' characteristics is available in section 3.3.2. Apart from the viewpoint structure the Modular Construction System as well reflects the cross-sectional aspects touched briefly in section 3.3.3. In each viewpoint a subset of modules for the cross-sectional aspects like IT-security, privacy and information quality can be identified (vertical bars in Figure 5.1), however not all modules are concretely tied to a cross-sectional block (shapes not assigned to one of the vertical blocks in Figure 5.1). It is conceivable that such cross-sectional blocks are as well established for C-ITS subsystems representing high-level abstract domains, e.g. individual transport – but this is not inevitable.
Summarizing this, the Modular Construction System can be structured internally into two dimensions, one reflecting the viewpoints and perpendicular to this plane the cross-sectional issues like security. Both, the viewpoints and cross-sectional structures of the Modular Construction System, are interwoven and therefore closely linked.

Each module in the Modular Construction System not only can be located in the previously described two dimensional structure but is additionally associated with a set of relations and dependencies. They describe with which other modules the respective module might interact or can be combined – both optional and mandatory. These associations can be realized through specific (communication) interfaces but as well might be implicit and context dependent i.e. roles (organizational modules) linked to tasks (functional components). The modules in the Modular Construction System already come along with the relations and dependencies from their original implementation in different Reference Architectures. The transfer and anchoring of modules into the Modular Construction System might result in more general module descriptions and therefore leads to a bundling and accumulation of different interfaces. Modules in the Modular Construction System might provide more interfaces than their related, actually implemented instances.
The single modules are linked with each other within and across the dimensions of the Modular Construction System i.e. modules from the same viewpoint might be associated with each other and together provide a more generic role, functionality or technical component (horizontal links between shapes in Figure 5.1). But links might as well exist across viewpoints like the previously mentioned example of functional modules linked to specific roles (vertical and diagonal links in Figure 5.1). Both options are included in the abstract example in Figure 5.1.

In general, the modules within the Modular Construction System can be compared with pieces of a puzzle. Every module has a characteristic shape with specific tabs and blanks. It only can be combined with matching elements that provide the corresponding counterpart, when all pieces are present the picture is complete. The single modules in the Modular Construction System allow for more possible combinations than the pieces in a classical puzzle, where usually every piece fits only at one specific location. The modules are more like the popular Lego pieces which can be assembled to many different shapes,

having only few limitations. This is as well called the Lego-principle [Lamparter, 2014].

Within the Modular Construction System modules belonging to different domains can be found. Partially, they are so generic that they are shared by different domains' Reference Architectures, partially they are exclusively implemented in one single domain. As the Modular Construction System is located between the Framework and Reference Architecture it is not focused on a specific domain but subsumes the modules from different domains. The respective structure in the Modular Construction System is not specific for a domain nor is it the architectural element itself. The general concept might be applied in many different fields.
NOTE: The general concept of the Modular Construction System, including the aspect of being not domain specific with regard to ITS, might even be extended to non ITS architectures. This is not in the scope of this thesis.

5.3. Developing the Modular Construction System for a C-ITS architecture

The Modular Construction System is a completely new element in the structure of the overall architecture, therefore no method is developed so far for actually setting up and shaping this new structural element. Based on the considerations on the internal structure of the Modular Construction System made in section 5.2 and depicted in Figure 5.1 an approach for identifying modules that can be attached to this structure is designed. The developed approach should help to actually fill the toolbox with modules and thereby practically realize the characteristics described in section 5.2.

The Modular Construction System consists of elements both from legacy ITS and new ITS architectures. Hence, the method for developing it needs to provide an approach for modularizing legacy ITS architectures and transferring their non-modular structure in suitable elements for a Modular Construction toolbox. Elements discovered with this part of the method may provide already a fundamental basis for the Modular Construction System.
Apart from that every element from newly developed ITS architectures shall be included as module in the Modular Construction System. Those modules are developed from scratch and therefore their structure can be influenced in the respective architecture design process. Requirements for new modules therefore complement the approach for the legacy ITS architectures.

For the identification of **modules in legacy ITS architectures** the Matrix report [Lotz et al., 2012] already developed a methodology including the sample application on different implementation variations of the service selected by the report (traffic information service for Hazard Location Warning). Core element of the approach is the mapping of different implementation options of the Hazard Location Warning Service to a template developed by the authors of the report (example for empty template see Figure 5.2). It comprises a simplified version of the TISA value chain (top row in Figure 5.2) that structures the whole description of the service. Each element in the value chain can be further detailed by addressing organizational ('Responsible'), functional ('Description', 'Communication bea-

rer', 'Data protocol standard') and technical aspects (assignment to individual elements). In line with the viewpoint definition in section 3.3.2 a full description for each of these aspects along the value chain is possible.
Actually mapping a legacy ITS service to the structure of the template forces the user to partition the service, what results in a set of individual modules. The single elements identified through this mapping can be extracted and assembled in the Modular Construction System. Depending on the level of detail in which the single elements are described rather abstract or more detailed modules are derived.

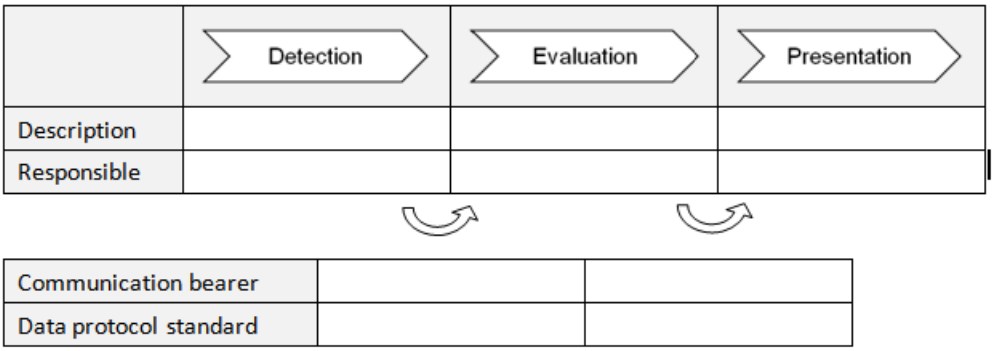

Figure 5.2.: Template for identification of modules out of existing reference architectures based on approach from the Matrix report [Lotz et al., 2012]

The Matrix report did not only provide a method to identify modules, it already identified on a rather abstract level the modules for the Hazard Location Warning Service. The results from the Matrix report are included as a first basis for the Modular Construction System (section 5.6 and Appendix E).

Modules for the Modular Construction System are not only derived from legacy ITS Reference Architectures, it is as well possible to **generate new modules when a new Reference Architecture is developed** – in case that no suitable module is already available in the Modular Construction System. In order that the new modules fulfills the requirements of the Modular Construction System, it is proposed that the design of modules from scratch follows a similar approach like the one that is used to modularize legacy ITS architectures. The template developed by the Matrix report (Figure 5.2) supports as well the description of new modules in new architectures: when an architecture is initially designed, its organizational, functional and technical aspects need to be described. Doing this with the support of the generic value chain used in Figure 5.2 leads to modular elements. For each element is checked whether the Modular Construction System already provides suitable modules. If not, new modules are added.
This approach will be mainly used to describe the Reference Architecture for C-ITS (chapter 7), the newly identified (C-ITS specific) modules will be added to the Modular Construction System. The additional modules are described in Appendix F.

Combining both approaches, which actually are based on the same concept, covers all possibilities to derive new elements for the Modular Construction System. Applying them

consequently should lead to modules with comparable characteristics. They will provide compatible interfaces and therefore will allow to realize the initial idea of easily putting together new modules to implement defined functionalities or replacing single existing modules.

5.4. Modules of the Modular Construction System

In fact, the Modular Construction System is a kind of database for modules from different Reference Architectures. To facilitate the reuse of already existing modules registered in this database, it is necessary to describe every single module in the same way, so that important information can be found efficiently and that similar modules can be compared easily. A generic structure for the description of the modules of the Modular Construction System is depicted in Table 5.1 and explained below.
Each individual module which is part of the Modular Construction System comprises a rather detailed description of itself. For organizational modules this is a description of the role and its corresponding responsibilities and actions. Functional modules require a description of what functionalities are realized by the module. The description of technical modules comprises the characteristics of the respective physical components.
For the assignment of the module to the internal structure of the Modular Construction System it is tagged with the respective key words: possible are organizational, functional and technical (for the viewpoint classification) and IT-security, privacy and quality (representing the cross-sectional aspects discussed in section 3.3.3). In case that the module is already in use in a specific Reference Architecture a reference to this architecture is included.
Occasionally, the Modular Construction System only contains the generic, abstract version of a module, but the Reference Architectures use profiles or deductions of the module. The adjustments of the module for the respective Reference Architecture are so specific that it does not make sense to add all the variants to the Modular Construction System. In this case an annotation is included in the description, the link to the corresponding Reference Architecture is added.

Each module optionally has two kinds of interfaces. It might be linked with other modules from the same viewpoint, those are called here horizontal interfaces following the graphical description of the internal structure of the Modular Construction (see Figure 5.1). The number of interfaces is not restricted, usually a module has at least one interface with another module from the same viewpoint.
Apart from the horizontal interfaces a module has as well vertical interfaces to modules from other viewpoints. These interdependency was already described in section 3.2.5.
Both types of interfaces can be optional or mandatory. In case that an interface is mandatory the respective module cannot be implemented without the corresponding module.

Based on the previous description the template in Table 5.1 was developed and serves as meta model in the description of the modules of the Modular Construction System. A sample application is given in section 5.5. For a complete description of the Modular Construction System each of its elements with its respective characteristics is filled into one

Title = *name of module*			ID
Detailed description of module			
Addressed viewpoint	☐ organizational	☐ functional	☐ technical
Cross-sectional aspects	☐ IT-security	☐ privacy	☐ quality
Corresponding generic module with existing description: *optional: add module name*			
Implemented in Reference Architecture(s)	*Reference Architecture X*		
Horizontal interfaces	*interface a*		
	interface b		
Vertical interfaces	*viewpoint*	*interface k*	
		interface l	
	viewpoint		

Table 5.1.: Template for description of modules in Modular Construction System

instance of Table 5.1.

5.5. Sample application of the Modular Construction System

Although this thesis provides the theoretical approach as well as sample modules from the Modular Construction System this document will not contain a complete description of a Modular Construction System including all possible elements. The reasons is that ITS is a very large field with a huge number of different domains and therefore different Reference Architectures. Each of these Reference Architectures provides modules for the Modular Construction System and only a complete description of all Reference Architectures may lead to a complete description of a Modular Construction System with all possible modules. This is beyond the scope of this thesis and therefore this document only comprises a sample application of the Modular Construction System that illustrates the procedure on how this was achieved. The sample is picked sufficiently typical to show the structures within the Modular Construction System, with the viewpoints and cross-sectional aspects, as well as the relations and interdependencies between different modules.

In the following subsections one module is described in detail to show the relevant aspects and the required level of detail (section 5.5.1). This is complemented with some generic recommendations on how to adapt this to other modules (section 5.5.2).

5.5.1. Application to functional module 'closed lane'

It is most illustrative to start the description of a sample module from the Modular Construction System with a functional module and broaden the obtained findings into a generic description for the other viewpoints.
The selected module is implemented in the System Architecture described in chapter 8: Determine the lane closed by the road works safety trailer. The module is part of the Road Works Warning service implemented in the C-ITS corridor, it receives as input information about a road works safety trailer, which is part of a short-term road works, e.g. its position. Output of the module is the exact lane on which the road works safety trailer is placed. This information might be used by subsequent modules to combine trailers that belong to the same short-term road works or to generate a precise warning. (Details on the whole process chain for the Road Works Warning service are available in section 8.7.)
The functional module is linked to organizational modules, e.g. a road operator responsible for service provision. From a technical perspective links to central infrastructure components are likely.

5.5.1.1. Horizontal interfaces of 'closed lane' module

For the description of the horizontal interfaces the concatenation of modules from the same viewpoint, here the functional viewpoint, are analysed. Therefore, the different processes and work flows that traverse the module are examined. The more complete the inspection of possible processes incorporating the module, the better the list of resulting interfaces.
Applying this to the module 'closed lane' results in two types of horizontal interfaces: interfaces to modules from the same level of detail which directly precede or follow the 'closed lane' module and interfaces to modules that are rather sub-functionalities of the 'closed lane' module. Both are depicted in Figure 5.3.
In the present scenario (Figure 5.3) the 'closed lane' module (here shortened to: M_2) is part of the Road Works Warning use case. As mentioned in the introduction it implements at least two interfaces (I_1 and I_2) to its predecessor and successor modules. The predecessor module in the Road Works Warning use case (here shortened to: M_1) realizes the filtering of messages received from the road works safety trailer. The successor module (here shortened to: M_3) implements the combination of multiple trailers, in case that more than one road works safety trailer secures the short-term road works setup.
The 'closed lane' module requires a submodule (here shortened to: M_{21}) that does the map-matching, a core feature of the 'closed lane' module. The map matching done by the submodule might be realized with different algorithms. Each algorithm has advantages for specific use cases. Depending on the use case a suitable map matching module needs to be selected. Accordingly, different variations of the submodules are possible. Apart from that, the map matching submodule might integrate different maps, depending on the preferences of the actors responsible for the use case as a whole (here: short-term Road Works Warning). Usually, the submodule integrates the map already in use by the responsible actor. This ensures that the road works content is recorded based on the same geographic reference as other traffic relevant events.
The interfaces I_1, I_2, I_3 and I_4 can be implemented both as proprietary and generic interfaces, in the Road Works Warning use case proprietary interfaces will be used as the

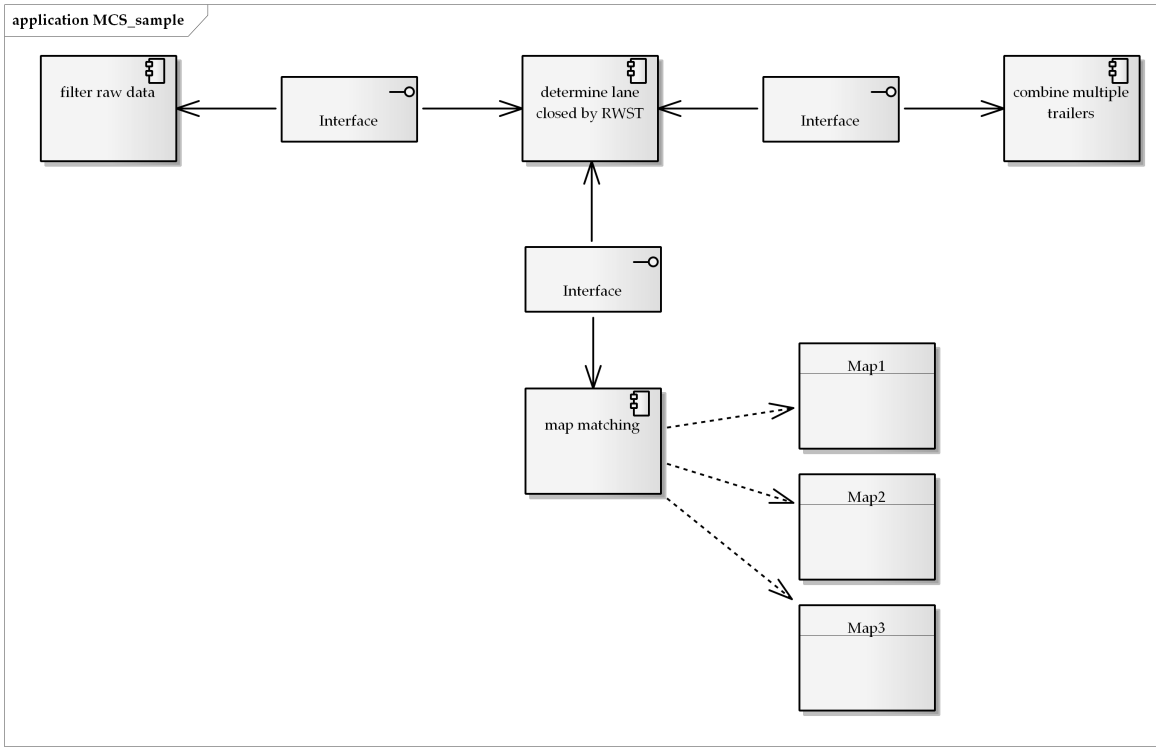

Figure 5.3.: 'Closed lane' module and its interfaces to neighbour modules and submodules

module is tightly embedded between its neighbor modules. Though, the content passed over I_1 and I_4 will follow the data model developed for Road Works Warning in the C-ITS Corridor (section 8.7.4). Both interfaces transmit road works objects derived from this data model.

Summarizing this, the 'closed lane' module realizes the following functionalities and interfaces:

- **interface I_1**: receive input data from 'filter messages' module (M_1)
  - in this use case the interface is internal and proprietary
  - a road works object is transmitted (based on the RWW data model defined in the C-ITS Corridor, Figure 8.12)
- module M_2: 'closed lane' module extracts the position information from the received object and passes it to the map matching submodule (M_{21}) via **interface I_2** requesting to map the road works safety trailer (object) to a road element of the respective map
- module M_{21}: map matching submodule runs its map matching algorithm on the road works safety trailer position and returns via **interface I_3** the road element on which the trailer is parked / stopped / driving
- module M_2: for the exact determination of the roadworks layout the 'closed lane' module combines the sign board configuration on the back of the trailer with the re-

sults from map matching (position of trailer), the 'closed lane' module (M_2) updates the road works object with the lane information

- **interface I_4**: the 'closed lane' module (M_2) passes the updated object to the module that combines multiple road works safety trailers (M_3)

The corresponding interdependencies within the functional viewpoint are

- $M_1 \longrightarrow M_2$ via I_1: filter messages module $\rightarrow$ interface $I_1 \rightarrow$ 'closed lane' module
- $M_2 \longrightarrow M_{21}$ via I_2: 'closed lane' module $\rightarrow$ interface $I_2 \rightarrow$ map matching submodule
- $M_2 \longleftarrow M_{21}$ via I_3: 'closed lane' module $\leftarrow$ interface $I_3 \leftarrow$ map matching submodule
- $M_2 \longrightarrow M_3$ via I_4: 'closed lane' module $\rightarrow$ interface $I_4 \rightarrow$ combine multiple road works safety trailers module

5.5.1.2. Vertical interfaces of 'closed lane' module

The (horizontal) interfaces between elements of the functional viewpoint and the module 'closed lane' are listed in the previous subsection. Aside from that there are as well (vertical) interfaces to the other viewpoints, organizational and technical, which are analyzed in detail in this section.
The links to other viewpoints which are as well part of the Modular Construction System are depending on the functional configuration. The combination, both with organizational and technical modules, is depending on the selection of neighbor modules and submodules tied to the functional module. The variety of generic interfaces for in- and output per se enables more options for the choice of organizational and technical modules, it potentially suspends the dependency introduced by the choices of preceding and consecutive functional modules.
The **organizational aspects** address the responsibilities around the module 'closed lane'. In general, the respective actors from the C-ITS Corridor will belong to the high-level role 'Functional Operation' (section 7.1.3.2). From its subrole 'Generic functional operation' the sub(sub)roles 'Content Provision' and 'Service Provision' come into consideration. Those might be combined with sub(sub)roles 'Road Operator', 'Roadworks Operator' and 'Infrastructure Operator' from the subrole 'Specific functional operation' (see as well Figure 7.2). Examples in terms of respective actors are road operators like Hessen Mobil (Germany, federal state Hesse), Strassen.NRW (Germany, federal state NRW) or ASFINAG (Austria). Alternatively, the named actors might authorize other entities to take over this task. Depending on the national legal and organizational background, other example actors might be service providers in the field of traffic management.
The **technical options** involve different hardware solutions for the implementation of the 'closed lane' module. Due to its dependency on a map, the module probably will be running in a rather central infrastructure component, as the use of a map usually is closely related to licence fees which arise per instance in operation. Accordingly, candidate technical components are located in the traffic control or cooperative centres. Possibly, roadside units come into considerations as infrastructure components.
Often, the selection of organizational and technical for the vertical interfaces cannot be

Closed lane module			ID 0815-2016
The module determines the lanes closed in a road works by a road works safety trailer. Therefore, it receives information about the road works safety trailer, e.g. its position. Output of the module is the exact lane blocked by the road works.			
Addressed viewpoint	☐ organizational	☑ functional	☐ technical
Cross-sectional aspects	☐ IT-security	☐ privacy	☐ quality
N/A			
Implemented in Reference Architecture(s)	C-ITS Corridor Germany		
Horizontal interfaces	$M_1 \longrightarrow M_2$ via I_1: filter messages module $\rightarrow$ interface $I_1 \rightarrow$ 'closed lane' module $M_2 \longrightarrow M_3$ via I_4: 'closed lane' module $\rightarrow$ interface I_4 $\rightarrow$ combine multiple road works safety trailers module		
	$M_2 \longleftarrow M_{21}$ via I_3: 'closed lane' module $\leftarrow$ interface I_3 $\leftarrow$ map matching submodule $M_2 \longrightarrow M_{21}$ via I_2: 'closed lane' module $\rightarrow$ interface I_2 $\rightarrow$ map matching submodule		
Vertical interfaces	organizational viewpoint	road operator	
		service provider	
	technical viewpoint	traffic control centre, cooperative centre	

Table 5.2.: Description of 'closed lane' module based on template for Modular Construction System 5.1

done completely stand-alone. Organizational and technical modules are often linked – actors usually do not support all possible hardware but only a specific selection.

5.5.1.3. Resulting template filling for 'closed lane' module

The details collected and described in the previous subsections are finally summarized in Table 5.2.

5.5.2. Generic application of template

With the 'closed lane' module the template description for modules from the Modular Construction System was implemented for one sample from the functional viewpoint. In

a similar way the description for other modules from the same viewpoint or even modules from other viewpoints can be obtained. Most parts of the template are self-explaining and do not demand additional explanation here. More complex is the identification of interfaces, therefore, the following subsections provide generic strategies for the description of horizontal and vertical interfaces of a selected module.

5.5.2.1. Generic horizontal interfaces

For most functional modules the horizontal neighbors easily can be derived based on the process chains and work flows the module co-creates. The elements of these procedures can be mapped to modules preceding and following the module under consideration. The abstract visualization is depicted in Figure 5.4. Negligible is the fact whether the modules are from the same level of detail or whether they rather correspond to submodules. Emanating from this representation, the interfaces between the identified modules are described. The more complete the inspection of possible processes incorporating the module, the more exhaustive the list of resulting interfaces.

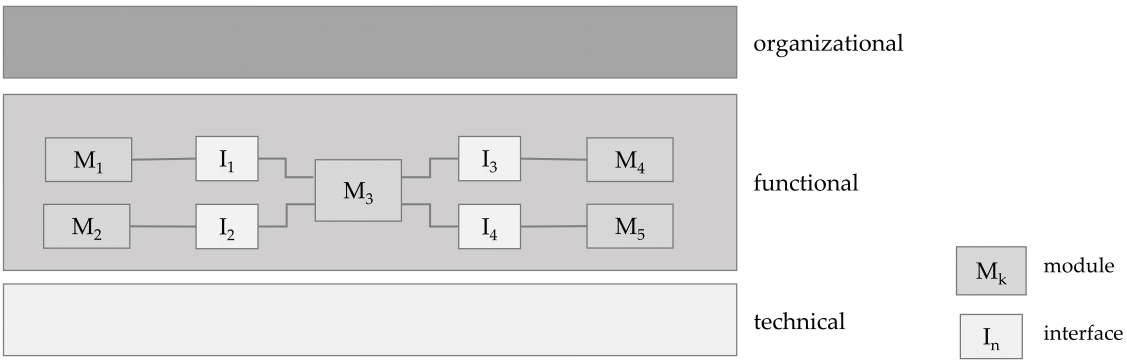

Figure 5.4.: Generic module with different horizontal interface options

Though the general illustration in Figure 5.4 is as well applicable to the organizational and technical viewpoint, the underlying analysis might be slightly more complicated. Of course, the functional processes might be helpful here as well. But if they are not known, it is necessary to analyze existing organizational structures and relationships between actors to identify the horizontal interfaces between different organizational modules.
Similar implications may take place for technical modules. However, the evaluation of existing technical implementation structures including conjunctions of different technical modules might reveal many possible horizontal interfaces.

Some examples for the abstract elements in Figure 5.4 can be found in Table 5.3.

5.5.2.2. Generic vertical interfaces

The sample application for a functional module in section 5.5.1.2 already addressed the maximum complexity regarding vertical interfaces – only functional modules can be linked

	organizational	functional	technical
$\mathbf{M_k}$	Road Operator	closed lane	Road Works Safety Trailer
$\mathbf{I_n}$	SLA, contracts	content, protocol	cellular networks
$\mathbf{M_{k+1}}$	Service Provider	combine multiple trailers	traffic control centre

Table 5.3.: Examples for the module and interface elements in Figure 5.4

both with organizational and technical modules. Hence, the transfer to a generic description is rather basic, the generic description is depicted in Figure 5.5.

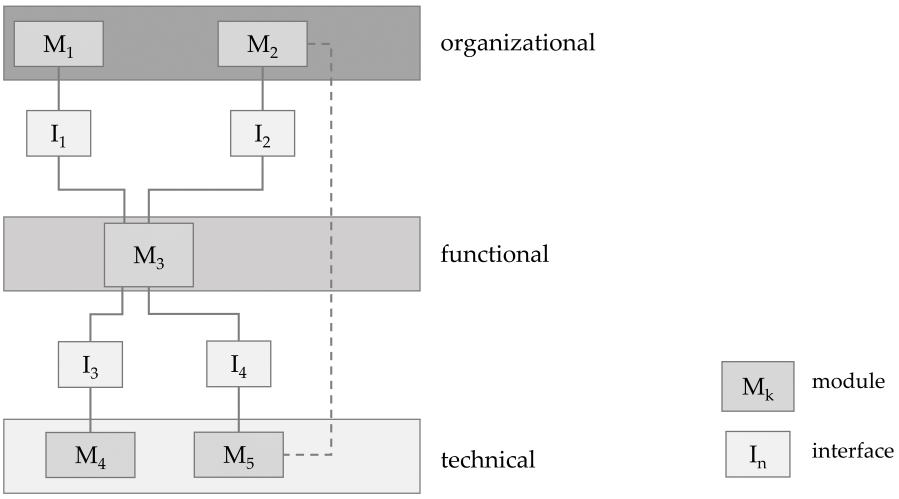

Figure 5.5.: Generic module with different vertical interface options

Comparable to the horizontal interfaces the module under consideration is as well tightly linked with modules from the superior and / or subordinate viewpoint. The vertical interfaces across different viewpoints are actually rather dependencies and links and not so much intersections where something is exchanged between the involved modules. Depending on the viewpoint, in which the respective module is positioned, the options of vertical interfaces is smaller or larger.
The implicit link between organizational and technical modules, that was already identified in the example description (5.5.1.2) exists as well in the generic description in Figure 5.5, the dotted line symbolizes this dependency.

The identification of vertical interfaces is mainly based on the study of existing implementations. The association of modules from the different viewpoints is closest to reality in actual systems.

5.5.2.3. Dependencies between horizontal and vertical interfaces

Describing a generic approach to identify the horizontal and vertical interfaces may lead into temptation to additionally undertake theoretical reflections on possible neighbour modules – independent from the fact whether they are part of the horizontal and vertical structures. However, one need to bear in mind that each interface leads to another module – either in the same (horizontal) or another (vertical) viewpoint. And this neighbor module again has interfaces pointing to other modules. Pursuing this thought assembles a whole network of modules and interfaces, that span the organizational, functional and technical viewpoint. The resulting structure is very fragile and not tolerant towards arbitrary extensions. Therefore, the identification of potential interfaces – no matter whether they are horizontal or vertical – needs to be handled with much care. Each module and its interfaces needs to be regarded as single element within a complex and sensitive network.

5.6. Sources for modules

To further illustrate the possible content of the Modular Construction System a list of all modules deduced from the results of the Matrix report [Lotz et al., 2012] are included in Appendix E.
The modules from the Matrix report are not simply transferred to the Modular Construction System. The level of knowledge and view e.g. of organizational modules developed since the publication of the Matrix report and no longer all conclusions are today still state of the art. Nevertheless, the modules are included as samples in Appendix E – including a short placement in today's interpretation.

Additional modules will be derived when actually describing the Reference Architecture for C-ITS (chapter 7). Appendix F shortly summarizes these modules.

In the future, any other ITS architecture might contribute to the modules collected in the Modular Construction System, ensuring that the growing pool of modules introduce rising design opportunities for new architectures.

5.7. Summary and Conclusion

The Modular Construction System was previously identified as important additional element in an overall C-ITS architecture to fulfill the requirements towards such an architecture. The chapter at hand is dedicated only to this new part. It illustrated the dependencies to the remaining architecture and associated with this explained the internal structure of the new architecture element.
Based on this theoretical placement a practical approach is presented to actually enrich the generic structure with content. The relevant aspects, which are characterizing modules, are identified and a template for the description of modules in the Modular Construction System is introduced. For one example from the C-ITS Corridor System Architecture the template is filled. Finally, generic support and suggestions for filling the template is provided.

6. Deduction of an architecture from the generic overall architecture for C-ITS

The approach developed in the previous chapters resulted in a generic architecture framework description for an overall architecture for C-ITS (chapter 4). The framework consists of a high-level matrix structure (details see Table 3.1) and the generic scope description for the respective viewpoints (section 3.3.2). Based on these findings a generic structure of the overall C-ITS architecture framework was finally developed (chapter 4) including a new architectural element, the Modular Construction (chapter 5).
The developed framework shall be the basis for the description of Reference Architectures for different domains – complemented by the corresponding System Architectures. Before a sample Reference and System Architecture are presented in this thesis, some general recommendations and guidance for the transformation of the generic framework into an actual architecture description shall be given.
This chapter describes the two main paths that can be followed for assembling architectures based on the overall C-ITS architecture developed in this thesis.

6.1. Guidance for the description of an architecture for a system and its services

Usually, the trigger for the description of a new architecture is a new service that shall be realized within either an existing or new system. The most descriptive facet usually is the functional workflow of this service, therefore the stakeholders that have the responsibility to develop the new architecture commonly start on this level. Accordingly, the provided recommendations for deriving a practical architecture from the generic structure has a comparable approach and focuses on the functional description as guideline – the remaining viewpoints are complemented respectively.

Every service for which an architecture can be described is part of a system. In general, a system circumferes a number of objects in a defined framework which have a relation with each other. System boundaries define which components belong to the system [Kopacek and Zauner, 2004]. Within such a system one or more services might be realized, where a service is a functionality provided to users of ITS, designed e.g. to increase safety, sustainability, efficiency, or comfort [ISO 21217, 2009].

For the description of the architecture of a system – and thereby as well the architecture of the service which is running in this system – two options exist. One is most suitable to develop the architecture for a service with a strictly sequential, well defined workflow. It focuses on the description of the **service process** and emanating therefrom identifies the

elements from the Modular Construction System that are suitable to realize this process across all viewpoints (organizational, functional and technical).
The other way is rather suitable for the description of the system as a whole, addressing as well aspects which are not in focus of the service process. As well services with workflows, that do not follow a linear path of steps for the resume, can be described with state machines, as it would be excessively hard to produce conditional rules to capture all possible paths [Jausovec, 2008]. In both cases all relevant objects are identified and the **state transitions** for each object are described. To each state transition, modules from the Modular Construction System can be assigned, leading to a similar but much broader result than the process oriented approach. The resulting description will as well capture elements around the core service workflow which are still part of the system but not in the main focus. The result is often called 'state machine'.
The service process oriented description is addressed in detail in section 6.1.1, the state transition oriented description in section 6.1.2. Both approaches do not compete with each other but complement one another. This is summarized in section 6.1.3. Finally, the expansion of both concepts to the organizational and technical aspects are addressed in section 6.1.4.

6.1.1. Service process oriented description of a system

The service process oriented description focuses on one or several services which are implemented in the system. The main course of action of the service(s) can be modelled with one or more processes. Each process consists of a number of process steps, depending on the level of detail that is addressed with the process chain, there might be more or less process steps. Contingent on the complexity of the service, one or more processes are required to capture the whole service. An abstract sample processes is depicted in Figure 6.1.
Many theoretical approaches for the description of an architecture, as well as existing

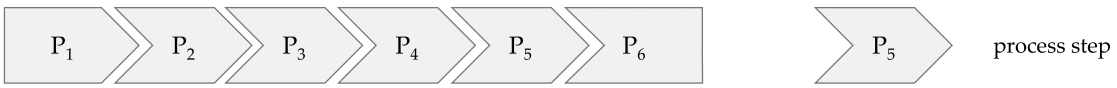

Figure 6.1.: Generic description of process

architectures, focus on the process oriented description of their architecture. Therefore, right in the beginning of an architecture description the respective (business) processes are identified. These descriptions are then used to develop and refine the architecture description: usually elements from the functional part of the Modular Construction System are selected, which correlate with the process steps, resulting in the functional description of the services. Modules for interfaces are picked and a data model is assembled. Subsequently the organizational aspects like roles and responsibility can be addressed before finally turning towards the technical modules. This all results in a selection of modules across all viewpoints which are required to realize the service. Additionally, the process links together the selected modules. Accordingly, the result is a detailed and complete architecture description based on the core process(es) of the service.
The service process oriented description rather matches a Bottom Up Approach.

6.1.2. State transition based description of a system

The definition of a system from Kopacek and Zauner [2004] states that each system consists of a large number of objects. ISO 10746-2 [1996] defines an object as a model of an entity that is characterized by its behaviour and its state. Objects can represent different aspects, they might be physical (often corresponding to elements from the technical viewpoint) or virtual (elements from the functional viewpoint). A system as a whole can be split up into objects, depending on the level of detail that is addressed, this might result in a large number of different types of objects. Examples for objects can be the presentation panel on a variable message sign, which is able to show different information, or a data object that plays an important role in the information (data) flow of the system.
Independent from the type of the object, each object can undertake different states – the transition from one state to another is called state transition (Figure 6.2). This transition can be triggered by different causes. The summary of all state transitions is a state machine, which is defined as a model of behavior composed of a finite number of states, transitions between those states, and actions [Wikipedia, 2016b]. The resulting state machines are usually object specific.

The sum of state machines for all objects and therefore the whole system leads to the

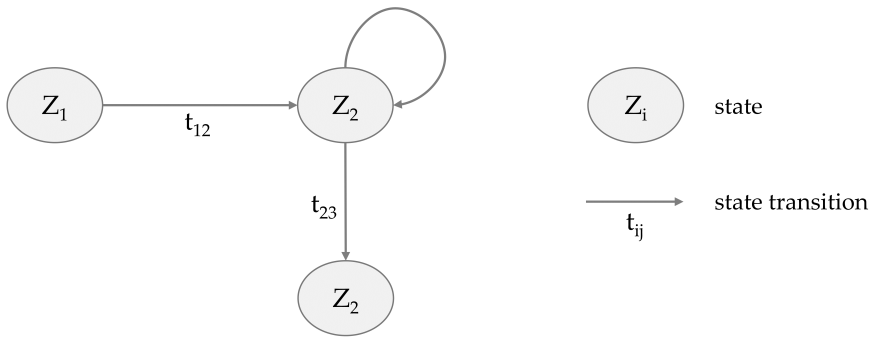

Figure 6.2.: Generic description of a state machine that has three different states, transition between states and within a state are possible

description of the system behaviour. Unfortunately, this either involves a large number of state diagrams or one state diagram that is very complex. According to this, not all state transitions for a system are modelled, the focus is on those which are in direct relation with the core business process of the system. This either results in a rather process oriented state machine or the use of UML activity diagrams to describe the behaviour of the system [Stotts, 2000]. The activity diagram addresses the most relevant state transitions within the system.
The state transition based description rather matches a Top Down Approach.

6.1.3. Combination of both approaches

The two approaches presented in sections 6.1.1 and 6.1.2 are not completely independent from each other. Especially the states and state transitions which are very close to the core service process usually become part of the process (Figure 6.3): process steps are at the

same time state transitions, e.g. the element P_1 from the generic process chain describes a state transition of an object A from state Z_1 to Z_2. In general, a process step is equal to a state transition of an object, the input before and output after the process step can be described with two states of the respective object. Hence, business process and state machine can be conveyed into one another.
The objects of the system which are described with the state transitions might occur mul-

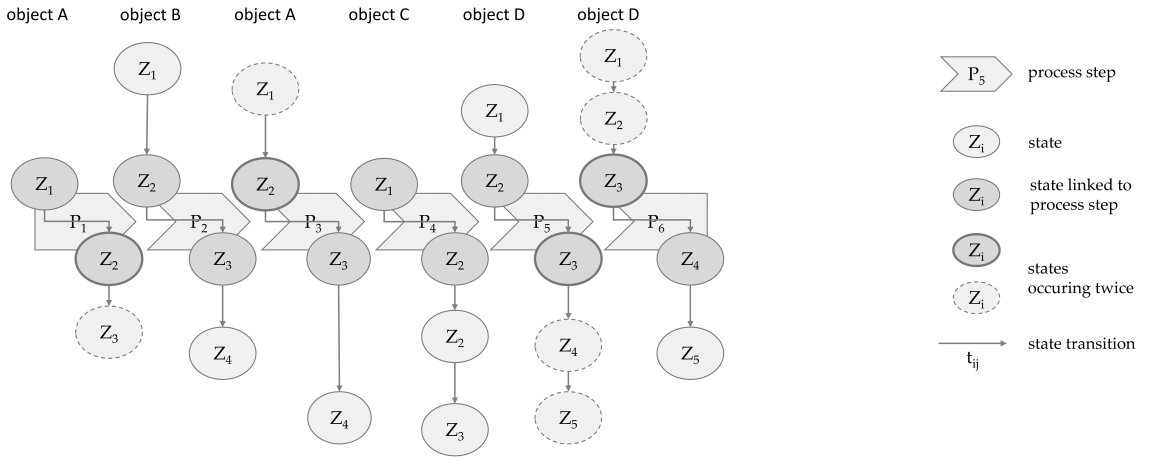

Figure 6.3.: Context and dependencies between process and state oriented description of system and its service

tiple times within a process. This option is included in Figure 6.3: object A and D are each involved in two process steps.

Apart from this tight connection between both approaches, which is described above, they both built up a framework specific for the object or the service that serves as basis for the respective architecture description and that can be augmented with the modules from the Modular Construction System. The modules described in the Modular Construction System already have a structure that allows them to be placed both in the process and state oriented descriptions. The modules selected with the process oriented approach shall be a subset of the modules selected with the state transition based approach.
The two procedure models, process oriented and state transition based, used for the identification of modules for a specific architecture, do not result in new, additional elements inside the architecture but represent the central theme that sticks together the flexible and free elements of the Modular Construction System.

6.1.4. Expanding the service process oriented and state transition based approach to other viewpoints

Applying the concepts described in sections 6.1.1 to 6.1.3 will lead to the description of the architecture's functional viewpoint. Independent of the approach that is actually selected, the remaining viewpoints can be added to either proceeding:
Core element of the **organizational** viewpoint are stakeholders and actors, which are tightly

linked to functional modules (actions) – which both occur in the process oriented and state transition based approach. Hence, roles and responsibilities can be assigned both to process steps as well as to objects and their corresponding state transitions.
The technologies from the **technical** viewpoint are identified in a similar way. They have a strong dependency on the functional workflow, hence, available and suitable technologies are selected to match either the process steps or the objects and their state transitions.

6.2. Summary and Conclusion

The description of an overall architecture for C-ITS (chapter 4) provides a comprehensive and valuable but theoretical framework for the description of architectures. The Modular Construction System (chapter 5) supplies a huge toolbox of components which can be arranged to an architecture resembling the theoretical framework. To close the gap between the theoretical framework, the extensive Modular Construction System and the objective of describing real architectures on different levels, two additional workflows are added.
The service process oriented approach focuses on the workflow in terms of core business processes, that traverse the system. The process in turn backs up the selection of the respective functional, organizational and technical modules. The scope of the state transition based description may be much broader, addressing a whole system, for which an architecture shall be developed. Starting point are the system's objects and their state transitions resulting in numerous workflows which can be underlined by functional modules, complemented with organizational and technical facets. The main profit of both approaches is the link they establish between self-sustaining modules.
The present guidance for the description of an architecture not only closes the gap between the theoretical framework and its practical application that will follow in the subsequent chapters. It additionally emphasizes that, despite the structure applied for the resulting overall C-ITS architecture description, the actual process of developing this structure has a strong focus on the functional workflow. The following chapters comprise the generic description of the Reference and System Architecture – developed through the guidance given in this chapter but resulting in a generic structure like it was given in chapter 4.

The architecture descriptions in the following chapters focus on the process oriented approach as this approach is mainly applied in the corresponding material from already existing architectures. Nevertheless, these results are combined with additionally developed state transition descriptions.

7. Reference Architecture for C-ITS

A Reference Architecture provides a generic blueprint for domain specific implementations. It comprises all specifications and standards which are required for interoperable instances [Definition from section 3.2.5]. The Reference Architecture realizes and details the requirements and statements made in the Framework Architecture, basically the Reference Architecture is the concretization of the Framework Architecture. The Reference Architecture – like the Framework Architecture – is structured in the viewpoints organizational, functional and technical.
This chapter describes the Reference Architecture for the domain C-ITS. This implies that the description of the viewpoints in the subsequent sections explicitly reflect the requirements and characteristics of C-ITS.

The different viewpoints of the C-ITS Reference Architecture are not all described to the same extent.
There are only few descriptions of organizational aspects available – in particular no abstract description of the **organizational** viewpoint does exist so far. Therefore, this will be one of the focuses and the description of the organizational aspects will be very extensive and detailed. The organizational viewpoint is described in section 7.1.
In the **functional** area already a lot descriptions as well as specifications, white papers and standards are available. Some of them were analyzed in detail in section 3.3.2.2. Therefore, the description of the functional viewpoint will focus on the depiction of the general framework, its core aspects and where possible refer to existing standards and descriptions. The consequence being that this part rather summarizes and references existing documents, not explicitly diving into details. The functional viewpoint is described in section 7.2.
The **technical** aspects are much depending on the requirements and boundary conditions of each individual implementation scenario. Though it is possible to describe some general abstract principles – specifying the details is linked to becoming implementation specific and is therefore not addressed here but in the practical example. The technical viewpoint is described in section 7.3.

The Reference Architecture and the Modular Construction System are closely linked (see section 5.1) – elements applied in the Reference Architecture can be found in the large toolbox of the Modular Construction System. Hence, elements identified in the following sections will be transferred into the Modular Construction System. A detailed description of the Modular Construction System can be found in chapter 5. The sample modules derived from the C-ITS Reference Architecture are listed in Appendix F.

For the actual realization of the Reference Architecture the process oriented and state transition based approaches described in chapter 6 were applied. Like in chapter 6 the description was developed emanating from the functional viewpoints and subsequently

deriving the organizational and technical viewpoint. The following sections summarize the resulting C-ITS Reference Architecture, its description follows the generic structure of an (overall) C-ITS architecture structure like it was concluded in chapter 4. Therefore, the viewpoint order in this chapter does not reflect the realization process but the generic architecture structure.

NOTE: The description of each of the three viewpoints follows the same generic structure: Starting from the initial definition of the respective viewpoint, as it was developed in chapter 3, then the motivation for the definition of the viewpoint is stated. Afterwards, the approach which was applied to develop the detailed viewpoint description is described, including a short summary of the results from the applied Top Down and Bottom Up Approach. Finally, the resulting viewpoint is specified. Partially, this is complemented with additional information.

7.1. Organizational Viewpoint

The organizational viewpoint describes the strategic goals and objectives as well as the rules and policies applicable in the system. It describes the roles and responsibilities for the system, comprising not only the individual roles but as well the link between the different roles. [Definition of Organizational Viewpoint from section 3.3.2.1.3]

7.1.1. Motivation

Any ITS implementation requires a group of actors that realize the processes and activities of a defined system. All required stakeholder activities together are named the organizational architecture. The organizational architecture consists of a number of complementary roles and the corresponding responsibilities. The individual actors select one or more roles out of the organizational architecture and from then on fulfill the related responsibilities. Not all roles in an organizational architecture are apparent and it is possible that in the process of staffing the different roles with actors particular roles are missed. In this case an organizational architecture supports the stakeholders leading deployment activities to even proactively cover such organizational 'blind spots' with corresponding actors. Otherwise, missing actors might be a crucial show-stopper of any deployment.
Characteristic for C-ITS is the involvement of a large number of stakeholders and actors from different industries as well as the public sector. This fact even increases the complexity of an organizational architecture for C-ITS, as assigning roles to actors is no longer an activity amongst a small group. Therefore, a blueprint of roles is an important utility to successfully operate C-ITS.

7.1.2. Process of defining the organizational viewpoint

The general description of the organizational viewpoint in section 3.3.2.1.3 does not provide any blueprint description that only needs to be customized for the Reference Architecture. Therefore, the Top Down Approach and Bottom Up Approach are used again to develop a detailed description of the Reference Architecture organizational viewpoint. Aspects, methods and useful approaches mentioned in section 3.3.2.1 are taken up again and

will be applied in detail in the following paragraphs.

Chapter 6 already concluded that the approaches for deriving an actual Reference Architecture has almost no implications on the description of the organizational viewpoint. The resulting roles and responsibilities both in the process oriented and the state transition based approach are almost identical, usually only the scope of the viewpoint description gets broader in the latter case.
Basis for the description of the organizational viewpoint are the functional work flows of services addressed in the respective architecture, hence, the same processes and state machine like in section 7.2 are applied.

7.1.2.1. Top Down Approach

The Top Down Approach identifies suitable high level descriptions of organizational architectures, selects an appropriate one and customizes this according to the needs and requirements of C-ITS.
The evaluation in section 3.3.2.1 showed that only few organizational architecture models are available that might be consulted as high level blueprint for the C-ITS organizational architecture. The only one that in fact practically supports the high-level description of roles and responsibilities was ITIL v3 developed by the Open Group [ITIL, n.d.]. ITIL v3 provides a large number of roles that cover all phases of software and product development starting from strategic and design decision to implementation, operation and maintenance. Its scope thereby is already much broader than a pure service process focused approach. Therefore, the consideration of ITIL resembles the state transition approach (6.1.2).
A first pre-selection and structuring of the ITIL v3 roles was done within the development of the CEN / ISO 17427 standard [ISO 17427, 2013]. The details on the selection and manipulation process can be found in Appendix C.

Result of the pre-selection and structuring activity are the following remaining (modified) ITIL roles: Financial Manager, Service Catalogue Manager, Service Level Manager, Service Owner, Technical Analyst, Risk Manager, Capacity Manager, Availability Manager, IT Operations Manager, Information Security Manager, Compliance Manager, C-ITS Architect, Change Manager, Project Manager, Configuration Manager, Test Manager, Access Manager and (modified) the Service Recipient.
For the C-ITS characteristics the role of the Communication Manager was added in the description in section 7.1.3. Together with the results of the Bottom Up Approach (section 7.1.2.2) they will form the basis for the organizational viewpoint of the Reference Architecture (7.1.3).

7.1.2.2. Bottom Up Approach

The Bottom Up Approach starts from practical examples and implementations describing a system in detail and develops based on that a more abstract and general description. The existing descriptions are mainly based on process oriented procedures.
Main focus of the Bottom Up Approach in this thesis is the operational process of the se-

lected service, therefore, the identified roles are from the field of Functional Operation. A similar analysis is of course possible for other aspects of a system but is not in the scope of this thesis. Details on these facets, which are required for the complete description of the organizational viewpoint, are derived from the Top Down Approach.

The steps of the Bottom Up Approach are accomplished on a set of services which first needs to be identified. Currently, there is no real-world implementation of C-ITS services available. Several research projects developed and implemented different C-ITS services, various initiatives defined lists with so called 'Day 1 services' which probably will be implemented first when deployment of C-ITS starts. Examples are the Day 1 services listed by the Amsterdam Group, by the Car2Car Communication Consortium or European projects like Easyway (details in section 7.2.2). For the development of the organizational viewpoint with the Bottom Up Approach, services shall be selected in a way that the results are comparable with already finished evaluation activities on ITS architecture structures. Therefore, the example service selected for the Matrix report [Lotz et al., 2012] is chosen here again: Traffic Information on Hazardous Location.
For the selected service the corresponding actors responsible for certain activities within the service's workflows are identified and help to develop general roles and responsibilities that finally are documented in the C-ITS organizational architecture. A detailed description of the approach can be found in Appendix D. The C-ITS specific functional roles identified through the Bottom Up Approach are Content Provider, Service Provider and Service Recipient.

Besides the analysis of services, the results of three projects are taken into consideration.
The C-ITS project SafeSpot executed a similar approach like the analysis in the Bottom Up Approach, a summary of the results was already presented in section 3.3.2.1.2. The system operation related roles described in SafeSport and those identified through the Bottom Up process cover the same responsibilities and mainly differ in their names.

A detailed stakeholder analysis was carried out by the European Easyway project [Schindhelm et al., 2012]. Therefore, the top-priority services selected within the project were mapped to a general process description like in the Bottom Up Approach described in Appendix D, additionally a set of stakeholder interviews were conducted. Based on those interviews a Strengths Weaknesses Opportunities Threats (SWOT) analysis of potential organizational structures for the individual services were undertaken. The stakeholder analysis did not yet draw any conclusions on preferred scenarios but paved the way for activities on the organizational viewpoint like the standardization in ISO 17427 [2013].
Different aspects addressed in the EASYWAY stakeholder analysis were picked up again for the description of roles and responsibilities in ISO 17427 e.g. the TISA value chain as basis for the analysis of the operational process. The results from the stakeholder analysis gave first ideas on the stakeholders perspective on possible roles – and thereby introduced and reflected the true reality in the discussion about the organizational viewpoint.

And last but not least, the FRAME project developed an extensive list of actors which is published in D15 part 6 [Bossom et al., 2011]. Like suggested in section 3.3.2.1.2 the list of actors was matched against the roles identified by the previously discussed input

sources of the Bottom Up Approach: The FRAME actors mentioned in D15 cover many different aspects of ITS and span a large number of different domains. Most of them can be matched to roles, especially from functional operation, and confirm the results from the other approaches described in this section. Unfortunately, there are as well actors mentioned which are actually elements of the technical viewpoint, a clear separation did not take place.

7.1.3. Resulting organizational viewpoint – Roles in C-ITS

For the description of the organizational viewpoint finally the results of the Top Down and Bottom Up Approach are merged. Both approaches contribute with valuable aspects and shall be included in the final description of the organizational viewpoint of the Reference Architecture.

Originally, the method described in sections 7.1.2.1 and 7.1.2.2 was developed and first time applied for the standardization of the C-ITS organizational architecture in CEN TC 278 WG 16 DT4 (lead: Teresina Herb). Results (as of July 2013) are documented in ISO 17427 [2013]. A short summary in German on ISO 17427 can be found in Straßenverkehrstechnik [Herb, 2013].

Since the publication of both ISO 17427 and the article in Straßenverkehrstechnik the discussion on ISO 17427 continued and first attempts were undertaken to practically apply the structures described in the standard. Those first experiences resulted in a need for some changes of names, descriptions and structures of roles. Due to the characteristics of the standardization processes, they are not yet published as an update but are already included in the following description of the organizational viewpoint. An update of the ISO 17427 standard is ongoing.

Apart from the roles and responsibilities the organizational viewpoint is supposed to describe strategic goals, objectives as well as the rules and policies applicable in the system (see definition in section 3.3.2.1.3). Those aspects cannot be described abstractly as they are system and implementation dependent. Therefore, they are not covered in this generic Reference Architecture viewpoint description.

7.1.3.1. High level roles in C-ITS

Before focusing on the resulting organizational viewpoint there are some general findings on organizational architectures that can be derived from combining the results of applying the Top Down and Bottom Up Approach (sections 7.1.2.1 and 7.1.2.2):

- roles and responsibilities can be identified and described on different levels of detail
- an implemented system does require different levels of detail for the organizational architecture of different parts of the system – the level of detail is not homogenous across all parts of the system

Referring to those general results the identified roles and responsibilities are structured accordingly. Different levels of abstraction and detail are reflected in the organizational

architecture and a set of high-level roles and corresponding sub-roles are identified and described. On the top level the following roles were determined (see as well Figure 7.1):

- System Operation (from Bottom Up Approach)
- System Management (from Top Down Approach)
- Functional Operation (from Bottom Up Approach)
- Policy Framework (from Top Down Approach)

The four high level roles are in line with the ones described in ISO 17427 and are defined as follows [ISO 17427, 2013]:

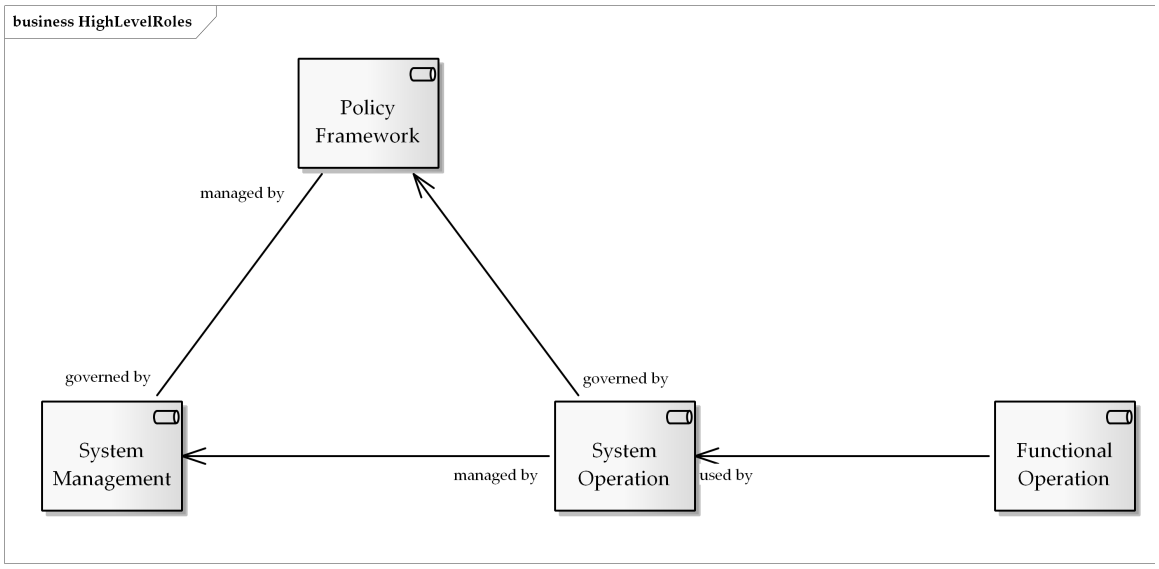

Figure 7.1.: High-level roles and their relationships

The role '**System Operation**' is responsible for the proper execution of the applications that provide an end-to-end ITS service. This includes reliability for the coordination, organization and execution of the whole process from initial data collection to the presentation of the final service result. One of the major interfaces of this role is with the actor(s) of the role 'Functional Operation' who use(s) the system.
The role '**Functional Operation**' is responsible for the proper functional operation of its particular sub-role. To perform an appropriate operation an actor of the role 'Functional Operation' uses the system provided by actors of the role 'System Operation'.
The role '**System Management**' is responsible to fulfill all required management activities within the system, this especially includes activities supporting 'System Operation'. Additional actions are the management of the 'Policy Framework' activities.
The role '**Policy Framework**' is responsible for all governing and institutional activities required in the system.

Usually those four high level roles will not be the roles that will be assigned to real actors in a system, the roles System Operation, Functional Operation, System Management

and Policy Framework require more detailed sub-roles which share the tasks and responsibilities originally assigned to the high-level role. The process described in the Top Down and Bottom Up Approach produced the following roles with sub roles:

7.1.3.2. Role: Functional Operation

The role 'Functional operation' has two different aspects modelled as sub-roles 'Generic functional operation' and 'Specific functional operation'. Each actor with a role 'Functional operation' has at least one sub-role in 'Generic functional operation' and at least one sub-role in 'Specific functional operation'. The '**Generic functional operation**' reflects the process chain of the corresponding services and the '**Specific functional operation**' reflects the functional sub-role within a specific C-ITS scenario.
Figure 7.2 shows the relation between the sub-roles of the role 'Functional operation'. The core roles of 'Functional Operation' are the 'Generic functional operation' sub-roles. The corresponding responsibilities are closely linked to a C-ITS services and were initially derived from the service process. Actors assigned to one of the 'Generic functional operation' sub-roles not solely cover these responsibility, they additionally have a 'Specific functional operation' sub-role. The dotted white oval in Figure 7.2 shows an example where an actor has the generic sub-role 'Service provider' and the specific sub-role 'Roadworks operator'. Depending on the C-ITS scenario different combinations of the generic and specific functional operation sub-roles exist.

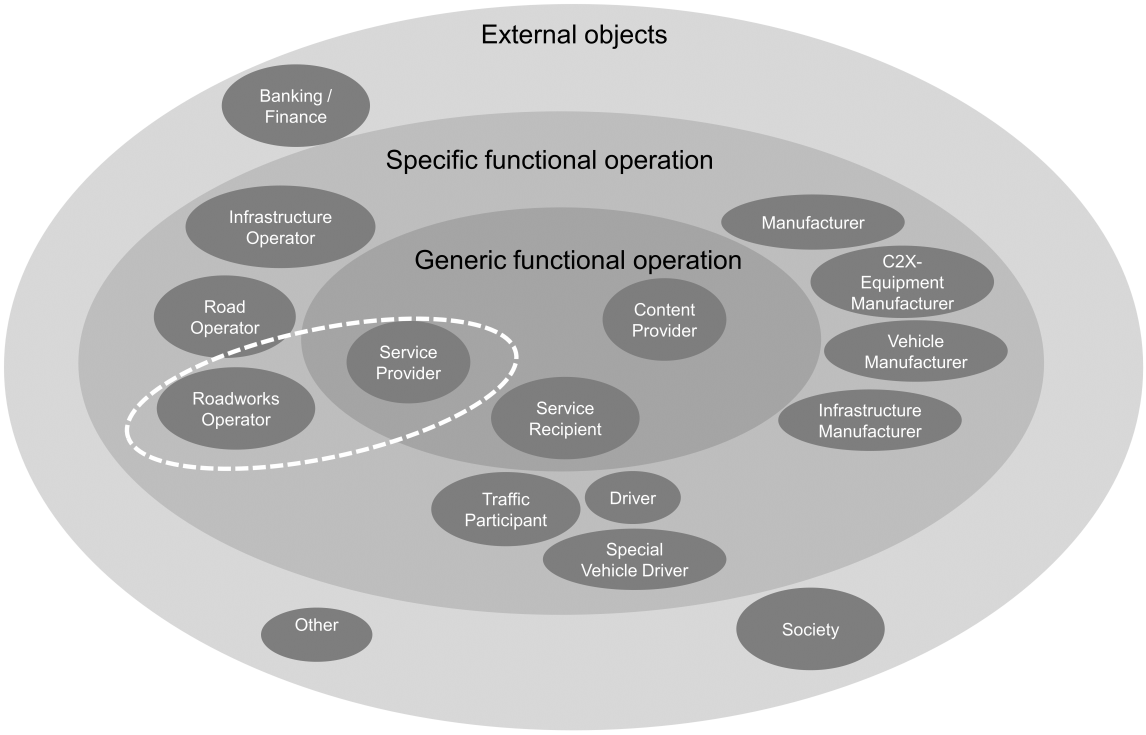

Figure 7.2.: Role 'Functional operation', its subroles and examples for their relation

The sub-role 'Generic functional operation' reflects the process chain of the corresponding service. It is composed of the sub-roles 'Content provider', 'Service provider' and 'Service recipient'.

- Content Provider

  provides various types of content

- Service Provider

  identifies which algorithm is suitable to fulfill the end-to-end ITS service, it determines the content that is required to run the ITS service, afterwards runs the ITS service and provides the service result

- Service Recipient

  incorporates the triggering of ITS services available within the system. The sub-role Service Recipient has a tight relation to the role System Operation

The sub-role 'Specific functional operation' reflects the functional sub-role within a specific C-ITS scenario. It is composed of the sub-roles 'Traffic participant', 'Infrastructure Operator' and 'Manufacturer'.

- Traffic participant

  summarizes traffic participants in a specific C-ITS scenario. (Sub-roles: Driver, Special vehicle driver)

- Infrastructure Operator

  summarizes any infrastructure operator involved in a specific C-ITS scenario. (Sub-roles: Road Operator, Road Works Operator)

- Manufacturer

  is responsible for the manufacturing of any products used in a specific C-ITS scenario. (Sub-roles: C2X equipment manufacturer, vehicle manufacturer, infrastructure manufacturer)

Details on the mentioned sub-roles are available in the updated but not yet published version of ISO 17427.

7.1.3.3. Role: System Management

System Management is responsible for all management activities in the system. It supports both 'System operation' and 'Policy framework'. It is a distributed role with multiple entities:

- Service Catalogue Manager

  responsible for up-to-date maintaining of the service catalogue that lists all registered ITS services

- C-ITS Architect

  maintains the implemented ITS architecture with its architecture viewpoints

- Change Manager

  responsible for all change activities including the collection of change requests, handling of change requests and application of changes

- Test Manager

  ensures that the deployed C-ITS services fulfill their specification

- Service Level Manager

  responsible for negotiating the C-ITS service level agreements and ensures that these are met

- Compliance Manager

  ensures that standards, guidelines, laws and regulations for C-ITS are followed and applied

- Financial Manager

  is optional, depending on the type of ITS service. Responsible for managing budgeting, accounting and charging in the context of the ITS service.

- Service Owner

  responsible for designing and delivering particular C-ITS services within the agreed service levels

- Project Manager

  responsible for planning and coordinating the resources to deploy, operate and maintain C-ITS

- Information Security Manager

  ensures the confidentiality, integrity and availability of the system, data, information services and users

7.1.3.4. Role: System Operation

The role 'System operation' shall be responsible for all activities related to the operation of the system.

- Communication Manager

  enables the communication between ITS Stations

- Risk Manager

  identifies, assess and controls risks

- Capacity Manager

  ensures that C-ITS services and infrastructure are able to deliver the agreed capacity and performance targets

- Availability Manager

  defines, analyzes, plans, measures and improves all aspects of availability

- Technical Analyst

  provides technical expertise and support for the management of the C-ITS infrastructure

- Configuration Manager

  maintains information about infrastructure equipment and hardware required to deliver C-ITS services

- IT-operations Manager

  responsible for the proper operation of the IT-system

- Access Manager

  responsible for granting the right to access a C-ITS service to authorized service recipients and preventing access of non-authorized service recipients

7.1.3.5. Role: Policy Framework

The role Policy Framework provides the governing and institutional activities in the system, including necessary policies, regulations, laws and agreements.

- Non-regulatory Policy Institution

  definition of non-regulatory policies (e.g. agreements between stakeholders, regulations)

- Authority

  definition of regulatory policies. (Sub-roles: Legislative, Jurisdiction, Executive)

- Standardization

  develops, maintains and provides standards

- Security Certificate Body

  issues certificates, keys, pseudonyms to secure C-ITS communication etc.

7.1.4. Implementation recommendations for organizational viewpoint

Those ready for deploying C-ITS might expect recommendations for the implementation of the C-ITS organizational architecture. For instance, important to know is a potential subdivision into mandatory and optional roles and thereof derived the minimum set of roles that need to be overtaken by actors. Linked to that is the question of how to deal

with missing actors. It cannot be expected that actors for each role are easily identified and assigned – new roles might require new organizational entities that fulfill the corresponding responsibilities.
And last but not least, a sample profiling of the organizational architecture is of interest. Usually theoretical architecture specifications come with potential profiles to give the stakeholders an idea how to practically realize the theoretical model. For the organizational architecture that might include a potential split of single roles between multiple actors, single actors taking over several roles or the merge of individual roles to an appropriate bundle.

So far, no implementation of the C-ITS organizational architecture does exist. First discussions on the defined roles and sub-roles started in recently initiated European deployment activities like the C-ITS Corridor [Cooperative ITS Corridor, n.d.]. Those front runners will make their experiences with the theoretical model and reflect their results and need for changes in the standardization activities on the organizational architecture. A sample application of the theoretical description of section 7.1.3 can be found in chapter 8. As mentioned previously, this structure might be subject to change when first experiences are made within the front runner implementations.

7.1.5. Organizational architecture with economic focus

Besides the technical focus of the organizational architecture described in section 7.1.3 there are activities on roles and responsibilities with a slightly different focus.
In 2013 BASt did allocate a project called 'Development of a concept for institutional role models as contribution to the deployment of C-ITS in road traffic' (BASt report not yet published 'Entwicklung eines Konzeptes für institutionelle Rollenmodelle als Beitrag zur Einführung kooperativer Systeme im Straßenverkehr' [Schulz et al., 2013]). The contracted experts analyzed from an economist's perspective the relevant C-ITS stakeholders, their motivation and potential business models in C-ITS. The focus of their work was not only the operation of C-ITS but all economic phases necessary to provide C-ITS, including research, development, production, maintenance and shut down. The corresponding roles for those phases were analyzed both from a technical and economical point of view and hence covered aspects like controlling, procurement, human resources and others. Result of the project is a first proposal for a structure to determine an **institutional role model**. This combines the identified set of economic meta roles, e.g. business management, sales, procurement, production, human resources, financial management and controlling (left column in Figure 7.3), with the different economic phases (top row). For the different market phases, actors are assigned to roles, their respective action intensity (right column) is determined resulting in an institutional role model.

For the description of technical roles in this project, the results of ISO 17427 were picked up and integrated. The project team did not identify any discrepancies and there was no need to make changes to the already identified roles and the respective responsibilities. Accordingly, this can be seen as review and verification of ISO 17427.
Beyond that, the scope and the corresponding structure developed for the description of institutional role models is broader than the one for the technical roles. Nevertheless,

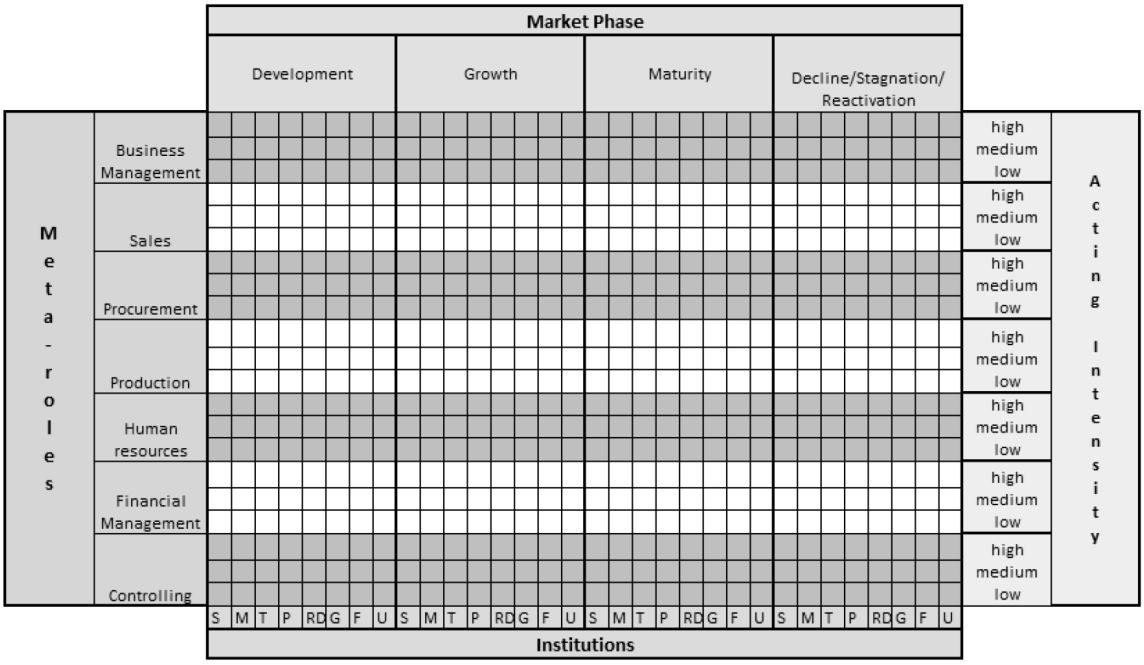

Figure 7.3.: Graphical summary of results from BASt project report [Schulz et al., 2013]

the two approaches complement each other and the more specific, technical approach fits well in the generic economic approach: The technical roles defined in section 7.1.3 (or ISO 17427) can be mapped completely to the economic meta roles (left column in Figure 7.3). In terms of the market phases (top row in Figure 7.3) the description of the technical roles in section 7.1.3 and ISO 17427 currently only address the operational phase of the system (corresponds to 'production'). But it is possible to extend the general approach described in this thesis and develop a description for the other market phases. This may comprise a slight modification of some responsibilities addressed in the current description, to some extent additional roles need to be included, other existing roles might not be needed.

In the project 'Development of a concept for institutional role models as contribution to the deployment of C-ITS in road traffic' an institutional role model itself was not developed. This is part of currently ongoing activities that include the mapping of this theoretical description to a real world example to verify and adapt it:
In the German project CONVERGE [CONVERGE, n.d.] organizational aspects for C-ITS are discussed, too. In work package 1 several experts worked on an 'Institutional role model'. The Institutional role model developed in the project is supposed to identify potential C-ITS business models and determine the likelihood of a successful realization. A first deliverable was published in 2013 [Mann et al., 2013]. Based on this first deliverable that basically picks up the ideas already identified in the BASt project mentioned above [Schulz et al., 2013], the project applied the developed structure (that is slightly modified compared to the one depicted in Figure 7.3) with the support of all CONVERGE project partners. For a possible C-ITS scenario the involvement of different stakeholders and their

respective action intensity in the different market phases was analyzed. Results were presented at the final event of the CONVERGE project in 2015 [Schulz, 2015].

Complementing both activities on the institutional role model is a BASt internal project that incorporates the results of the work on institutional role models [Schulz et al., 2013] and the CONVERGE project. It will advance the results of both activities to a general concept including implementation recommendations and will identify opportunities and boundaries of the institutional role as potential support for the deployment of C-ITS. Results will be published as BASt report in 2017.

With the spread of the rather technical and operation focused description of roles and responsibilities (see section 7.1.3) towards a description that comprises as well economic aspects and different market phases, the organizational viewpoint becomes an ample role model. The activities mentioned in this chapter valuably contribute to these advancements. However, these research activities just started recently, as soon as they will be finalized it will be necessary to review the current description of the organizational viewpoint and if necessary update and adapt it.

7.2. Functional Viewpoint

The **functional viewpoint** describes for a selection of services the corresponding work flows and use cases. Additionally, the corresponding information structure and data model are defined and described. The services are split into appropriate modules and sub-services which are linked through interfaces, both are described within the functional viewpoint. For the link between these components communication plays an eminent role, therefore, a communication architecture comprising various communication aspects like data models, protocols and access media are defined. [Definition from section 3.3.2.2.3]

For the functional viewpoint no completely new description is needed like for the organizational viewpoint as a lot of material is already available. Therefore, this chapter rather collects all this information and relates it to each other, complementing it with additional descriptions and explanations. Not many new elements will be needed: for the functional viewpoint rather a clear and distinct structure is required – including the respective assignment of already existing elements. As structuring approach mainly the results from chapter 6 are applied.

7.2.1. Motivation

The functional part of the Reference Architecture covers different aspects and shall provide a toolbox of modules that can be combined to realize the selected service in a corresponding System Architecture. The focus is on modules, the sub-modules needed to realize the services and the corresponding interfaces between those elements.
The functional part described in this chapter covers various aspects from different layers that together form the functional viewpoint. The single aspects are all packed into modules but not all modules can be combined with each other, as they may belong to different

sub-layers. For example use case modules providing a defined functionality or sub-process shall not directly be combined with a communication channel option module. The detailed dependencies are modeled in the Modular Construction System.

7.2.2. Process of defining the functional viewpoint

The functional viewpoint will be developed through a combination of the Top Down and Bottom Up Approach like it was already done for the organizational viewpoint. The description reflects the functional aspects identified when defining the frame structure for the overall architecture, as it is described in sections 3.2 and 3.3, complemented with the structures from chapter 6. Thereto belong the **business processes** that describe the leading procedures within the system, the **state machines** that complement the business process and summarize the state transitions of selected objects from inside the system, the elements and **modules** that shape those business processes and state transitions by providing sub-functionalities that are part of the process chain as a whole and the **interfaces** that link the modules including various underlying aspects like data model, encoding and communication.

Central theme within the functional viewpoint are the **services** for which the functional aspects are described. They shape the process description, including the split into modules and interfaces as well as objects and states. Before actually describing the functional viewpoint, a closer look on relevant services is taken.
Currently, no implementation of C-ITS services does exist so far, therefore, the description of the functional viewpoint shall be close to future deployment candidate services. Though the final description of the functional viewpoint shall be as abstract and service independent as possible the examples from the existing Day 1 service lists will be consulted when developing the description of the functional viewpoint.

Various groups are dealing with the different aspects of deployment of C-ITS. Hence, they are as well discussing about suitable services for a Day 1 deployment – what results in different stakeholder dependent lists of Day 1 services. Examples here are organisations like the C2C-CC, the Amsterdam Group as well as projects like EASYWAY. They all developed their specific list of Day 1 services, the selection is heavily influenced by the focus of the stakeholders developing the respective list of services.
The C2C-CC published in 2010 the so called Basic Set of Applications [ETSI 102 637-1, 2010] which is considered to be (at least partially) implemented on Day 1. Services included in this set are: Co-operative Awareness, Road Hazard Warning, Speed Management, Cooperative Navigation, Location Based Services, Communities Services (Value Added Services) and ITS Station Lifecycle Management (Maintenance, Update).
The Amsterdam Group as a slightly broader stakeholder organization, not only involving the vehicle industry but as well representatives from the road authorities and operators, published in their roadmap two different lists of services [Amsterdam Group, 2013], one addressing V2V (vehicle2vehicle)-services, the other covering V2I (vehicle2infrastructure) / I2V (infrastructure2vehicle) services.
Typical V2V services in this respect are Hazardous Location Warning, Slow Vehicle Warning, Traffic Jam Ahead Warning, Stationary Vehicle Warning, Emergency Brake Light,

Emergency Vehicle Warning and Motorcycle approaching Indication. I2V day one use cases are Road Works Warning, In-vehicle Signage, Signal Phase and Time and Probe Vehicle Data.
Other lists of Day 1 or high priority use cases were for example developed in C-ITS projects like EASYWAY [Jandrisits, 2012, slide 5]. They mentioned as potential Day 1 services Hazard Location Notification, Traffic Jam Ahead Warning, Decentralized Floating Car Data, Road Works Warning, In-Vehicle Signage, Traffic Information and Recommended Itinerary and Automatic Access Control / Parking Management.

The initial analysis of the functional aspects will be done on the same basis like the organizational architecture, therefore as example 'Hazard Location Warning' will be used here as well. Hazard Location Warning is part of the Day 1 service lists mentioned above. Although it is usually enlisted with the V2V services, hazard location warning is definitely something that can be implemented in a V2I / I2V scenario. Various implementations of this service already exist in legacy ITS, they are detailed in the Matrix report [Lotz et al., 2012]. Other services from the lists above might be used to verify the resulting functional viewpoint achieved based on the service Hazard Location Warning.

For the development of the various aspects of the functional viewpoint, the previously described method based on Top Down Approach and Bottom Up Approach will be applied. In both parts of the approach the available material is analyzed against the requirements of the overall C-ITS architecture, suitable elements are transferred and recycled, gaps are identified and the missing elements are developed, described and added. The resulting functional viewpoint is described in section 7.2.3.

7.2.2.1. Top Down Approach

The Top Down Approach will take up the proposed generic structure that was identified through the detailed viewpoint description in section 3.3. The architecture models (e.g. Reference Model Open Distributed Processing (RM-ODP), TOGAF, FGSV pyramid) that are the basis for the generic structure of the functional viewpoint only partially provide methods to model the functional viewpoint (and its sub viewpoints) and thereby fill the abstract structure with life. Existing abstract descriptions of functional aspects are consulted to detail the description within the Top Down Approach.
The sources selected for the Top Down Approach need to cover the following aspects: the description of service workflows, the functional modules and the needed interfaces, including data models and communication.

Business processes comprise the description of value creating activities including the related input and output. It is applied in the process oriented approach.
The TISA value chain [TISA Executive Office, 2012] provides a generic description of ITS specific event driven process or value chains. It supports the end-to-end description of a service, including all its intermediate steps (see Figure D.1). The TISA Value chain was already used in the Bottom Up Approach of the organizational viewpoint and there provides the generic structure for the identification of roles and responsibilities. Its focus is on the description of services and their operation – business processes related to management

and policy activities are not covered. As the scope of this document is the operational business process this is no major issue. The TISA value chain was originally developed by the TISA members based on their experience, mainly in a European context.

A rather similar value chain was in use in the EASYWAY project, described in detail in the Traveller Information Service Deployment guideline [Cullen and Barr, 2012]. The value chain was mainly used to identify the different roles and responsibilities but the authors of the guideline additionally pointed out that the structure might also be used for the description of business processes [Cullen and Barr, 2012, page 26]. The EASYWAY value chain consists of five core elements (see as well Figure 7.4): the content provision, the service operation, the service provision, the communication network operation and the end user.

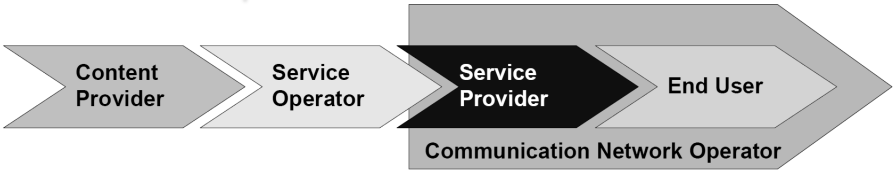

Figure 7.4.: EASYWAY value chain from deployment guidelines [Cullen and Barr, 2012]

The value chain was developed jointly by the EASYWAY partners and represents the generic resource for various traffic information services guidelines developed by the project. The elements easily can be aligned with the TISA value chain (Table 7.1). All elements can be mapped to a counterpart.

EASYWAY	**TISA**
Content Provider	Content Detection
Service Operator	Content Processing
Service Provider	Service Provision & Service Presentation
End User	End User
Communication Network Operator	Not explicitly named but as well part of the description

Table 7.1.: Mapping EASYWAY – TISA value chains

The TISA and EASYWAY value chain provide very precise and striking descriptions of business processes. For the definition of the functional viewpoint additionally the models previously analyzed for the generic structure of the overall architecture are considered. A thorough analysis of RM-ODP and the FGSV pyramid showed that they are suitable to respectively address particular aspects in the process of describing the overall C-ITS architecture. Both provide essential contributions to the definition of the frame structure but are

not that detailed in their description so that they fundamentally influence the description of individual viewpoints.
Slightly different is the TOGAF model, it provides a generic description on how the business processes may be described including proposals for possible formal models (see as well [The Open Group, 2011b]). Sample business processes are not provided as the descriptions themselves are fully aligned with the different models provided by UML [Object Management Group, 2015].
The general recommendations for UML models in turn well fit the state machine based description of the functional viewpoint. This respective description corresponds to UML activity diagrams and the resulting **state machines**.

For the generic description of management and policy related business processes no concrete blueprint like the value chain for the operational processes is available. Nevertheless, there are generic frameworks available which might be customized to the respective matter under consideration e.g. the approach described by TOGAF.

As the focus of this document is the operational business process in ITS, mainly the process chain developed by TISA will be considered. For the description of the respective modules associated with the process chain no specific theoretical approach was identified. Therefore, services will be described according to the structure of the TISA value chain, the resulting modules and interfaces will be transformed into elements of the functional viewpoint.

The state oriented approach would as well be suitable for the analysis of services with regard to work flows, unfortunately no corresponding sources were found. Though some sample state machines were defined and included in the resulting viewpoint description in 7.2.3.
Refining the description of service workflows from the functional viewpoints leads to what several models call information or **data flow** diagrams. All three previously mentioned models provide a suitable viewpoint for this: in RM-ODP these are the Information and Computational Viewpoint, in TOGAF the Information System Architecture with the details on data and applications, in the FGSV pyramid the information structure layer deals with these aspects.
In all three models the data or information flow is closely linked to the service workflow – though no detailed description on how to derive the information flow from an existing business process is provided. The information flow itself shall describe the exchange of information between system entities at a high level of abstraction [Fakhroutdinov, 2015]. This in turn implies the description of interfaces and the content that is exchanged over these interfaces. Applying this on the operational processes entails that the transformation of raw data, describing the initiating event, to the information, finally presented to the user, is modeled. With regard to state machines the data flow can as well be described through state transitions of a data object.

Given that the TISA value chain is the basis for the description of the business process in the functional viewpoint, and since the description of the information flow is closely linked to the business processes, the TISA value chain serves as well as input for the de-

scription of interfaces and content. The transition between elements in the value chain will serve as fundament for the description of the interfaces. Therefore, the flow of information needs to be specified in detail, including a description of the content used by the considered ITS services.
In due consideration of the requirement for a high level abstraction when describing the information flows, the concept of platform independence described in the Model Driven Architecture [The Open Group, 2016] is applied. It supports the generic description of a system without commitment to a specific underlying platform and therefore allows to translate the generic model to implementation specific technologies. Accordingly, a generic data model for the content transferred within the information flows is developed.

Based on the the previously defined modules and the data model finally the interfaces are identified and described as generic as possible. The communication over the identified interfaces needs to be described for the functional viewpoint to later ensure the link to the technical viewpoint. For the abstract top down description the ISO OSI Standard [ISO / IEC 7498-1, 1996] is mentioned that provides a huge framework for various communication options. The C-ITS specific requirements are reflected in the wide spread implementation of the Communication Reference Architectures [ISO 21217, 2009; ETSI 302 665, 2010]. They represent customizations of the ISO OSI standard with a strong focus on cooperative and connected technology.

7.2.2.2. Bottom Up Approach

The Bottom Up Approach for the functional viewpoint starts similar to the organizational aspects from practical examples. Hence, based on an example service (Hazard Location Warning) the functional aspects are developed. The portability is verified by translating the results to other C-ITS services. For the functional viewpoint the common denominators across different services provide the guideline for the selection of the relevant aspects. This generic description is complemented by a variety of options realized by the individual services, those are summarized in the tool box (Modular Construction System) and allow to select the most suitable ones when actually developing a system architecture.

Sources that are used for the Bottom Up Approach of the functional viewpoint are limited to the process oriented approach from chapter 6. This includes

- results from Matrix report addressing both ITS and C-ITS related aspects, this consists of the application of TISA value chain on the Hazard Location Warning sevice
- modules provided by the FRAME Browsing tool

Those sources are complemented by existing standards that cover parts of the functional viewpoint, profiles that contribute lists of standards and their corresponding configuration for specific use cases and other documents that already provide functional descriptions or complete functional architectures.
Unfortunately no suitable state oriented description was identified which could be considered in the Bottom Up Approach.

The **Matrix report** is a rather valuable source for the description of the Bottom Up Approach of the functional viewpoint. It analyzed along a generic value chain (which is following the principles of the TISA value chain) a set of different ITS and C-ITS implementation variations and compiled a summarizing table, which is already reflecting the structural elements of the functional viewpoint, namely the modules and interfaces. The matrix report did not include all business processes but focuses on the operational business process. Hence, the identified modules and interfaces are restricted to this aspect.
The complete analysis in the Matrix report is done based on specific scenarios. However, those in the report slightly differ from the ones used in the Bottom Up Approach of the organizational viewpoint (described in Appendix D.4).
The extension of scope for the analysis of services in the Matrix report beyond the C-ITS specific scenarios like they are described in Appendix D.4 entails several advantages. Analyzing both ITS and C-ITS based on the same criteria leads not only to comparable structures and results but as well contributes to the compliance with the requirement of fully integrating C-ITS as a new technology in the existing ITS landscape: Identifying matchable modules and interfaces enables new combinations of elements previously implemented in monoliths and potentially ends up in fully integrated systems based on modules from legacy ITS and C-ITS.
A detailed description of the analysis and the resulting table (see as well Figure 3.15) can be found in Lotz et al. [2012]. The results of the Matrix report are additionally conveyed to Table 7.2, which is summarizing the modules identified through the Bottom Up Approach.

Apart from the Matrix report the functional viewpoint developed in **FRAME** and effectively implemented in the FRAME Browsing Tool poses another potential source for elements of the Reference Architecture functional viewpoint. The services implemented in FRAME with their modules and interfaces were not aligned with a generic process chain like in the Matrix report – therefore the respective mapping was undertaken.
The results only partially complement the Figure 3.15 developed in the Matrix report as the focus of the services included in the FRAME Browsing Tool is on the evaluation activities in the responsibility of the road operator, detection of events and therefore collection of raw data is only sparsely touched, the final presentation of the service results is not included at all. A detailed description of the interfaces is not provided besides a generic description in D3.3 [KAREN, 2000b].

Detection	**Evaluation**	**Presentation**
Mobile data collection with video, radar, lidar, geo-referencing based on GPS sensors or cellular networks	Evaluation of data based on public or private policies	Presentation of results according to public or private policies

Detection	Evaluation	Presentation
Movement profiles generated by mobile devices based on GPS sensors or cellular networks (Floating phone, floating car data)	Merge of different data sources for further processing according to public or private policies	Presentation on mobile device or in vehicles
Mobile detection of events by a driver or maintenance staff		Presentation on stationary facilities
Stationary detection with video, radar, loop detectors, overhead sensors, bluetooth		
Preprocessing of detected data for services implementing public or private policies		

Table 7.2.: Summary of Bottom Up Approach results in functional viewpoint

Table 7.2 summarizes the results of the Bottom Up Approach for the service and process related modules. For the table structure the categories from the Matrix report were applied again (Detection, Evaluation, Presentation).
The table and its content is not static and needs to be updated regularly with the most recent modules identified for example with the approach described in the Matrix report [Lotz et al., 2012].
NOTE: Similar categories are used for the general description of IT processes (Input, Evaluation, Output). Under 'Detection' the different modules qualified to record the initial event are subsumed. 'Evaluation' comprises the different opportunities to analyze the initial events and transform it into a service (result). 'Presentation' bundles different options for displaying the result to the receiver.

The modules listed in Table 7.2 are all from a rather generic high level. As a matter of course, it is imaginable to identify such modules on a more detailed level where each module has a much more limited scope. Bundles of those detailed modules together might form modules like they are listed in Table 7.2. The detailing of the generic modules in the table can be done recursively: a module currently assigned to the category 'Evaluation' (top level) might be split up into at least three modules from one level below which again can be assigned to 'Detection', 'Evaluation' and Presentation'. The result of the sub-process from one level below is fed as intermediate result in the superordinate process level. An abstract example is given in Figure 7.5.
Apart from that, the modules included in Table 7.2 are rather focused on end user services. Of course, it is as well possible to assign modules from services to the categories used in the table that do not result in display of the outcome to the end user. Service results might as well be used as input for new processes or trigger internal activities. The term 'pre-

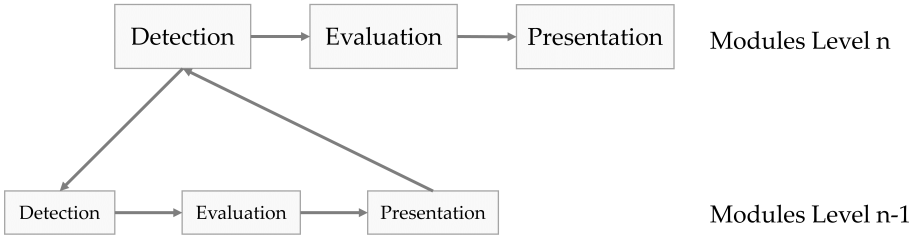

Figure 7.5.: Recursive breakup of module structure

sentation' leaves a lot room for interpretation. Hence, this case is as well in line with the recursive detailing approach described in Figure 7.5.
The modules from Table 7.2 may not only be mapped to the structures of the Matrix report but can as well be applied in a rather state transition oriented approach. In this case the affected objects need to be identified, all modules implementing state transitions for this object are bundled in a state machine. This structuring mechanism is not applied in the respective sources but is as well possible.

The **Communication Reference Architecture** developed by the projects CVIS, Safespot and Coopers was identified as another valuable source for the description of the functional viewpoint. It provides a framework for the description of the communication related aspects of the functional viewpoint and therefore introduces an abstract architecture structure with application, facility, network & transport, access, management and security layer. It was originally developed from a vehicle-centric perspective and does not fully cover the infrastructure side. To transform the current description in a communication architecture that is not only focused on V2V aspects, infrastructure specific aspects from standardization, best practices and guidelines need to be added (see section 7.2.3).
The resulting communication architecture was standardized in ETSI [ETSI 302 665, 2010] and ISO [ISO 21217, 2009] and is implemented in many project and deployment initiatives of C-ITS. Examples are – besides CVIS, Safespot and Coopers – the large European C-ITS projects simTD, Testfeld Telematic, Drive C2X. The Communication Reference Architecture addresses all aspects from a set of services (Basic Set of Applications [ETSI 102 637-1, 2010], application related standards (In-Vehicle Signage, Contextual Speed)) to various access technologies. The individual aspects are largely standardized in the respective standardization organizations. An exemplary compilation of standards coupled to the Communication Reference Architecture can be found in section 3.3.2.2.2.

7.2.3. Resulting functional viewpoint

The analysis conducted in the Top Down and Bottom Up Approach lead to the conclusion that the resulting functional viewpoint should be subdivided into the following aspects:

- service workflows described either with business processes or state machines
- modules / process steps
- interfaces

All aspects are already addressed in the abstract description of the functional viewpoint (section 3.3.2.2.3) and were analyzed in detail both in the Top Down and Bottom Up Approach in this chapter.

The generic description of the above mentioned aspects are recorded in the subsequent chapters. Like for the organizational viewpoint the textual descriptions are accompanied by formal diagrams modeled in Archimate.

7.2.3.1. Description of general (service) workflow

Chapter 6 already presented two different options for the description of service workflows. Though only few example descriptions of functional aspects based on the state machine approach, in contrast to the business process oriented approach, were found, they are both considered in the functional viewpoint of the C-ITS Reference Architecture.

A generic service workflow forms the abstract frame around the different modules that together form the functional viewpoint, ideally it is applicable to all services and use cases. Chapter 6 demonstrated that this generic frame maybe provided both by business processes and state machines.
The generic business processes is based on the same process description that was already used for the development of roles and responsibilities in the organizational viewpoint (section 7.1). The functional description of any service can be mapped to this generic description by assembling and combining the different service specific modules and interfaces.
A generic description of state machines that has a comparable structuredness like the business processes was not identified. This coincides with conclusions from Chapter 6, which demonstrated that the state machines are actually rather orthogonal to the business processes. Therefore, they only play a subordinate role in the generic workflow description and rather come to light when it comes to the ample description of modules and interfaces in a system.

Business processes are used to describe different parts of the overall system. The Top Down and Bottom Up Approach identified three core parts

- operational processes
  Describe the system operation and consists of detection, evaluation and presentation; communication (see Figure 7.6)
- management processes
  Describe the interaction of management roles and covers all backend functionalities; includes security aspects
- policy related processes
  Describe the interaction of policy related roles

Those three aspects are already addressed from a different perspective in the organizational viewpoint and therefore need to be picked up in the functional description to preserve the continuity across the viewpoints. The functional viewpoint in this thesis focuses

on the operation related workflows, but the management and policy related workflows, modules and interfaces can be developed easily using the same method.

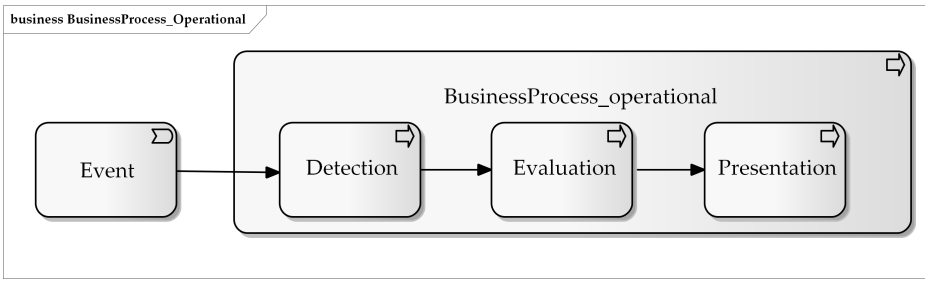

Figure 7.6.: Generic business process for operational process

The generic operational process (Figure 7.6) which was already used for the development of the organizational viewpoint (section 7.1) consists of the high-level elements Detection, Evaluation and Presentation. The terms were introduced in the Matrix report and are now reused for the generic description of the Business Process. 'Detection' subsumes the different sub-processes and modules qualified to record the initial event. 'Evaluation' comprises the different opportunities to analyze the initial event and transform it into the aspired results and 'Presentation' bundles different options for displaying the result to the receiver or user. Like already discussed in the Bottom Up Approach the Business Process can be applied recursively to transit from high to low abstraction levels (or vice versa) (section 7.2.2.2). And it might support the description of processes on different levels of detail. It may describe abstract high level processes, e.g. from the detection of a hazardous spot with the support of an in-vehicle system to the presentation of a warning on another vehicle's HMI, but could as well be applied on the description of detailed underlying processes, e.g. the ESP sensor recording specific friction values, the evaluation of those friction values with the result being above or beyond a critical threshold which is then passed to other in-vehicle systems for further processing.
The generalized version of the business process itself is not added as element to the Modular Construction System but the subdivision of the process into Detection, Evaluation and Presentation is reflected in the structure of the modules which are added to the Modular Construction System. Corresponding to their placement in the business process the modules can be assigned to the detection, evaluation and presentation category. Interfaces connecting the individual modules are subsumed under the communication category. To connect the elements from Figure 7.6 at minimum two generic interfaces are required. They will be described in detail in section 7.2.3.3. Ideally, generic interface descriptions are developed from which several different, specific interfaces can be derived.
The partition into the three core elements can be realized on different levels of detail, leading to a small total number of modules and interfaces in a rather generic and abstract subdivision or a large total number of modules and interfaces in a very fine granular subdivision. Ideally, the different degrees of detail can be conveyed into one another like it is originally done for the TISA value chain. This requires that the subdivision on the detailed levels still respect the module and interface structure from the overlying level of detail.

In case that a system is completely designed from scratch, the structure of categories described previously sufficiently covers all aspects of a business process and the elements assigned to the individual categories can be combined amongst each other almost arbitrarily. In the present case already a large number of systems and subsystems exist – therefore, it is not possible to start from a generic model and define and assign the specific modules and interfaces. Apart from that, the existing material often is such different that retrospective harmonization without fundamental adjustment of the existing modules and interfaces is not possible. This is the reason why in this document the proposed structure only serves as type case implemented in the Modular Construction System but it is not possible to arbitrarily combine the objects sorted into the different categories of the type case. Therefore, elements in the module and interface categories are complemented with a set of restrictions that narrow down the possible combinations of modules and interfaces. Those are conveyed to the description in the Modular Construction System.

Concluding the analysis of the business processes being part of the functional viewpoint of the Modular Construction System leads to the result that a generic business processes for operational process was identified (Figure 7.6) and will be the basis for the identification of modules and interfaces. Before actually diving into the details of modules and interfaces a substructure for the functional viewpoint within the Modular Construction System was identified based on the generic business process that consists of the four core elements Detection, Evaluation, Presentation and Communication. Along the lines of the functional viewpoint those vertical aspects are complemented by the horizontal aspects addressed by IT-security, privacy and data quality.
The elements of the Detection, Evaluation and Presentation category result in rather service-related modules discussed in more detail in section 7.2.3.2, the elements of Communication category comprise of the respective interfaces to link those modules and are detailed in section 7.2.3.3.

7.2.3.2. Description of service-related modules (selection)

The two types of workflows identified in the previous chapter (6) serves as basis for the deduction of service-related modules for the operational process. Modules can be identified from the operational business process at a rather high level covering a whole category as defined in the previous section (Detection, Evaluation, Presentation) and resulting in a single abstract module per category for the respective service. Beyond that it is as well possible that several detailed modules are assigned to the single categories and together supply the corresponding functionality. The actual subdivision of the categories is mainly influenced by the organizational and technical implementation of those modules.
Alternatively modules can as well be deduced from the state transitions of objects. Both structures lead to a partially identical subset of modules which might be sorted into the proposed structures.

The results of the Top Down and Bottom Up Approach are taken up to identify generic subcategories to further detail the categories Detection, Evaluation and Presentation.
The functional modules assigned to the category **Detection** are subdivided into those that

are placed into moving objects and others which are implemented stationary. The ones which are mobile are often built into vehicles. They collect data through (vehicle specific) sensors like video, radar and lidar. Partially similar sensors might occur in stationary implementations in the responsibility of the road operator or of service providers. Integrating them in moving or static objects heavily influences the characteristics of the collected raw data. Therefore, the Detection modules (Figure 7.7) can be subdivided into mobile and stationary elements.
The following options were identified:

- Mobile data collection with video, radar, lidar, geo-referencing based on GPS sensors or cellular networks
- (Mobile) detection of events by a driver or maintenance staff
- Movement profiles generated by mobile devices based on GPS sensors or cellular networks (floating phone, floating car data)
- Stationary detection with video, radar, loop detectors, overhead sensors, bluetooth

The actual detection is complemented by simple preprocessing operations which respect specific policies.
To depict the possible modules assigned to elements of the Business Process the initial representation of the (generic) Business Process (Figure 7.6) is enriched (Figures 7.7, 7.9 and 7.11). In the syntax of Archimate the C-ITS Service consisting of the three core process steps Detection, Evaluation and Presentation is modeled on the business process level (upper part of Figure 7.7). Each element from the business process level (Archimate: business process) can be detailed with elements from the application layer, hence the three core process steps are split up into different application layer modules (Archimate: application components, lower part of Figure 7.7). The application components exchange information through interfaces, they are realized with the support of so called application services (Archimate).
The 'Detection' business function is detailed with a Data Collection and (Pre-)Processing application component. Each application component can be further split up, the mobile detection application components are in the left column, the stationary ones in the right one. The Data Collection application component has an interface to perceive the initial event and it shares an interfaces with the (Pre-)Processing application component. The (Pre-)Processing application component provides an interface which will be used by the Evaluation Modules.

The state machine based approach would result in similar 'Detection' modules. An example object for which the states and state transitions are described and then can be converted into additional modules might be a raw data event object.
It moves from the state 'undetected' to 'detected' through various detection options, depending on the type of sensor (see list above). Additional modules linked with this object and not yet covered by the process oriented description are the transition to 'outdated' or 'invalid' configurations. The corresponding sample state machine is depicted in Figure 7.8.

The algorithms behind the **Evaluation** Modules are heavily driven by the entity that is

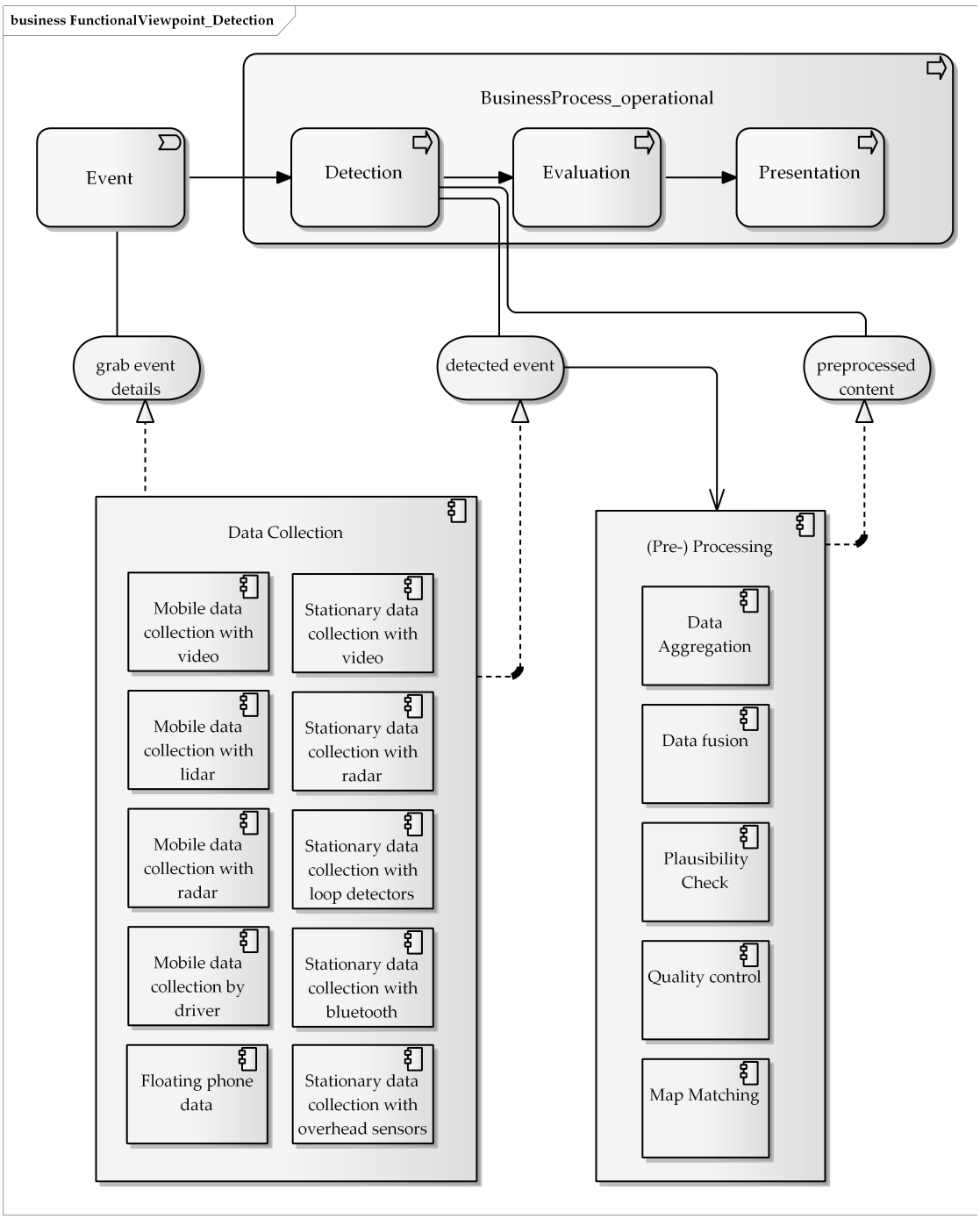

Figure 7.7.: Functional viewpoint – generic modelling of detection as part of the operational business process

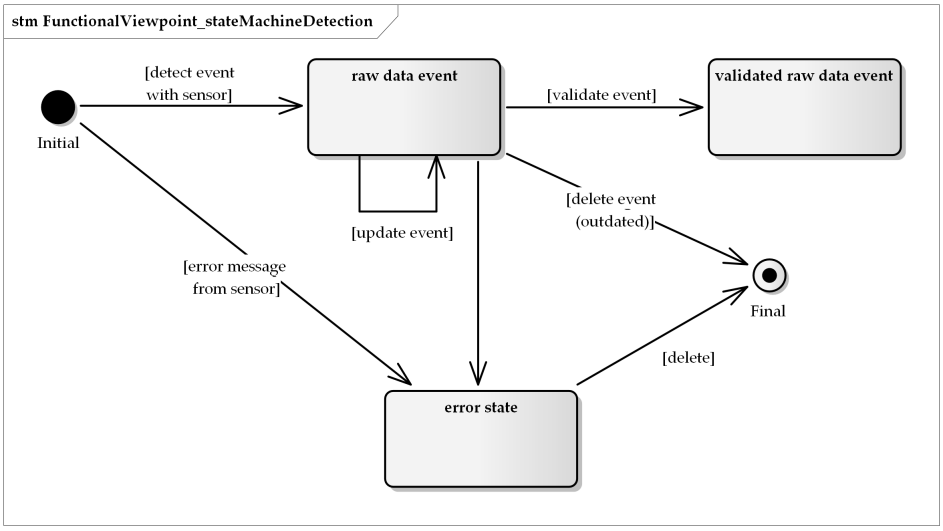

Figure 7.8.: Functional viewpoint – generic modelling of detection state machine for raw data event object

responsible for the respective modules. The key differentiator previously applied on the Detection modules of mobile and stationary is not relevant here. Every actor or entity operates the respective modules based on a specific policy. Usually, those policies differ between public and private organizations. Additionally, the latter ones can be subdivided into different industry sectors like vehicle manufacturer, nomadic or aftermarket device manufacturer, service providers and road operators. (This corresponds to the structure of the organizational viewpoint, especially the role 'specific functional operation' (7.1.3.2).) The generic structure of 'public' and 'private' is reflected by the modules depicted in Figure 7.9, where necessary an additional layer of different industries can be added.
The following options were identified:

- Merge of different data sources for further processing according to public policies
- Merge of different data sources for further processing according to private policies
- Evaluation of data based on public policies
- Evaluation of data based on private policies

In Figure 7.9 the 'Evaluation' business function is detailed with a (Pre-)Processing and Service Generation application component. The (Pre-)Processing application component has similar elements like the one located underneath the 'Detection' business function. Usually the modules from either application component are used, sometimes (Pre-)Processing activities take place twice, as part of the detection and the evaluation. The Service Generation application component provides different public and private algorithms for the data evaluation. The (Pre-)Processing application component has an interface to perceive the 'Detection' results and it shares an interfaces with the Service Generation application component. Finally, the Service Generation application components provide their results through an interface to the Presentation Modules.

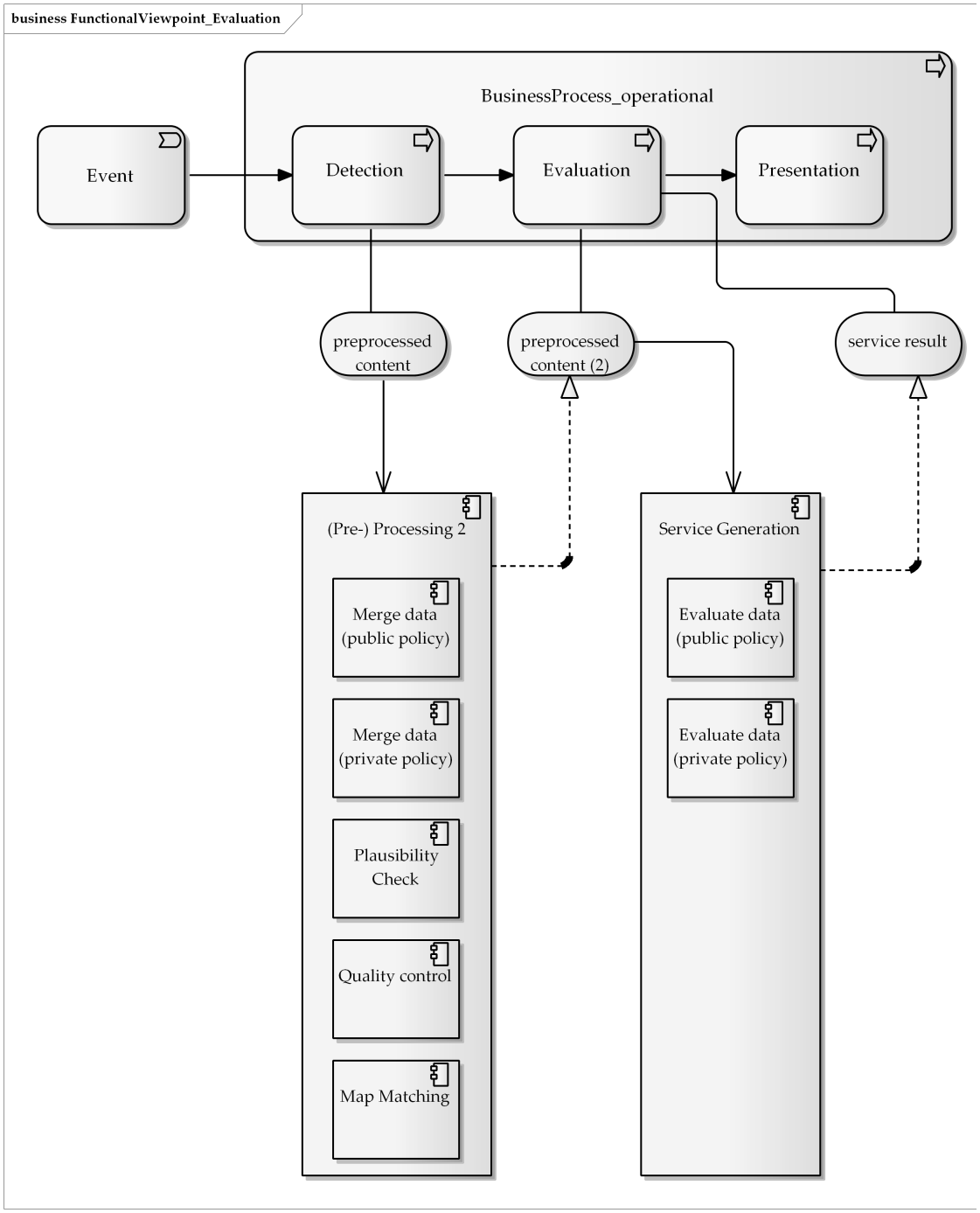

Figure 7.9.: Functional viewpoint – generic modelling of evaluation as part of the operational business process

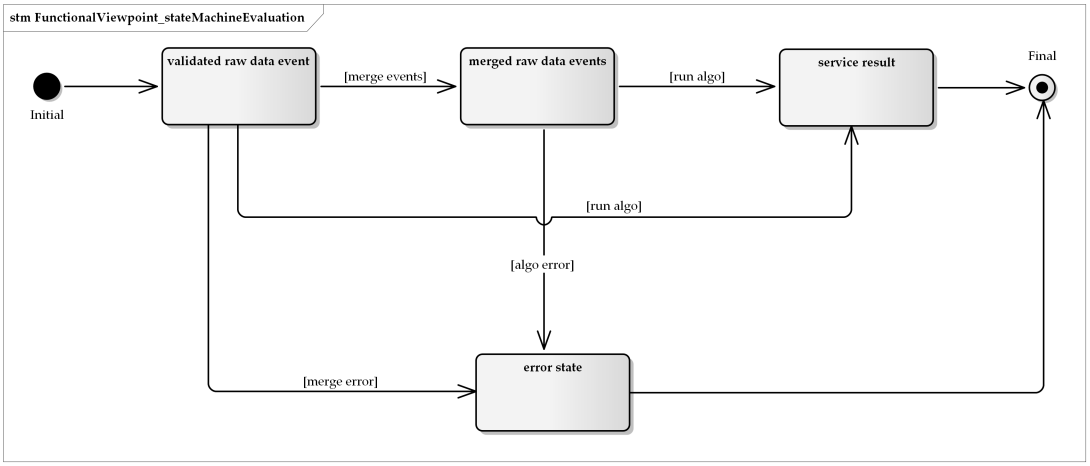

Figure 7.10.: Functional viewpoint – generic modelling of evaluation state machine

The state transition based approach results in similar modules, the state machine for a sample data object which is passed through different evaluation steps is depicted in Figure 7.10.
The description of state transitions again includes additional modules which are not part of the direct process but relevant for the system as a whole. In the example, these are error states which need to ensure the robustness of the system.

The **Presentation Modules** are subject to similar discrimination. The presentation of service results is heavily influenced by the policies of the responsible entity, therefore the modules can as well be structured according to the entity structures in the presentation sector consisting of public and private sector actors. Additionally, the physical presentation characteristics may influence the modules and lead to different elements (Figure 7.11). The following options were identified:

- Presentation of results according to public policies
- Presentation of results according to private policies
- Presentation on mobile device or in vehicles
- Presentation on stationary facilities

The Presentation business process module in Figure 7.11 is detailed with an application component that prepares the content received from the 'Evaluation' module for presentation. This comprises rendering and preprocessing for the service output. These intermediate results are finally passed to the Presentation application component through an interface, the corresponding modules offer different presentation options. This is completed with an interface to the user, who receives the service result.
The results of the state transition based approach for the 'Presentation' phase are already closely coupled to technical modules as presentation usually is linked to a medium. The

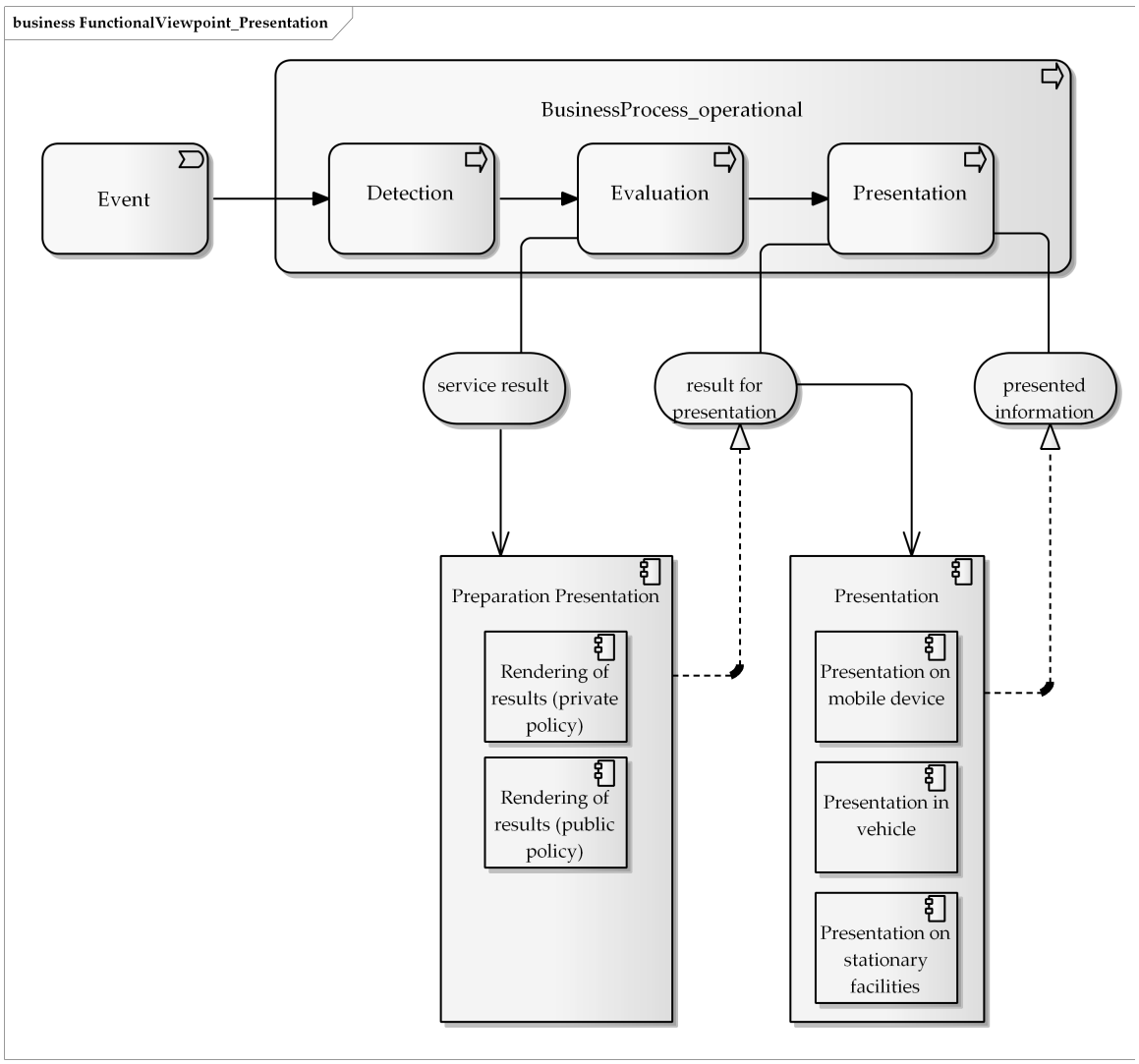

Figure 7.11.: Functional viewpoint – generic modelling of presentation as part of the operational business process

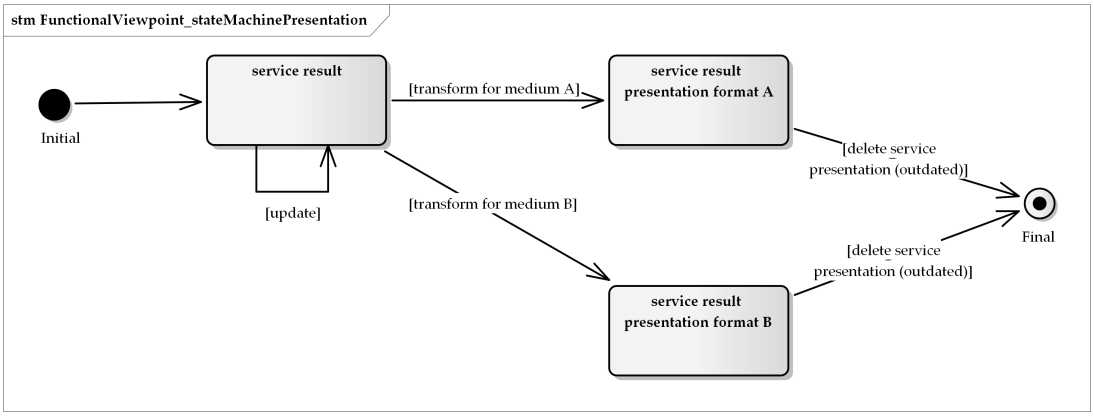

Figure 7.12.: Functional viewpoint – generic modelling of presentation state machine

service result therefore is subject to various transformations (Figure 7.12).

Apart from the service specific modules, several general repeatedly used modules were identified. Those specific modules are generic enough to be used in multiple scenarios and implementations and within the process at different positions as they provide a generic functionality. Additionally, they are equipped with standardized and generic interfaces – what serves as an additional enabler for multiple use. Examples for such modules are:

- Data aggregation and fusion
- Map matching – matching Global Positioning System (GPS) positions on specific maps (operating with different location referencing systems)
- Plausibility checks of data or information
- Quality control of data or information according to defined criteria

The modules are optionally included in the Figures 7.7 and 7.9.

A detailed list of different modules can be found in Appendices E and F. Unfortunately, it will not be possible to provide a complete list of all functional modules from which any future implementation will select its elements. It always will be necessary to extend the catalogue with recently identified modules. The Modular Construction System is a living toolbox that always needs to be adapted to the current situation and its modules.

7.2.3.3. Description of interfaces (selection)

The set of functional modules described in the previous section 7.2.3.2 implies the need for a fitting set of interfaces which connect the different modules. The required interfaces are in close respect to the already identified category of Communication aspects.
The implementation of the functional viewpoint of the different services and use cases will be carried out with the support of different technologies. The analysis of business

processes showed that the interfaces implemented in a service can be generalized to a minimum of two for the operational process: between the Detection and Evaluation and between Evaluation and Presentation. In consequence, this means that the interfaces between those modules may be realized through a large variety of available technology options. Therefore, the description of the interfaces in the Reference Architecture needs to reflect this variety of options. A completely generic description of the interface thus is not helpful as it will lead to such a high abstraction level that the description no longer fulfills the requirements of Reference Architecture elements. However, some specific aspects of an interface might be described generically. Examples here are the content that is subject to the information flow. There are ways for developing platform and technology independent descriptions of the applied data model. Methods like the Model Driven Architecture [The Open Group, 2016] provide procedures to transfer such a generic, platform independent description into various technology specific descriptions like they are used in the System Architecture description.
The benefit of the generic description of the content is that it might be transferred to different technologies – not only those already known at the time of implementation but as well others that will be developed in the future. Therefore, the concept of the generic platform independent descriptions supports the requirement of developing an interface description with potential for future extensions and new technologies.

When a system is designed completely from scratch it is possible to develop the required interfaces in an abstract and generic way and later on transfer the abstract model into implementation specific descriptions – like it is supported by methods like Model Driven Architecture. In ITS already a large number of different services with various interfaces exist that still will be used for C-ITS services. They usually come along with their own service and technology specific interface description, only occasionally harmonization activities took place that were transferred to standardization. (One example is DATEX II were some harmonization efforts with TPEG took place within the EASYWAY project [Lin, 2012]).
Consequently, instead of deriving the description of the interfaces for the functional viewpoint of the Reference Architecture from a hypothetical, generic and technology independent description, the different aspects included in the existing interface descriptions are used as a basis to develop a generic interface description. However, this requires adaptations of the existing structures and their implementations to allow for a bidirectional mapping between the generic model and the specific implementation. For those modifications the boundary conditions of the legacy implementation of the respective interface need to be considered. Despite the effort this approach is deemed constructive and is applied here.

In general, the description of the interface will comprise two core aspects: the data model and the communication. The data model describes the structure of the content used and exchanged in the respective service (section 7.2.3.3.1). The communication includes the composition of the required communication stack (section 7.2.3.3.2).

The analysis of the interfaces in the Top Down and Bottom Up Approach clearly shows that C-ITS primarily provides new (communication) technologies to ITS. The results illustrate that the functional elements used in C-ITS are rather similar to what is already in use in ITS and that they easily can be combined with each other. The fundamental in-

novation lies in the additionally provided interfaces and the underlying communication architecture that is tailored to the requirements of wireless communication.

7.2.3.3.1. Data Model

The detailed description of the interface starts with the definition of the data model. It resembles the information flow within the service which in turn can be modeled with a state machine. Like previously stated, it is possible to develop a generic description for the data model which later can be realized in various technologies. But although the term generic is used here, the data model usually is region specific, normally it is not required to have an internationally valid data model that incorporates all region specific, platform specific data models. Respecting such a requirement only increases the complexity without a significant benefit. The focus of the data model in this Reference Architecture is Europe and Germany.

In general, a data model is tailored to specific services, their use cases and their requirements. Therefore, it is not possible to provide right from the beginning of any implementation an all-time valid and complete data model. Examining and describing all the services and use cases implemented in the analyzed system and incorporating their requirements and needs in the data model allows to develop a complete data model for this snap-short. Ideally, single elements of the data model might be (re-)used in different use cases. Overall, the data model needs to be designed in a way that it allows for future extensions when new services need to be integrated or new technologies require modifications.
In turn, no completely new data model shall be developed only because the existing data model does not yet cover specific new technologies, use cases or services. Usually, there is at least some partial overlap that serves as basis for the necessary extensions.
Both aspects together lead to the conclusion that the description of the data model in the Reference Architecture is rather about developing a suitable generic and platform independent structure out of existing and implemented data models while considering the new and additional requirements of C-ITS.

The idea of defining platform independent models originally was proposed in the Model Driven Architecture developed by The Open Group [2016]. The Model Driven Architecture states that a generic (platform independent) data model can be mapped to different (platform specific) data models by using Model Transformation Languages.
For the generic data model of the overall C-ITS architecture data models from existing ITS need to be considered and partially even integrated. Applying this requirement on the data model implies that modifications of the existing data models may be necessary to incorporate the characteristics of the generic (platform independent) data model. It is not possible to develop a generic data model on top of several platform specific data models without modifying any of the existing data models.
NOTE: Of course, one of the possible platform specific models might serve as blueprint for the platform independent model and therefore no severe modifications of this specific model will be necessary.

The mapping from the platform independent model that will be developed for the C-ITS architecture to the platform specific data models, e.g. already existing data models, is de-

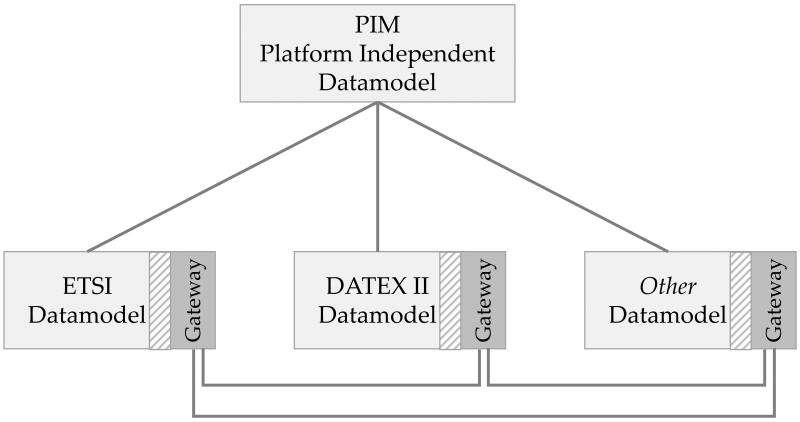

Figure 7.13.: Platform Independent Model of the data model and example for its transfer to platform specific encodings

picted in Figure 7.13. The required modifications and changes of the existing data models are implied with the shaded boxes.

The analysis in the Top Down and Bottom Up Approach showed that existing data models already cover a variety of different use cases. Partially, different data models for the same type of service implemented with different technologies are existing. Often, no harmonization did take place so far as this is a rather difficult task: the different data models were developed completely independent with a slightly different focus, often due to different underlying technologies. Some activities on harmonizing core data models were initiated, e.g. EASYWAY spend some efforts on aligning DATEX II and TPEG. Recently it was agreed to possibly extend those harmonizing activities with the existing C-ITS data model developed in ETSI (Common Data Dictionary [ETSI 102 894-2, 2013]).

From the data models identified in the Top Down and Bottom Up Approach the following will be considered for the generic description of the C-ITS data model:

- DATEX [DATEX II, n.d.] – largely in use in communication between traffic control centres, covers already a large number of use cases; harmonization activities with TPEG
- TPEG [ISO 18234, 2013; ISO 21219, 2014] – largely in use in the traffic information field, covers a large number of use cases; harmonization activities with DATEX II
- CDD [ETSI 102 894-2, 2013] – especially used by the vehicle industry for the C-ITS communication; harmonization with DATEX II under discussion, partially harmonized with TPEG
- TLS [BASt, 2012] – largely in use in the infrastructure side implementations, so far no harmonization activities
- IVI [ISO 19321, 2015] – currently developed dictionary for in-vehicle information, mainly to be used in C-ITS for the communication from infrastructure to vehicles,

complementing both the CDD from ETSI and the existing legacy ITS data dictionaries like DATEX, TPEG. The data dictionary is currently standardized in TS 19321.

- OCIT [ODG, n.d.] – largely used in urban scenarios, e.g. for controlling and operation of traffic lights, currently the extension for urban C-ITS use cases is under discussion
- DELFI [DELFI, n.d.] – especially used in public transport use cases to exchange information on time tables and live departures between public transport service providers

Of course, there are many other data models that might be included here but with focus on ITS and C-ITS the listed candidates above are the most prominent and widely used ones.

Although, the generic description of the data model is heavily depending on the use cases and services that are implemented. It needs to provide a close link to the functional modules, the following rather general aspects need to be included in basically every data model for ITS and C-ITS services:

- **location referencing** both of the raw data detected by sensors and the events determined by the service. This might not only involve different map basis with different encoding schemes but as well rather abstract descriptions of the location e.g. roads with lanes. Additionally, it might be necessary to describe the location not only as a point but as well as a linear or polygon
- **time stamps** of the raw data, the event, the object generated out of the data model
- **raw data elements** to describe the triggering event originally detected through sensors
- various elements to describe the results of the services (=event), this includes a list of different **event types** which are detailed by different event type specific attributes
- **quality information**, quality levels and indicators of the respective data (applies to all processing stages)
- operational messages and **error codes**
- meta information

The previous considerations lead to the conclusion that it is not possible to describe a generic data model without a clear relation to a service. Both ITS and C-ITS enable a large number of possible services – developing a data model without omitting any service is not realistic.
The other possible way forward would be to combine the already existing data models mentioned above. Each of them already covers a large number of ITS services and serves the current need for data models in the respective field. But the combination of the different data models is a rather complex task as the different data models cannot only be merged. Overlapping aspects need to be identified and harmonized. Partially, a clean-up might be necessary. Apart from that, the C-ITS specific requirements so far are only moderately reflected in those data models. Some harmonization activities already were

initiated, others are currently under consideration. The results of these activities ideally provide the generic data model for ITS and C-ITS. Currently, not even preliminary results are available – therefore this part needs to be complemented as soon as the outcomes are available.
The generic data model, developed in the context of the System Architecture for the C-ITS Corridor (see chapter 8), provides a first example on how such a data model for a specific system and its services (in C-ITS) might look like.

Closely linked to the data model is its encoding. The encoding basically comprises of a transfer syntax that allows to transfer the generic, platform independent description of the data model into an implementation specific description. The transfer syntax consists of a set of encoding rules that allow for the exchange of data in a structured way. It is still independent of machine architecture and implementation language.
Several options for encoding the content of the data model are available – which one is actually selected is heavily depending on the requirements and boundary conditions of the implementations. The different encodings provide different characteristics e.g. in terms of required bandwidth for the transmission of the encoded payload.
Examples for possible encodings are ASN.1 (used in the ETSI CDD [ETSI 102 894-2, 2013]) with BER (Basic Encoding Rules), CER (Canonical Encoding Rules), DER (Distinguished Encoding Rules) PER (Packet Encoding Roles), XER (XML Encoding Rules). Other alternatives are XSD (transfer syntax for UML applied in DATEX II [CEN 16157-4, 2014]) or JSON.
As the transfer of the abstract data model in a specific encoding is implementation specific this is not addressed in the Reference Architecture but described in detail in the System Architecture (chapter 8).

7.2.3.3.2. Communication

For the description of the communication aspects different existing communication architectures are available. Which one should be selected is heavily depending on the implementation characteristics of the interface – what in turn is closely linked to the entities that are on each side of the interface and with which technologies they (usually) operate over their interfaces. The Reference Architecture description of the communication aspect of the interface provides a list of options from which the implementation in the System Architecture can select.

The architecture for the C-ITS specific wireless communication is described by the two Communication Reference architecture standards currently available [ISO 21217, 2009; ETSI 302 665, 2010]. Both describe an almost identical framework for the communication between so called ITS Stations. ISO 21217 and ETSI EN 302 665 both only provide a framework architecture, linked to the standards is a large list of potential implementation options for the different layers which are part of the communication stack.
The architectures described in both standards have in their structure a very close link to the ISO OSI Standard [ISO / IEC 7498-1, 1996] but with a focus on C-ITS communication. The layers defined in ISO 21217 and ETSI EN 302 665 can be matched to the layer and cross-layer structures of ISO OSI. The facility layer in the Communication Reference archi-

tecture corresponds to a generic description of the application layer, the presentation and session layer in ISO OSI. The network and transport layer in ISO 21217 and ETSI EN 302 665 resemble the network and transport layer in the ISO OSI model. The access layer in ISO 21217 and ETSI EN 302 665 correlate with the physical and data link layer in ISO OSI. The security and management layer in all standards correspond to each other.
ISO 21217 and ETSI EN 302 665 are in their content rather equivalent although they refer to different sets of linked standards. The suite complementing ISO 21217 is also known as the *Communications in Cooperative Intelligent Transport Systems (CALM) Standards* series [ESF GmbH, 2016]. Because no project or implementation initiative is known that implemented this set of standards recently – the last practical implementations were done in the projects CVIS, SAFESPOT and COOPERS which were all closed in 2010 – they are not considered in detail in this Reference Architecture description.
The ETSI Architecture described in EN 302 665 refers to a different set of standards. Some examples are given in ETSI 302 665 [2010], the full list of standards is constantly growing. Depending on the needs within the community new standards are developed and integrated in the architecture framework.

Originally the communication reference architecture like it is described in ISO 21217 and ETSI EN 302 665 was supposed to be designed in a way that as well all existing legacy ITS communication might be realized based on these architectures. Discussions with experts from the legacy ITS showed that this is not the case, although this is possible from a pure technical viewpoint. Both architecture standards originally were driven by the vehicle industry and were developed with a focus on these stakeholders' requirements. Legacy ITS architectures from other domains and their characteristics were not taken into account.

The legacy ITS communication usually is based on ISO OSI derived communication stacks and makes use of IP (Internet Protocol)-based communication patterns. (Exceptions are old implementations of TLS. Implementations based on recent versions of TLS allow for IP-based communication as well.) Considered in the description of the Reference Architecture are therefore as well the ISO OSI Standard extended with the specific layer 5-7 protocols.
The different systems from legacy ITS come along with their own traditional protocols usually residing in the layers 5-7 of the OSI stack. TLS has its own – both overIP and non-overIP capable – protocols and messages which are described in TLS [BASt, 2012]. Other popular protocols for legacy ITS are OCIT developed by the OCA (Open Traffic System City Association e.V) organization and closely linked to the OTS protocol. RDS-TMC [FORCE 1 et al., 1999], a predecessor of TPEG [ISO 18234, 2013; ISO 21219, 2014] that is still widely in use today as well as DATEX II, are popular in the road operator and infrastructure operator community.
The mentioned protocols are completely residing in the top layers of the ISO OSI architecture. They are all running on top of various lower layer protocols included in the ISO OSI architecture. Which one is actually selected highly depends on the system and service requirements.

Examples for the available options are given in Table 7.3.

Layer	Interface focus C-ITS (ETSI)	Interface focus legacy ITS
Facility / OSI 5-7	CAM [ETSI 302 637-2, 2014], DENM [ETSI 302 637-3, 2014], CDD [ETSI 102 894-2, 2013], In-Vehicle Information (IVI) [ISO 19321, 2015], Local Dynamic Map (LDM) [ETSI 102 863, 2011], others	TLS [BASt, 2012], OCIT [Nolle, Kindler, Wenter, 2012], DATEX II [CEN 16157-4, 2014], TPEG [ISO 18234, 2013; ISO 21219, 2014], others
Network / OSI 4	User Datagram Protocol (UDP), Transmission Control Protocol (TCP), ITS-specific, others	TCP, UDP and others
Transport / OSI 3	Geo-Networking (ITS-specific), Internet Protocol version 6 (IPv6) networking with mobility support, IPv6 over GeoNetworking, CALM FAST protocol and others	IP, Internet Protocol Security (IPSec) and others
Access / OSI 1-2	ITS G5, cellular networks, infrared and others	Ethernet and others

Table 7.3.: Sample standards from the Communication Reference Architecture, both C-ITS and legacy ITS

7.2.4. Implementation recommendations for functional viewpoint

The description of the functional viewpoint – complemented by the details on the identified modules described in the Modular Construction System (Appendices E and F) – provides a large number of options to implement the functional part of an architecture. Hence, like for the organizational viewpoint (7.1.4) a few implementation recommendations for the functional viewpoints are included here.

When actually transferring the Reference Architecture into a service specific System Architecture a so-called functional profile is developed. A profile is one specific implementation variation derived from a generic description. In fact, much more standards and specifications for a selected subject areas exist than those that are needed for the implementation and depending on the requirements of the individual implementation the most suitable documents need to be selected. For C-ITS services that focus on V2V communication there is already a profile available developed by C2C-CC based on the experiences from the project and deployment implementations that provides recommendations for a V2V implementation. It is called Basic System Profile (BSP) [Buburuzan, 2014] and comprises a list of mainly communication related standards relevant for the deployment of C-ITS, supplemented by the selection of options in the individual standards that ensure interoperable implementations.

The generic BSP is completed by a list of Triggering Conditions documents that contain the detailed standard configurations for specific services. The Triggering Conditions documents mainly cover V2V Day 1 services, they are currently extended with the services deployed in the C-ITS Corridor.

So far, no comparable basic system profile was published for implementations of C-ITS on the infrastructure side – but the entities which are currently deploying C-ITS in various European initiatives are in parallel working on such a profile (supported by the European ITS project [EIP, n.d.]). Partially, both profiles will be overlapping: to ensure interoperability on the communication level similar or joint 'Basic System Profiles' are needed, using comparable standards in interoperable implementation variations.
In parallel, special profiles for infrastructure services (triggering conditions) are currently developed, the activities are hosted by the Amsterdam Group. Special task forces were set up and recently started to work on the topics.

7.3. Technical Viewpoint

The **technical viewpoint** describes the choice of technology (hard- and software) for the deployment of services and functionalities of the system. Existing technology is taken into account and integrated. [Definition from section 3.3.2.3.3]
The description of the technical viewpoint is according to its definition already very close to the actual implementation. The challenge of the technical viewpoint in the Reference Architecture is to provide a generic technical structure to which functional aspects, requirements and characteristics can be assigned without being system and implementation specific.

7.3.1. Motivation

The technical viewpoint is with its description of technology choices already very close to the implementation and therewith the System Architecture. The generic description in the Reference Architecture hence shall comprise an abstract description of possible technical elements for the realization of the operational processes of any service. They are still implementation independent and realize the idea of structural, logical bundles.
Like in the previous sections the elements of the viewpoint are extracted from existing theoretical models and practical architecture descriptions through the application of Top Down and Bottom Up Approach. Combined with the logical grouping mentioned before the Technical Viewpoint is modeled.

Analyzing technical architecture descriptions shows that the technical viewpoint is influenced in its structural concept by the other viewpoints of the overall architectures. The technical elements usually bundle a set of functionalities which together form logical-technical entities. Generalizing this shows that the bundles are not necessarily linked to one single technical component but might be realized through combinations of technical elements in the System Architecture – as long as they respect the logical-technical structure.

For the identification of the bundles the results of the organizational and functional viewpoint are taken into account. The organizational structures are in a close relationship with the logical-technical structures as they need to fit together in the final implementation: partitions which are contradicting with regard to the organizational and technical structures are likely to fail as it is improbable that either significant changes to the organizational structures are enforced or a set of new technical components is developed to allow for atypical implementations. From the perspective of the technical viewpoint only, this might be possible, for the system in general, the costs and efforts need to be traded.
Hence, the functional viewpoint mediating between the organizational and technical viewpoint provides the basis for the logical bundling. The functional modules already provide a basic and simple structure that is in line with the organizational viewpoint. This structure is now advanced by strategic and meaningful grouping of single modules to larger packages and assignment to available technical elements.

The rather theoretical study of inherent logical structures within architectures is complemented by the analysis of existing implementations. Therefore, legacy ITS e.g. from the Matrix report [Lotz et al., 2012] are examined to ensure that the developed framework is in line with the identified logical structures.
These considerations lead to a technical viewpoint description with a focus on structural and logical architecture opportunities.

7.3.2. Process of defining the technical viewpoint

The analysis of candidates for the approach in chapter 3 already indicated that only few of them will be able to supply at least some contributions to the technical viewpoint. The available material is compiled in the subsequent chapters.
Like for the organizational viewpoint, the functional workflow with its different description options serves as basis for the definition of the technical viewpoint in the C-ITS Reference Architecture. The technologies from the technical viewpoints can be assigned both to process steps or objects and their state transitions.

7.3.2.1. Top Down Approach

The generic methods (e.g. RM-ODP, TOGAF, FGSV pyramid) which were analyzed for the definition of the frame structure as well as the detailed description of the organizational and functional viewpoint provide only limited input to the description of the technical aspects.
Like already for the functional viewpoint TOGAF is the only method that provides an approach on how to define the so called technology architecture – which corresponds with the technical viewpoint of the Reference Architecture [The Open Group, 2011b]. Core steps in the definition of the TOGAF technical viewpoint are the grouping of functionalities, which are verified against the requirements of the different stakeholders, and the subsequent modeling of different technology specific views. TOGAF as well proposes a set of views to describe the technical aspects, due to the restricted scope of the C-ITS Reference Architecture they are not relevant here.
The approach proposed by TOGAF conforms to the thoughts from section 7.3.1, the con-

cept of grouping functionalities is reflected in the final description of the technical viewpoint.

7.3.2.2. Bottom Up Approach

The Bottom Up Approach derives its conclusions from existing architectures. Currently, practical implementations only exist for legacy ITS but not yet for C-ITS. The conclusions for legacy ITS are extracted from the results of the Matrix report. For C-ITS, existing technical project architectures were taken into account.

The core logical-technical bundles of the technical viewpoint are like the elements in the other viewpoints closely linked to legacy ITS. The analysis of legacy ITS components undertaken in the Matrix report [Lotz et al., 2012] identified the following technical elements: (the) vehicle system(s), nomadic devices, roadside infrastructure and central or backend infrastructure like traffic control centers. The mentioned elements are rather general representatives of the technical viewpoint. Diving more into the details reveals that each of them comprises several technical features and specific for every implementation scenario a decision needs to be taken which of the available features are deployed or used. This is clearly linked with deployment scenarios like they are described in Appendix D.4: various technical components are involved in the different scenarios but in each scenario different features of the respective components come into operation. For example roadside infrastructure might be involved in the detection of an event, but in a different scenario it might as well realize evaluation functionalities.
In reverse, the functional modules from the functional viewpoint can be assigned to different elements of the technical viewpoint what leads to a large number of possible combinations – which are not all equally likely. An abstract attribution is only possible within certain limits. Corresponding examples are given in D.4.

The identified legacy ITS components are complemented by cooperative aspects. Though the Matrix report [Lotz et al., 2012] discusses as well cooperative scenarios this facet is only touched with respect to the communication channel. A closer look to the technical architecture of C-ITS research projects, e.g. simTD or DriveC2X, shows that C-ITS has implications on the technical viewpoint. Partly the elements mentioned above are extended with communication elements e.g. ITS Stations as defined in ETSI 302 665 or ISO 21217. Apart from that the cooperative technology might lead to additional technical elements. Examples here are independent central or backend structures specifically for cooperative services or cooperative central elements complementing existing central or backend structures, both are known as cooperative centers.

7.3.3. Resulting technical viewpoint

The technical viewpoint consists of the following core technical elements:

- vehicle system(s),
- nomadic devices like smartphones, navigation devices,

- roadside infrastructure like roadside units, traffic lights,
- central or backend infrastructure like traffic control centers,
- communication networks like cellular networks, fiber optic networks,
- cooperative elements amongst them ITS Stations and cooperative centres

The elements from the list above can be further subdivided into subsystems. Depending on the characteristics of the component and the level of detail this results in subsystems which provide the technical base for data collection, e.g. various sensors, evaluation i.e. computing power, buffer etc. and presentation. Like described in detail for the functional viewpoint, this process can be executed iteratively (see Figure 7.5), leading to technical elements on the micro sensor and chip level.
For each technical element a state machine describing the possible state transitions can be defined. Especially these state machines address system states which are not covered by the process oriented description. Examples are activation and de-activation of components which are usually not part of the business process but eminent in the system description.

Apart from the selection of components and specific features, additionally structural choices are part of the technical viewpoint. That is on the one side the decision which technical components from which specific group are selected (e.g. vehicle / nomadic device vs. infrastructure components like roadside units and traffic control centers) – this has implications on the design of the implementation scenario. On the other side this includes the determination how to assemble the selected components from a structural perspective. Some components might be implemented both in a centralized or distributed way, one example are traffic control centers that might occur with a single instance or multiple, eventually connected instances. Apart from the two extreme poles all nuances in between are imaginable.

Crucial for the structural architecture decision in the technical viewpoint are the requirements that need to be fulfilled when implementing a specific service. They might allow for different options – hence it is important to weigh the different options and consider organizational, strategic, financial, market-driven (only specific variations are available) and other arguments before making a decision. Additionally, structures from legacy ITS that need to be integrated might influence the design of the technical viewpoint.
Structural decisions have as well implications on other viewpoints – and the other viewpoints might influence the structural partition in the technical viewpoint: each technical component is closely linked to functional modules and organizational entities. Hence, the structural partition reflects organizational aspects like multiple actors implementing the same functional modules and functional aspects like centralized vs. distributed preprocessing or evaluation of data.
Accordingly, the variety of technical elements is supplemented with the structural architecture options – leading to a multiplication of options from which the system architecture implementation can select.

7.3.4. Technical architecture with focus on urban implementation variations

The recently published UR:BAN guideline [Böhme et al., 2016] developed as well an architecture description with a similar but still different approach. Both approaches, the one described in this thesis and the one developed in the UR:BAN guideline, are leading to more or less the same structural architecture results. From an academic perspective this strengthens the resulting overall architecture and its elements described in this thesis, confirming that the developed structures are stable and not heavily depending on one single approach to identify them.
The UR:BAN guideline has a strong focus on the practical implementation and the needs of the actors which actually have to realize these services. From this perspective, the guidebook is seen as very valuable contribution in the C-ITS community. Regarding the technical viewpoint in a Reference Architecture, the experts in the UR:BAN project identified the same strong relationship between technical and organizational architecture like it is described in section 7.3.1.

The blueprint descriptions in the UR:BAN guidebook consists of three core options for the technical implementation which are called 'clusters'. They all can be traced back to the same generic dependencies between technical and organizational structures (Figure 7.14). Each of the clusters may be realized in a centralized or decentralized approach.
The first cluster is characterized by a central traffic management system complemented by a traffic computer. The link between the distributed components in the field and the central backend are established either via legacy infrastructure or direct communication.
The second cluster is characterized by a traffic computer only, to which the distributed components are connected. Traffic management applications are not deployed.
The third cluster is characterized by the absence of any central traffic management unit, it is implemented in the so-called cloud-based example. In this case the external service provider (in the cloud) provides the traffic management or traffic computer infrastructure.
All three clusters alternatively can be deployed in decentralized scenarios. In this case stand-alone solutions in the field are realized which are directly linked to external service providers.
The guideline provides three sample implementation scenarios that realize the theoretical cluster options. The detailed description of each option allows the stakeholder to select the option that matches best its own technical / logical legacy structures and apply it in its own implementation.
In general, the cluster structures described in the UR:BAN guideline corresponds to the generic logical-technical structure mentioned in section 7.3.1. It enables numerous implementation options, the most prominent ones are illustrated with the three cluster descriptions.

7.4. Summary and Conclusion

The Reference Architecture is the element in the overall architecture that links the Framework and System Architecture. It provides a generic blueprint for domain specific implementations and has a very close link to the Modular Construction System. The Reference

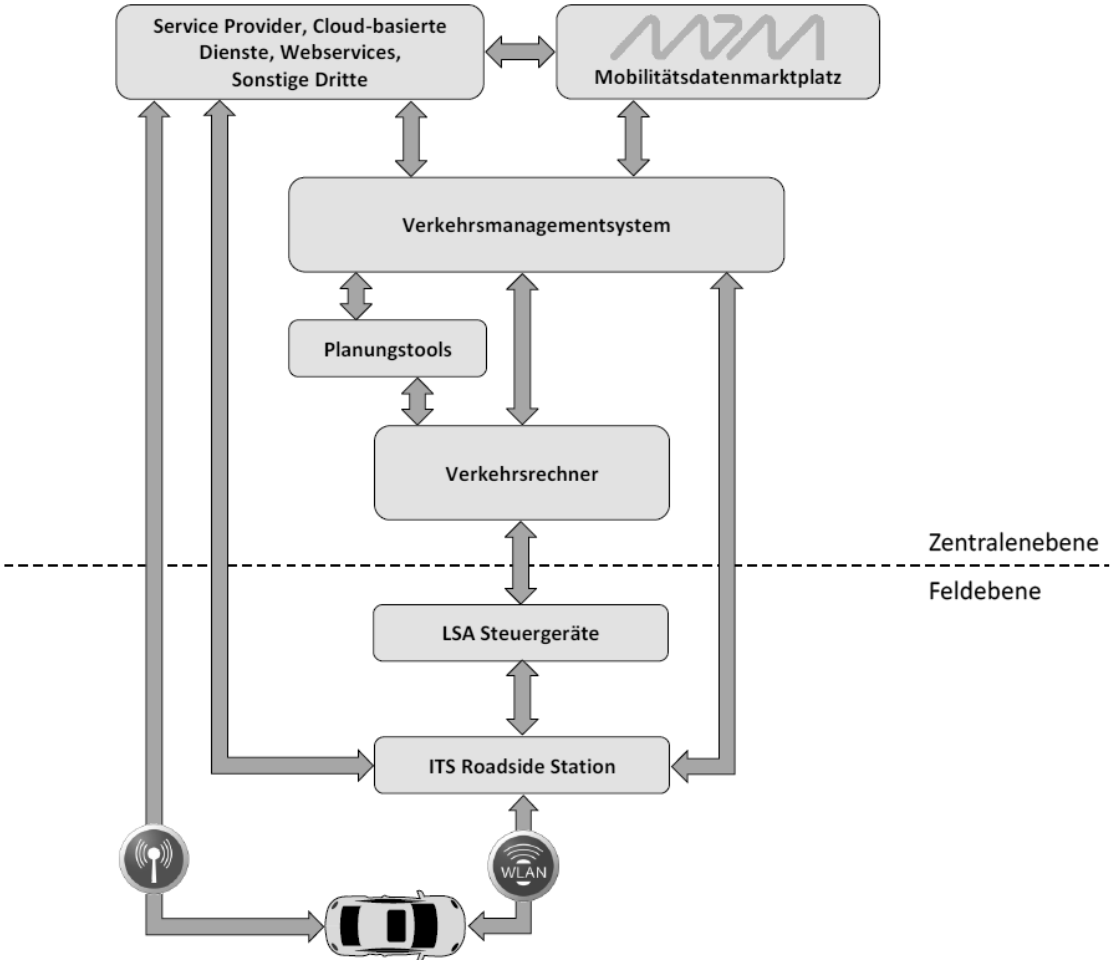

Figure 7.14.: Generic technical structure developed in UR:BAN project [Böhme et al., 2016]

Architecture picks up the policies and strategic guidelines immanent in the Framework Architecture and transfers them to a generic but domain-specific description. On the other side, the generic description from the Reference Architecture is mapped to a (service) specific System Architecture in which generic modules are selected and customized to the requirements of the System Architecture.

The generic blueprint (Reference Architecture) in the present chapter focuses on the domain C-ITS – with the assumption that C-ITS is not only interpreted from a communication technology perspective i.e. the use of ETSI ITS G5 but follows the generic definition in chapter 2 that emphasizes that C-ITS is about cooperation between stakeholders, the involvement of multiple stakeholders that together provide a specific service. The underlying communication is flexible and not fixed to a certain technology. The Reference Architecture developed in this chapter respects these requirements.

For the description of viewpoints, the two approaches presented in chapter 6 were con-

sulted. For the process oriented description plenty source material was available, the additional state machines were compiled in this thesis due to lack of existing descriptions.
The individual sections of this chapter address the different elements of the Reference Architecture i.e. the individual viewpoints. Section 7.1 comprises the organizational viewpoint, which was developed from scratch based on the Top Down and Bottom Up Approach resulting in a generic description of roles and responsibilities that help to organize such a multi-stakeholder structure like it is characteristic for C-ITS. The functional viewpoint incorporates a large number of different aspects which are described in section 7.2. Amongst them are business process that describe the system's behaviour, modules that are required to realize the processes, (communication) interfaces to connect the different elements and generic models for the data flows within the system. The technical viewpoint in section 7.3 offers various opportunities for an implementation of the organizational and functional aspects. It tries to provide a generic and abstract description of technical and physical structures.

As mentioned before, the Reference Architecture has a very close link to the Modular Construction System, hence, the preceding sections are in a tight relationship with chapter 5 and its subchapters. This chapter provides the framework and structure and some details of the Reference Architecture, the options from which the one actually developing the System Architecture can select are all summarized in the Modular Construction System (some examples are given in Appendices E and F).
The process of selecting suitable elements is the transition from Reference to System Architecture. This transition is usually called profiling – a profile for a specific implementation is designed and later implemented. For one single Reference Architecture multiple profiles will be available. As they are reusing the building blocks of the Reference Architecture (which are stored inside the Modular Construction System), this approach shall ensure and enable interoperability between different implementations (profiles). An example profile is given with the C-ITS Corridor System Architecture in chapter 8.

8. System Architecture for C-ITS Corridor Germany

Concluding the whole approach of defining an overall C-ITS architecture as it was initially described in section 3.1 and with Figure 3.1, the results of the chapters 5 and 7 are finally applied in a real world example.
C-ITS is a rather new technology that was so far only implemented in various projects and field operational tests throughout Europe. But none of the projects developed a close to reality system. Lately, several C-ITS deployment initiatives started. Amongst them are the C-ITS Corridor from Rotterdam (Netherlands) via Frankfurt (Germany) to Vienna (Austria), the French SCOOP@F initiative, the Nordic Way initiative and the deployment activities in Czech republic.
The first one, originally started in 2012, was the C-ITS Corridor. It is as well the one with the most mature specifications. Hence, it will be used for the description of a real world practical example architecture. The subsequent sections describe the System Architecture for the German part of the C-ITS Corridor developed based on the theoretical and practical background described in chapter 3 to 7. Due to expert overlap both the description of the methodological aspects in this thesis and the description of the System Architecture are in line. The latest version of the architecture is available on the C-ITS Corridor Website [Cooperative ITS Corridor, n.d.].

8.1. The C-ITS Corridor

The C-ITS Corridor is a deployment initiative of the ministries of transport in Germany, Austria and the Netherlands. They agreed to deploy two C-ITS services in a corridor from Rotterdam in the Netherlands via Frankfurt (Germany) to Vienna in Austria. The selected services are **Road Works Warning** and **Improved Traffic Management based on vehicle data**. The System Architecture description in the subsequent chapters focuses on the service Road Works Warning as this is the more advanced, stable and mature service.

8.1.1. Background C-ITS Corridor

The C-ITS Corridor initiative started in 2012 and an official launch took place in 2013 when the three ministers of transport signed a Memorandum of Understanding (MoU) [BMVBS et al., 2013] in which they agreed to cooperate on the following topics:

- development of a common implementation schedule for the implementation of the first C-ITS applications
- definition of common conventions that ensure a harmonized interface with the vehicles in the three countries

- construction of roadside equipment and systems along the motorway corridor Rotterdam – Frankfurt – Vienna for the first C-ITS applications
- definition of a common implementation strategy for further C-ITS applications on motorways

For the realization of the deployment a project structure was set up in each of the three countries including cross-national groups for harmonization and exchange of information about the national activities. Details (especially for Germany) are described in section 8.1.3.

8.1.2. Services and technologies in the C-ITS Corridor

As first C-ITS applications in the three countries **Road Works Warning** and **Improved Traffic Management based on vehicle data** were selected (a more detailed description of the services can be found in sections 8.2 and 8.3). Both services excellently complement each other – in the 'Road Works Warning' service the passing-by vehicles are provided with information on upcoming road works, in the 'Improved Traffic Management based on vehicle data' service the vehicles provide data to the infrastructure side and support various traffic management services. However, both services come along with different organizational, functional and technical issues for which reason they are examined separately. The description on hand focuses on the Road Works Warning, a general description is given in section 8.2. Before a detailed description of the Improved Traffic Management based on vehicle data service architecture can be finalized various privacy and security related aspects need to be solved first. The respective System Architecture will be published from the C-ITS Corridor partners as soon as it is available. Though a short general description of what Improved Traffic Management based on vehicle data is about is given in section 8.3.

The selected services implemented in the C-ITS Corridor will be realized with a focus on the ITS G5 technology. This technology decision is part of the agreement made through the MoU between Germany, Netherlands and Austria. In Germany the Road Works Warning service is additionally realized through cellular network. The slightly different characteristics of cellular network as underlying communication technology allows for additional implementation variations of the Road Works Warning service. In consequence, the System Architecture is modeled accordingly.

8.1.3. Project organization

Each country set up individual national project structures to realize the deployment of C-ITS including the development of the required specifications. The German part has a Steering Committee on the highest level followed by strategic and operational structures. In Austria and the Netherlands similar structures were set up. Additional international coordination links between the three different national projects were established to harmonize the activities across the countries – both on a strategic and operational level. (For details see official website of C-ITS Corridor [Cooperative ITS Corridor, n.d.])

In Germany a structure with various projects groups on the operational level was established. The project groups cover all relevant aspects e.g. system architecture, the individual components of the system, the integration in the existing system, security, privacy and roll-out. The single groups closely cooperate and together develop the later implemented System Architecture, the corresponding detailed descriptions and specifications of the associated components. The activities in the project groups incorporate the existing (legacy) ITS structures and architectures and ensure the seamless integration of the new C-ITS technology in the already existing system.

All countries participate as well in the strategic and operational cross-national group. The focus of those two groups is the harmonization of specifications and results. The harmonization activities are limited by the slightly different legacy systems and national requirements – hence, no fully harmonized specification across the whole C-ITS Corridor is aspired but aspects suitable for harmonization e.g. the core interfaces are addressed.

8.1.4. Prototype implementation

Apart from the national specification activities each country runs in parallel prototype developments of the needed components. Due to the new technology no complete solution is available at the market. In the prototype phase the System Architecture and the (theoretical) specifications are implemented and their suitability for daily use is tested in a small test setup (in Germany: Hesse, Frankfurt region). This includes as well a series of component and system tests. If necessary modifications are made both to the prototype components and the respective documents. The mature System Architecture and specifications are later used for large scale tenders (whole Germany). Austria and the Netherlands apply similar approaches.

8.1.5. Link to other initiatives and organizations

The C-ITS Corridor is one of the first deployment initiatives in Europe and has a strong interest in interoperability with future deployment initiatives. Therefore, the three countries are involved in various other groups that contribute to harmonization, dissemination of results and standardization. Examples are the Amsterdam Group that serves as a platform for stakeholders interested in deployment. The Amsterdam Group not only enables the information exchange but as well developed various white papers and specifications. Additionally, the Amsterdam Group organizes workshops and webinars to disseminate information and best practices.

On a more formal level is the cooperation with the different European and international Standardization Organizations (CEN, ISO, ETSI, SAE (Society of Automotive Engineers)). Partially, C-ITS standards were already developed and are now implemented – experiences from implementation may lead to necessary modifications of the existing standards. On the other hand new interfaces require additional standards. Often the white papers drafted in stakeholder organizations are converted into standards. The C-ITS Corridor implements existing standards, promised to give feedback and provides change requests. Where necessary white papers are drafted and passed to standardization. The Standardi-

zation Organizations introduce them in the formal standardization process.

A third important player are European projects. They support the dissemination of results, provide a platform for the exchange with other stakeholders involved in C-ITS deployment and partially host technical drafting activities, like the development of a European infrastructure profile (EIP [EIP, n.d.] and CODES [CODECS, n.d.] project). Some of the partners involved in the C-ITS Corridor as well participate in the respective projects, partially a close link between the Amsterdam Group and the projects exist, so in total the composition of deployment initiatives (C-ITS Corridor), strategic stakeholder organizations (Amsterdam Group), standardization organizations and European projects together address specific aspects of C-ITS deployment.

8.1.6. Additional information

Additional information on the C-ITS Corridor is available on the website [Cooperative ITS Corridor, n.d.] and the flyer [C-ITS Corridor, 2013] (partially outdated). The website provides additionally public documents developed within the project. Links to the national projects of Austria (ECo-AT [ECo-AT, n.d.]) and the Netherlands (DITCM [DITCM, n.d.]) are available there as well.
C-ITS Corridor representatives participate in various (C-)ITS Congresses and fairs to present the current status of the deployment activities.

8.2. Brief introduction to Road Works Warning service

Focus of the System Architecture described in this chapter is the service Road Works Warning. Therefore, a detailed and abstract functional description precedes the description of the System Architecture itself to ensure a coherent understanding of the service Road Works Warning.

Road Works Warning in general is not tied to a specific use case or communication bearer. The service informs drivers about road works, its parameters and associated obstruction (e.g. reduced speed limits, closed lanes, deviated lanes, extended travel times etc.) on the route ahead. The purpose is to inform the driver in advance to increase awareness and to inform of potential dangerous conditions.
Specific for the implementation with C-ITS technology is the increased accuracy of the road works information in time and location for the benefit of the end user. It will also be possible to explain the background of the road works and thus raise the user acceptance.

There are two major types of road works: short-term and long-term. **Short-term road works** usually takes place when urgent or small maintenance or repair is required. The safety equipment setup is different from the one that is used for long-term road works, both are described in detail in the respective national guidelines (e.g. for Germany in the RSA (Guidelines for safety of working places at streets, Richtlinie zur Sicherung von Arbeitsstellen) [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995]).
Usually, short-term road works is secured by a road works safety trailer and an optional

pre-warner. The road works safety trailer actually blocks the lane on which the road works takes place (hard-shoulder or driving lane) and thereby protects the workers. If several lanes are blocked each lane has its own safety trailer. The sign configuration on the road works safety trailer indicates where to pass the trailer (left or right). The pre-warner provides additional information on applicable speed limits and whether the lanes are reformed (e.g. left lane blocked or traffic running across hard-shoulder). The pre-warner is placed on the hard should in some distance to the actual road works.
A short-term road works can be either mobile or stationary. Examples for mobile short-term road works are lane marking or grass cutting activities, the road works safety trailer is moving slowly while the maintenance activities take place. Examples for stationary short-term road works are maintenance repair (potholes, crash barriers). In this case the trailer is not moving.

Maintenance activities that have a duration of at least one day are called **long-term road works** [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995]. They are always stationary and can be operated in different layouts which are described in the national RSA [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995]. Like the short-term road works, long-term road works is secured by a defined set of safety equipment, usually no road works safety trailers are involved. Long-term road works is as well under discussion for the implementation in the C-ITS Corridor but with a slightly larger time frame. The specifications are developed at the moment.

Both types of road works can be implemented in a connected set-up. In this case the road works is equipped with different communication technologies to communicate both with vehicles or mobile devices and the road operator's backend. In the implementation of backend communication via cellular network the service needs to realize two different operation modes: the stand-alone mode is active in case that the road works is not able to establish a connection with the backend. In this case only a very simple message will be broadcasted to the vehicles via ITS G5. The more elaborate mode is the basic mode in which the road works is connected to the backend: additional information is available and plausibility checks are possible.

The system architecture for the C-ITS Corridor is designed in a way that both the short-term stationary and mobile version might be implemented, they might be operated both in stand-alone and basic mode. Partially, the system architecture is already prepared for the future use case of the long-term stationary road works. But the use case is not yet covered at the moment due to its complexity and will follow in a later phase of the C-ITS Corridor deployment.

NOTE: The Amsterdam Group Road Works Warning Functional Description [Amsterdam Group Road Works Warning Task Force, 2016b] and the Amsterdam Group Message Set and Triggering Conditions [Amsterdam Group Road Works Warning Task Force, 2016a] document comprises as well a detailed description of Road Works Warning service. This is more general than the C-ITS Corridor specific description above.

8.3. Brief introduction to Improved Traffic Management based on vehicle data

The **Improved Traffic Management** service is as well not completely new. Traffic management is already done today in the traffic control centre but they work with a slightly different data basis: along the highways are lots of loop detectors and video detection systems installed. This is complemented by data from private parties e.g. floating phone data. The 'new' service Improved Traffic Management based on vehicle data will re-use the existing traffic management algorithms and enhance them with an additional source of data, the data collected by vehicles. [Depending on the principles behind the algorithm this extension might be complex – most traffic management services are designed in a way so that they are able to deal with defined cross-sections; the C-ITS equipped vehicles will broadcast single, individual data tuples [Kühnel, 2011].]

8.4. Scope of System Architecture in the C-ITS Corridor

Before actually starting with the description of the System Architecture the scope of the architecture description in the context of the C-ITS Corridor needs to be defined.
The System Architecture focuses only on the respective national situation. The legacy ITS in the different countries which needs to be taken into account when describing the System Architecture are too different to allow for one single System Architecture across all C-ITS corridor countries. Hence, only the System Architecture for Germany is described in this chapter.

Focus of the German C-ITS Corridor are currently two services: Road Works Warning and Improved Traffic Management based on vehicle data. For both services different phases were defined where each phase comprises a different set of functionalities. The first phases start with comparatively simple services, which are rather easy to implement. The different phases are defined in the C-ITS Corridor Management paper (non-public document of C-ITS Corridor). Currently, the first phase is implemented, in which the short-term road works based on a road works safety trailer is deployed. The implementation of the second service (Improved Traffic Management based on vehicle data) is under preparation but did not yet start. In a later phase more elaborate use cases for short-term road works and as well long-term road works will be implemented.

The scope of the System Architecture described in this chapter is the current implementation phase, though the architecture in general is designed in a way so that it could easily follow the migration to the next stages of deployment.
The complete description of the System Architecture (including the legacy ITS and its extension for C-ITS) is included in section 8.6 to 8.8.

NOTE: From an architecture perspective the sequence of the subsequent chapters follows the structure developed in chapter 3 to 7. From a comprehension perspective it might be helpful to start with the functional viewpoint (8.7) instead of the organizational structures (8.6) to first get a good grasp of the Road Works Warning functionalities realized in the current deployment phase.

8.5. Application of modular approach in C-ITS Corridor System Architecture

Both services that will be implemented in the C-ITS Corridor are from a traffic management perspective (in Germany) no completely new services.
Some of the Bundeslaenders already deployed a system for **short-term road works** that allows them to know in the traffic control centre where in their network a short-term road works secured by a road works safety trailer takes place in real time. Currently, the data is mainly used for internal purposes (e.g. logging, operational parameters) and traffic management (e.g. shut down short-term road works if this causes a severe traffic jam). As there are heavy accidents of trucks crashing into road works safety trailers a warning is broadcasted through citizens band (CB) radio. At present, this data is not published on a regular basis e.g. via the MDM. Projects were run in cooperation with automotive manufacturers to pass the information as well to vehicles via cellular network – but there is no day-to-day operation so far.

The German C-ITS Corridor implementation of the Road Works Warning service is implemented based on the already existing legacy road works positioning systems like described above. For the realization of the new service the existing modules and functionalities are analyzed and partially reused, where necessary they are extended or modified. Hence, the description of the C-ITS Corridor System Architecture follows the principles of this thesis: legacy ITS is conveyed into modular structures like described in the Matrix report and transferred to the newly developed Modular Construction System (chapter 5). The description of the C-ITS Corridor System Architecture then selects modules from the Modular Construction System for the implementation of the service across all viewpoints. Details on the adaptations and modifications are described in the subsequent chapters.
NOTE: The same applies for the Improved Traffic Management based on vehicle data service: existing traffic management algorithms will be adapted to additionally cover the new data source provided by C-ITS equipped vehicles.

8.6. Organizational Viewpoint of C-ITS Corridor System Architecture

For the organizational viewpoint the Modular Construction System (chapter 5, Appendices E and F) provides a bundle of modules mainly derived from the standardization activities of the C-ITS organizational architecture [ISO 17427, 2013]. This set of generic roles and responsibilities is adapted to the organizational structures required for the operation of the Road Works Warning service in Germany.

The organizational viewpoint, as part of the System Architecture for the service Road Works Warning, represents a specific national arrangement (grouping or split) of roles as well as a specific national assignment of roles to actors (as far as this is already known). The national organizational architecture might partially overlap with the organizational viewpoint of other C-ITS Corridor countries, possibly resulting in roles which might be assigned to transnational actors.

The national assignment of roles and responsibilities for the Road Works Warning service is summarized in the following table. The organizational architecture is currently under development and the system is not yet fully deployed and rolled out. Therefore, not yet for all roles the corresponding actors are identified. A complete overview of roles and responsibility will be published on the C-ITS Corridor Website [Cooperative ITS Corridor, n.d.]. The assignment in Table 8.1 is the current state of discussion and not yet finalized.

Role	**Subrole**	**Actor(s) Germany**	**Details, additional description**
Functional Operation	Content Provider	Road Operator (e.g. Hessen Mobil, Strassen.NRW)	The responsibility with the content provision lies with the Road Operators of the 16 federal states in Germany. They might delegate parts of the work to their subcontractors who are actually executing the maintenance activities
	Service Provider	Road Operator (details see above)	
	Service Recipient	Driver	
System Management	Service Catalogue Manager	not yet defined	
	C-ITS Architect	BMVI with support of BASt	
	Change Manager	currently under discussion	
	Test Manager	Road Operator with support of external experts	
	Service Level Manager	currently under discussion	

Role	Subrole	Actor(s) Germany	Details, additional description
	Compliance Manager	possibly BMVI with support of BASt	
	Financial Manager	this role is not covered as the service is free of charge for the user	
	Service Owner	Road Operator	
	Project Manager	BMVI	
	Information Security Manager	BSI	
System Operation	Communication Manager	Cellular Network Operator e.g. T-Mobile, O2, Vodafone and others Sender / Recipient for ITS G5 communication: Road Operator (examples see above) and Vehicle Manufacturer	
	Risk Manager	not yet defined	
	Capacity Manager	not yet defined	
	Availability Manager	not yet defined	
	Technical Analyst	not yet defined	
	Configuration Manager	not yet defined	
	IT-Operations Manager	not yet defined	
	Access Manager	not yet defined	

Role	Subrole	Actor(s) Germany	Details, additional description
Policy Framework	Non-regulatory policies	Amsterdam Group, Car2Car Communication Consortium	deployment organizations providing white papers
	Authority	European Commission (EU level) National level: BMVI Federal state level: Straßenverkehrsbehörden	
	Standardization	ISO, CEN and ETSI	Agreement available for cooperation between C-ITS Corridor and Standardization Bodies
	Security Certificate Body	Currently under discusion with BSI, probably some national organization for infrastructure Own solution from C2C-CC for vehicle part possible	

Table 8.1.: Assignment of roles to actors for RWW service in Germany

Road Works Warning is the first C-ITS service which is actually deployed – hence this is as well the first practical application of the organizational viewpoint. Considerations of transferring the methodology to other services show that depending on the main characteristics of a service as well the assignment of roles and responsibilities leads to similar results. This especially applies when particular stakeholder groups provide not only one single service but a whole bundle of services. In this case only small differences in the miscellaneous organizational viewpoint descriptions occur. Especially the assignment of roles supporting the actual functional operation of a service are often the same what leads

to benefits for those involved in the provision of a service. Accordingly, the organizational viewpoints clearly show that the profit for the individual stakeholders rises with the number of synergetic services they provide.

8.7. Functional Viewpoint of C-ITS Corridor System Architecture

The functional viewpoint describes the procedures and workflows for the Road Works Warning service. Since there is a legacy ITS implementation available in Germany a valuable fundament exists that can be reused.
Considering this, the functional viewpoint and its more detailed sub-elements are specified:

- business process
  Starting with a general prose description of the Road Works Warning use case and the corresponding UML model for the specific national implementation of Road Works Warning in Germany. This is accompanied by the modeling of the relevant operational business processes based on the generic process description in section 7.2.3.1

- modules
  On the basis of the Road Works Warning business process the modules required for an implementation of the service are identified. The individual modules are selected from the Modular Construction System (chapter 5, Appendices E and F) – if they are not yet included in the Modular Construction System, they are added.

- interfaces
  Interfaces connecting the identified modules are described. The interfaces are selected from the Modular Construction System – if they are not yet included in the Modular Construction System, they are added. Interfaces which are not yet standardized or described in white papers will be handed over to the respective organizations to start this task.

Those elements will serve as well as substructure for this chapter.

The description of all three core fields of the functional viewpoint are developed based on elements from the Modular Construction System. The Modular Construction System provides a variety of options even when focusing on Road Works Warning only. Various legacy ITS services in this field already exist. The use case description in section 8.7.1 sets the framework for the selection of modules, the sections on modules and interfaces (section 8.7.3, 8.7.4) describe the used components from the Modular Construction System in detail.

NOTE: A partially more detailed description of the functional viewpoint can be found in the System Architecture document of the C-ITS Corridor [C-ITS Corridor, 2014]. The system architecture of the C-ITS Corridor is complemented by the requirements analysis for the roadside and central C-ITS components developed in the respective project groups. The results are recorded in the respective deliverables, which will be publicly available on the C-ITS Corridor website [Cooperative

ITS Corridor, n.d.].

8.7.1. Use Case description for Road Works Warning

The deployment of Road Works Warning in Germany follows a phased approach. In the first phase, only the road works safety trailer in short-term road works will be equipped with the technology and broadcasts messages. In the second, phase the pre-warner of short-term road works are included, additional information will be available and the communication range will be larger. In the third phase, warnings and information about long-term road works will be available. The scenarios from the second and third phase are not considered in this description.

Short-term road works as defined in the RSA [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995] are all road maintenance activities that exist only for a limited number of hours, usually during daylight, even if the activities continue on the subsequent days. There are three types: short-term stationary, short-term mobile and survey work (the latter is not considered here). The maintenance activities are usually secured by a road works safety trailer and (eventually) a pre-warner.

The short-term Road Works Warning service is a service that was already implemented before the C-ITS technology was available. There are several existing implementations in Germany which provide functionalities that are subsumed under the term Road Works Warning, one of them is DORA (System for Dynamic Positioning and Road Works, Dynamische Ortung von Arbeitsstellen). For the legacy road works positioning systems (like DORA) the ordinary road works safety trailer is additionally equipped with a positioning module (currently Global Navigation Satellite System (GNSS)) and a communication module for cellular network communication, so that the road works safety trailer is able to send messages to the traffic control centre. Similar systems with different names exist. Those existing systems are partially rolled out in Germany (not all federal states) and allow the traffic control centres (and its operators) to know where on their network short-term road works take place. This existing system is the basis for the C-ITS Corridor service on Road Works Warning and needs to be integrated in the C-ITS technology based implementation of Road Works Warning.

For short-term road works two different use cases are implemented in Germany, the **stationary** and **mobile short-term road works**.
The two use cases will be implemented in two different modes, **stand-alone** and **basic mode**. In the stand-alone mode the trailer has no connection to the backend (traffic control centre) (depicted in Figure 8.1) and therefore only a simple message can be broadcasted to the receivers. In the basic mode the trailer is connected to the backend (traffic control centre) (depicted in Figure 8.2) and may broadcast an enhanced set of data to the vehicles. The corresponding descriptions for the two possible modes are included in sections 8.7.1.1 and 8.7.1.2.
NOTE: Other countries will implement additional or different use cases, e.g. Austria and the Netherlands plan to implement the use case of long-term stationary road works already in an early

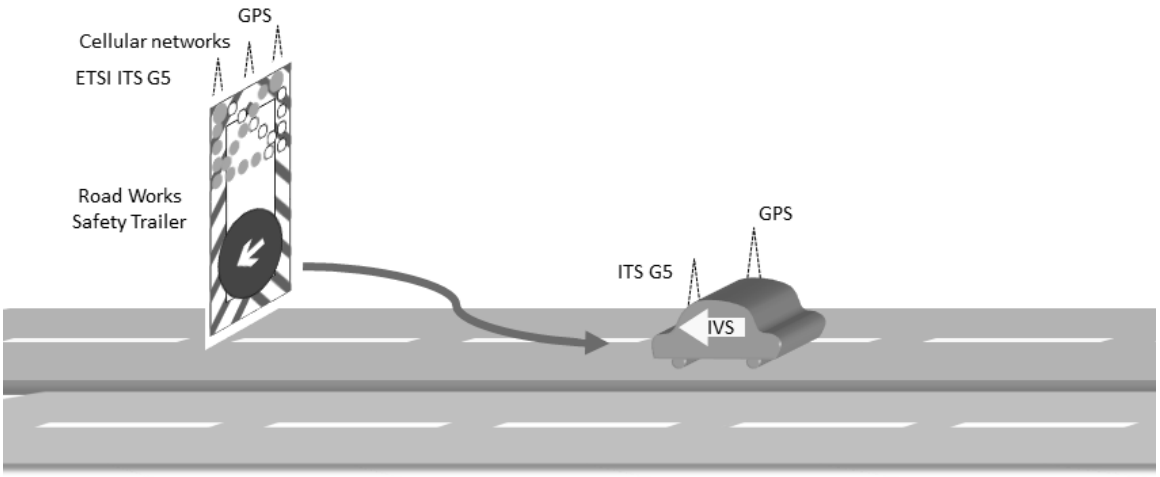

Figure 8.1.: RWW stand-alone mode (no connection to back-end)

phase of deployment.

8.7.1.1. Short term stationary use case implemented in C-ITS Corridor Germany

In the short-term **stationary** use case the road works safety trailer securing the short-term road works activities will not be moving (=stationary). The trailer is equipped with a positioning module, cellular communication, ITS G5 communication and the required software modules for the use case.
The maintenance staff has a mission for a short-term **stationary** road works. Therefore, they drive with their road works safety trailer to the position of the road works. According to the specification in the national guidelines they open the sign board of the trailer. Opening the sign board triggers the trailer's onboard equipment to send information about its position and arrow sign configuration to the traffic control centre via the cellular network channel. In the meantime the maintenance team starts to set up the road works, this includes for example the placement of signs, poles and other safeguarding equipment. Then they start working. The data sent to the traffic control centre will be validated, quality checked and enriched there and is merged with details on the road works from the road operator's road works management data base. Then the information is passed back to the trailer (via the cellular network channel). The trailer generates a DENM Road Works Warning message and broadcasts the information via the ITS G5 channel to all receivers (vehicles and nomadic devices) in the communication range. The receiving device presents the information to the driver. This use case is summarized in Figure 8.3 and is called basic mode.
In parallel, the Road Works Warning message from the traffic control centre is passed to other Service Providers via the MDM. The Service Providers generate warning messages for their clients, which they pass to them via cellular network.
NOTE: Corresponding layouts from the national guidelines are for example DIII / 2a or DIII 5. The Hessian traffic sign plan catalogue, Hessischer Verkehrszeichenplan-Katalog (He-VPZ) [Hessen

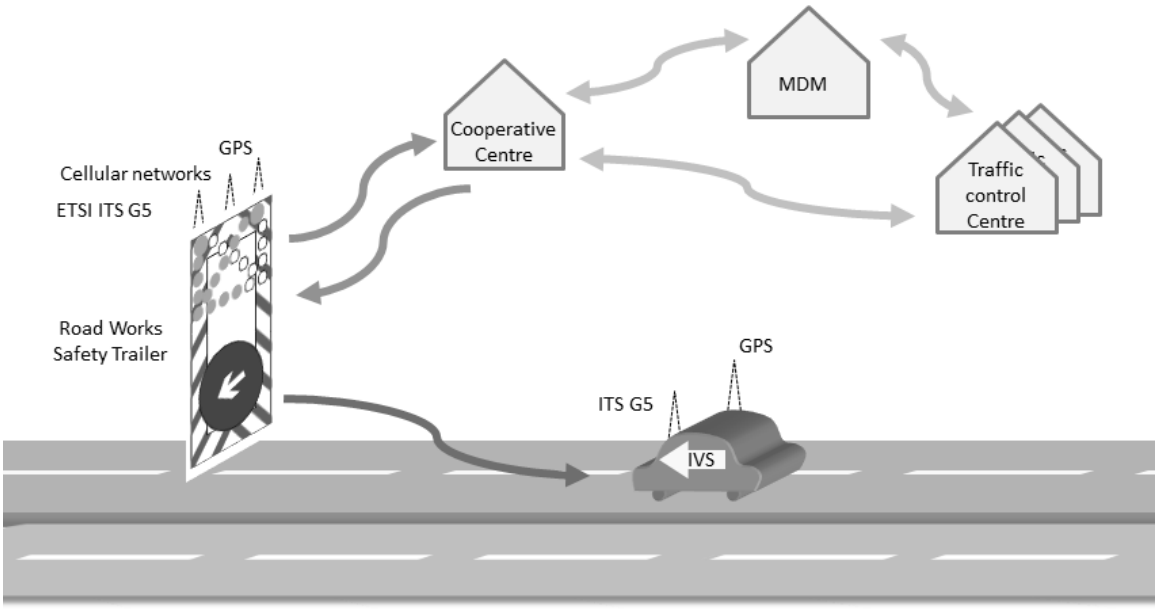

Figure 8.2.: RWW basic mode (with connection to back-end)

Mobil Straßen- und Verkehrsmanagement, 2013a,b] gives additional insights in how the layouts from the RSA [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995] are actually set up (examples for short-term stationary are in HE 1.2 RT). The He-VPZ is not a national guideline and only applicable in Hesse. Though other Bundeslaenders have no formal documents for this, similar processes take place when a short-term road works is set up and closed down.

Sometimes no cellular network is available. In this case, the trailer is not able to exchange information with the traffic control centre. Therefore, the trailer produces a rather simple and basic message out of the data available at the trailer that is broadcasted to the vehicles. This is depicted in Figure 8.4 and called 'stand-alone mode'.

8.7.1.2. Short-term mobile use case implemented in C-ITS Corridor Germany

In the short-term **mobile** use case the road works safety trailer securing the short-term road works activities will be moving (=mobile). Like for the stationary use case the trailer is equipped with a positioning module, cellular communication, ITS G5 communication and the required software modules.
The set-up procedure is similar to the stationary use case. Prerequisite for the start of a short-term **mobile** road works is that the maintenance staff has a mission for it. Then they drive with their road works safety trailer to the position where the road works shall start. According to the specification in the national guidelines they open the sign board of the trailer what triggers the trailer's onboard equipment to send information about its position and arrow sign configuration to the traffic control centre via the cellular network channel. In the meantime, the maintenance team sets up the road works, this includes for

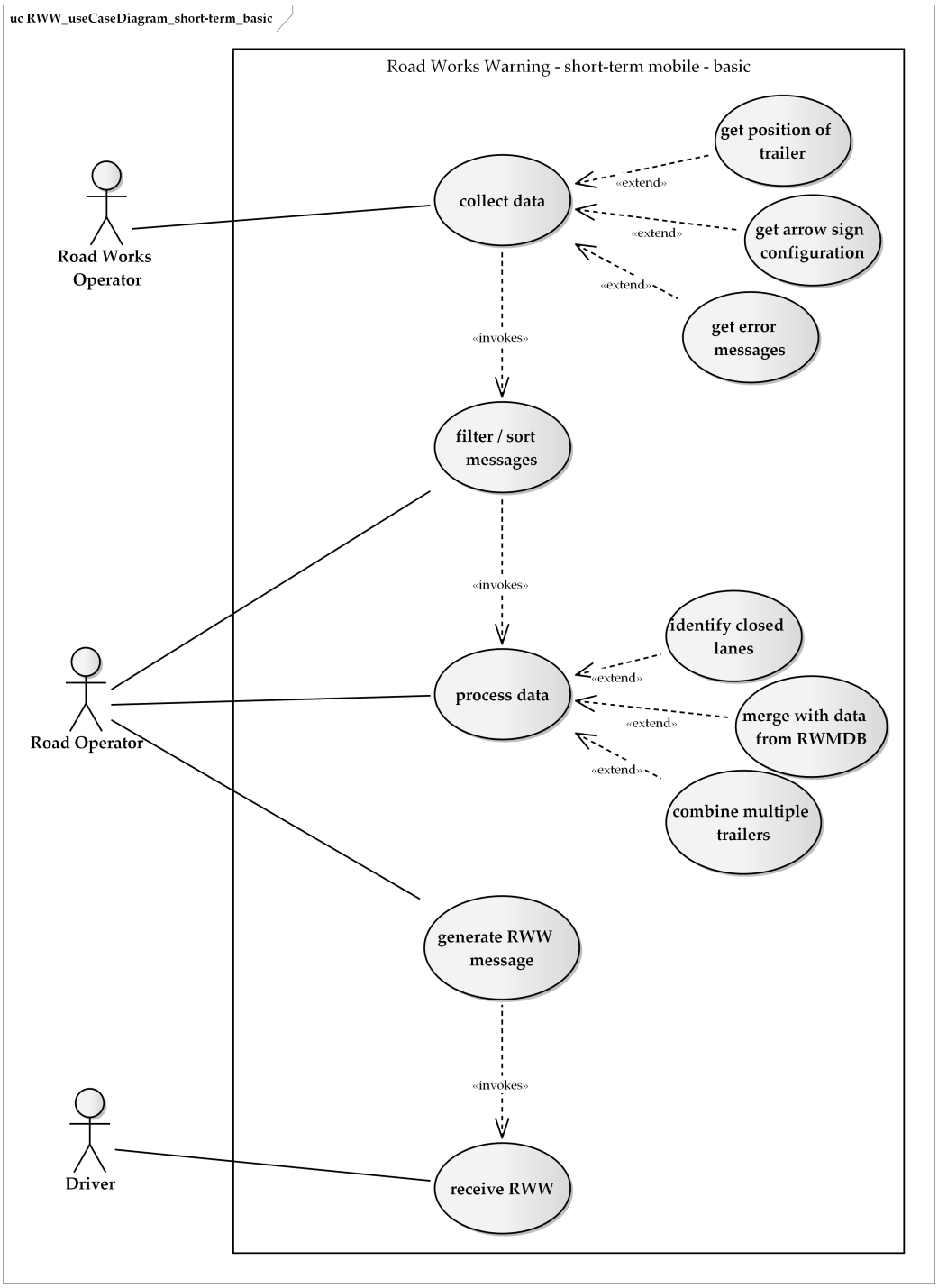

Figure 8.3.: UML Use case diagram for short-term stationary RWW in basic mode

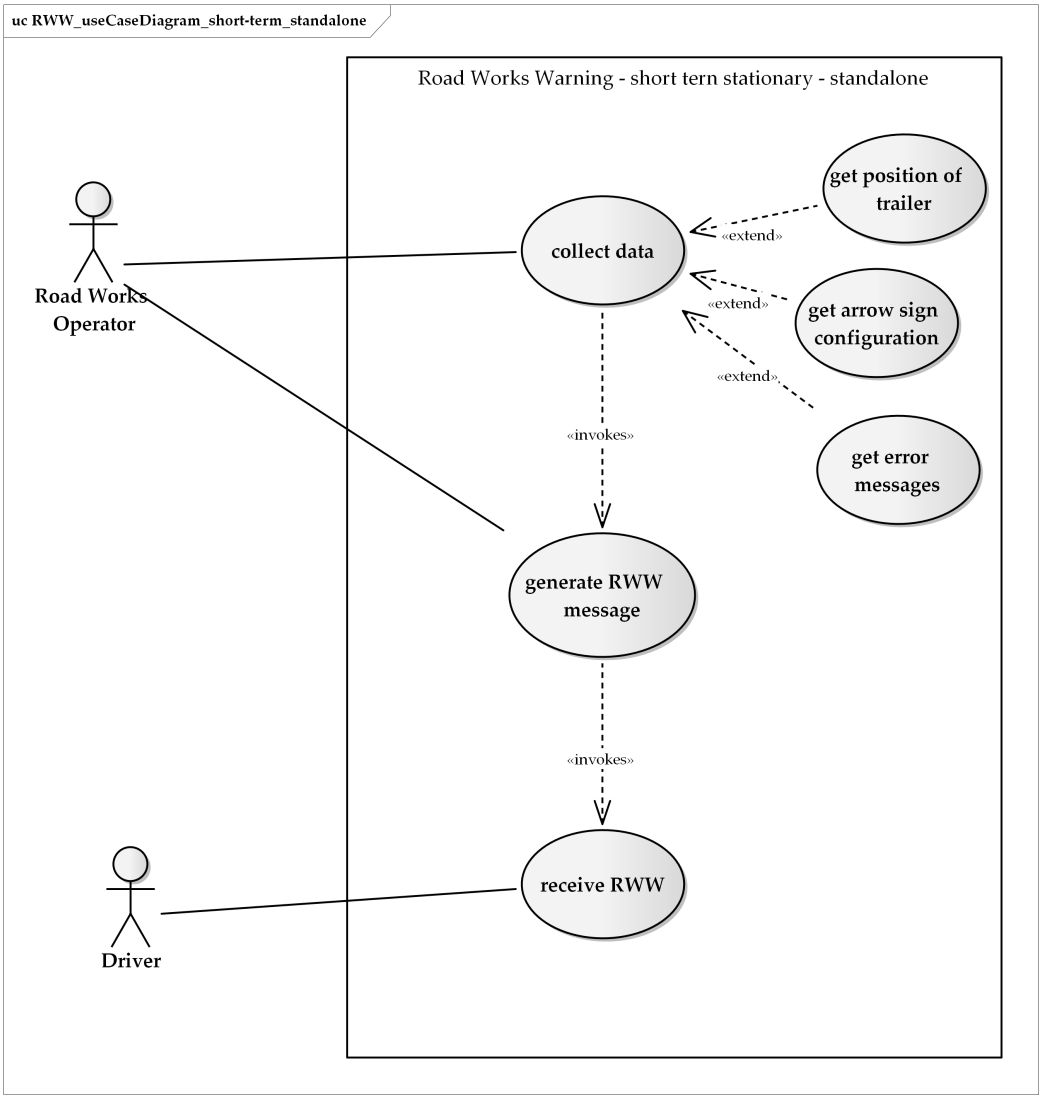

Figure 8.4.: UML Use case diagram for short-term stationary RWW in stand-alone mode

example the placement of signs, poles and other safeguarding equipment. Then they start working, the trailer is securing the moving maintenance team (e.g. cutting the grass). The movement pattern of the trailer has implications on the frequency with which information is transmitted from the trailer to the traffic control centre. The data sent to the traffic control centre will be validated, quality checked and enriched with details on the road works from the road operator's road works management data base. Then the information is passed back to the trailer (via the cellular network channel). The trailer first updates its position in the information pack received from the traffic control centre, generates a DENM Road Works Warning message and then broadcasts the information via the ITS G5 channel to all receivers (vehicles and nomadic devices) in the communication range. The receiving device presents the information to the driver. This use case is summarized in Figure 8.5 and is called mobile short-term basic mode.
NOTE: The national guidelines do not provide special layouts for mobile short-term roadworks. Examples from the He-VPZ for short-term mobile are in HE 1.65 LTB and following.

Sometimes no cellular network is available. In this case, the trailer is not able to exchange information with the traffic control centre. Therefore, the trailer produces a simple and basic message that is broadcasted to the vehicles. In this use case the message needs to be updated regularly with the recent position of the trailer. The use case diagram for this use case is identical to Figure 8.4 depicting the stationary use case and therefore not repeated here.

8.7.2. Business process description for Road Works Warning

Based on the general use case descriptions for the short-term stationary and mobile Road Works Warning service the respective business processes are identified. As template for the business process description the generic business process from the Reference Architecture (Figure 7.6) is used and adapted to the specific C-ITS Road Works Warning use cases. The comparison of the use case diagrams (Figures 8.3 and 8.5) shows that the processes of the short-term stationary and mobile use case are rather similar. Hence, in general both use cases can be described by the same process as the difference between the use cases is just in the update of the position for the short-term mobile road works before broadcasting the message to the receivers. Apart from that, the timing of the individual process steps might be different: the moving trailer in the short-term mobile scenario meets the trigger for sending updated information to the traffic control centre more frequently, therefore the centre-side process steps might be executed more often.

For a first abstract description the general process derived both from the TISA value chain and the Matrix report and generically described in detail in section 7.2.3.1 is used. Applying the general business process to the Road Works Warning use cases results in Figure 8.6.
The process describes – rather general but yet specific for the service Road Works Warning – the core intermediate steps from the initial trigger (road works started, the sign board was lifted up) until the final presentation of the warning to the driver. Both the short-term stationary and mobile use case can be mapped to the process – the differences are hidden inside the process steps. Not only the two use cases are covered by this general

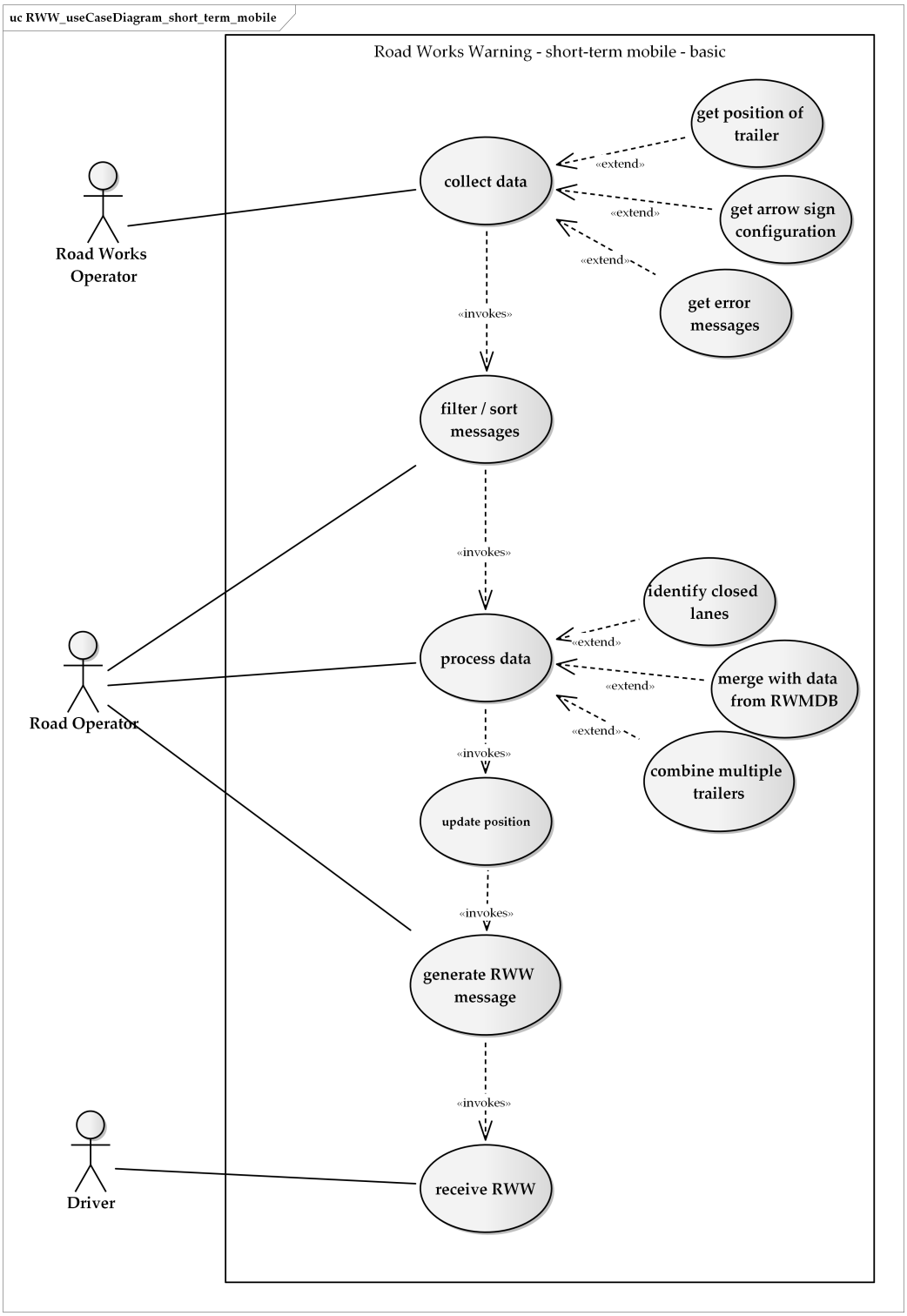

Figure 8.5.: UML Use case diagram for short-term mobile RWW in basic mode

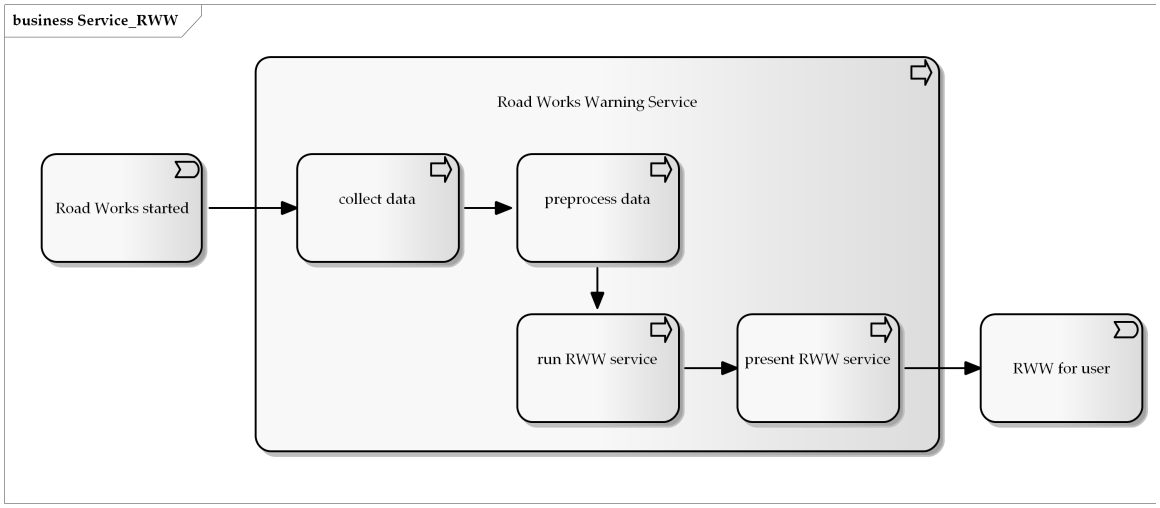

Figure 8.6.: General description of RWW process chain

description – as well the corresponding operation modes of Road Works Warning (basic and stand-alone) fit in there.

For a more specific description of the business process it is necessary to include some more details and to adequately describe the single steps that need to be taken in the individual use cases – from gathering the raw data until the warning is perceived by the driver – to highlight already with the business process model the differences between the use cases. In the more use case specific description the general process steps (collect data, pre-process data, run RWW service, present RWW service) therefore are split up into several elements. For the detailed description the following four scenarios are considered:

- short-term stationary basic service
- short-term mobile basic service
- short-term stationary stand-alone service
- short-term mobile stand-alone service

Basis for the description of the four scenarios is the more detailed but still generic description of the business process depicted in Figure 8.7.
In Figure 8.7, the core elements of the business process (from Figure 8.6) are complemented with all modules used in the implementations of the different short-term Road Works Warning scenarios.

The previous analysis already showed that the mobile and stationary short-term use case in general are rather similar, including their process chains. Hence, for the detailed description the use case options are not split up between the mobile and stationary use cases but according to the identified major difference, the operation modes of stand-alone and basic mode – here, substantial variations exist.

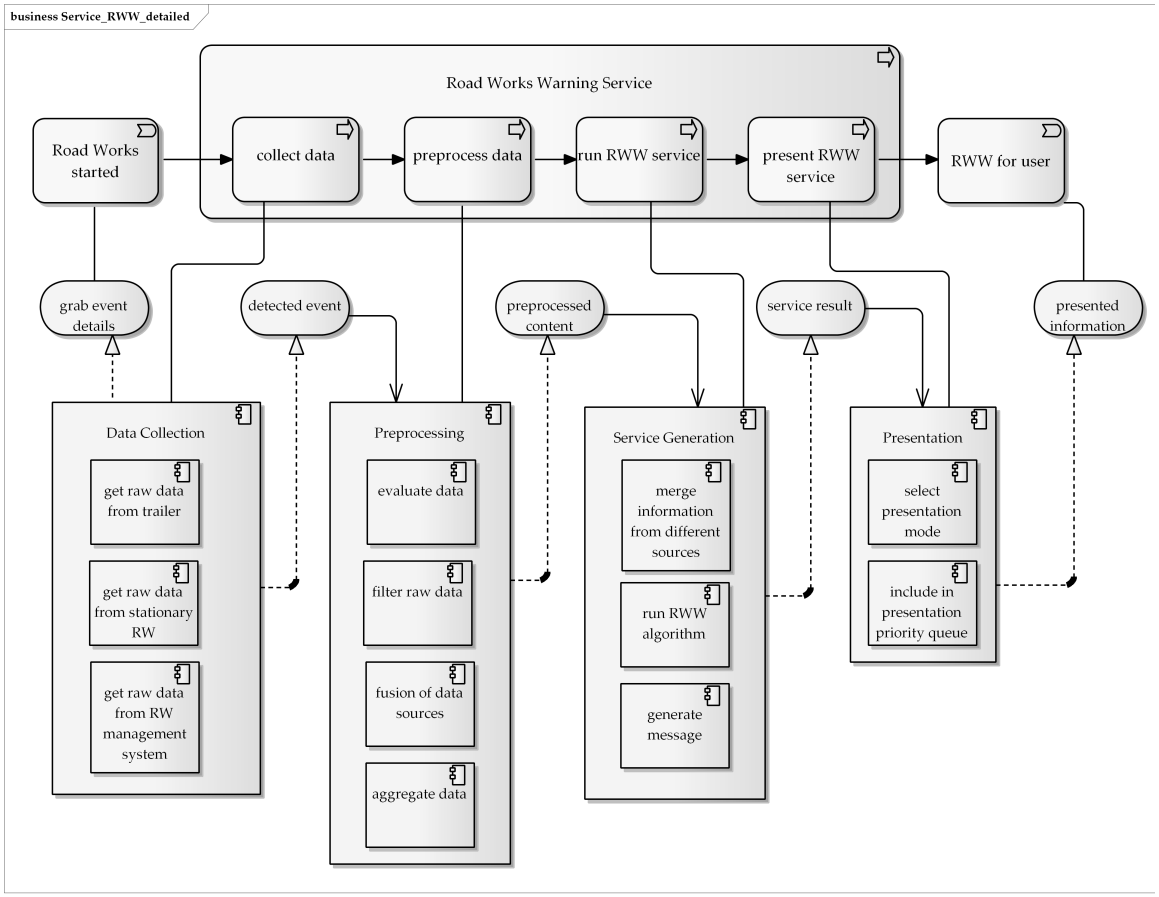

Figure 8.7.: Generic description of RWW use case – independent of short-term/long-term, mobile/stationary and basic/stand-alone mode

The two modes come along with different assignments of process steps to actors and component – depending on this assignment different degrees of complexity in the processing and evaluation modules are possible. Hence, two separate business processes are modeled for the basic and stand-alone use case of the short-term RWW scenario.

The short-term road works use case is realized based on the legacy road works locating system, the detailed business process for the **basic operation** mode is depicted in Figure 8.8. The data collection comprises the call of positioning information (of the road works safety trailer) from the GPS module that is mounted on the trailer and the call of the activated arrow sign configuration (metal sheet sign and LED panel). This set of raw data is then transmitted to the traffic control centre.
In the legacy road works positioning system several preprocessing steps are already implemented. This mainly results of the implemented technical architecture and comprises the filtering of messages (separate road works relevant messages from operational or error messages). In conjunction with other uplink service that will be implemented on the road works safety trailer (sending error messages to the traffic control centre) this functionality is still required – however it is not specific to the Road Works Warning service.

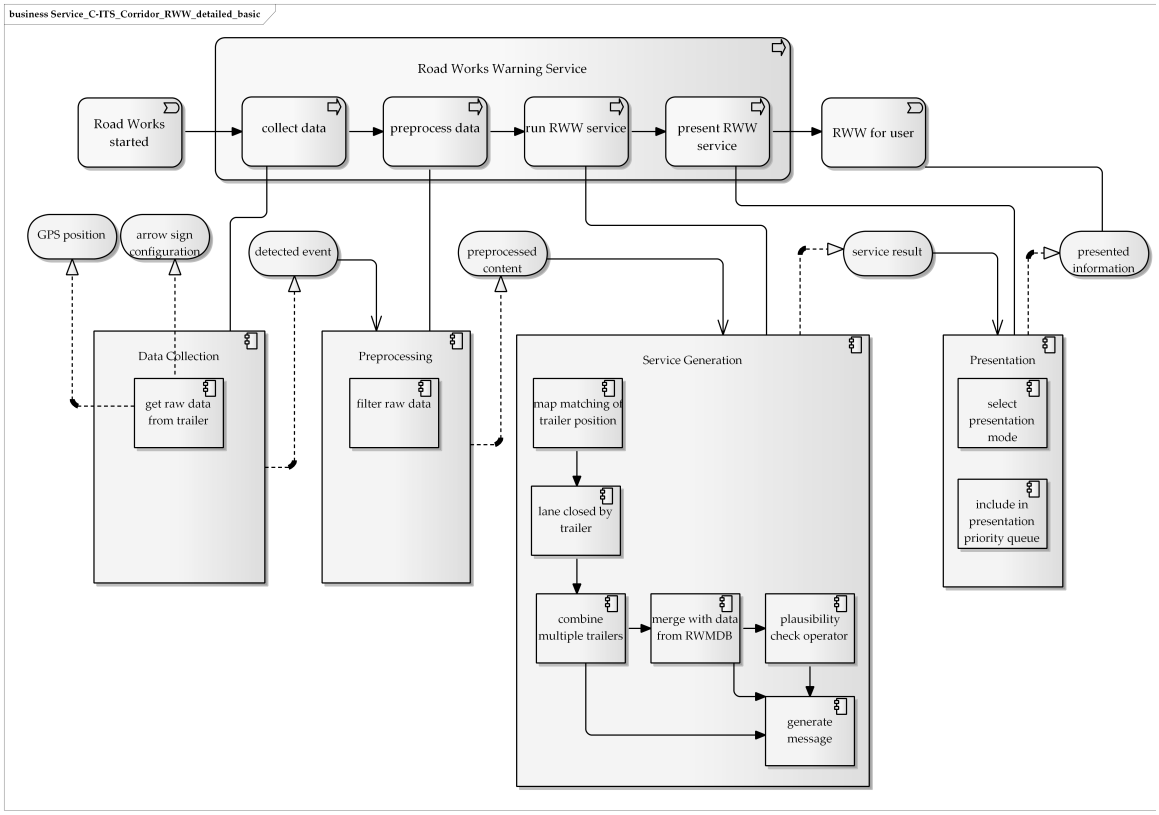

Figure 8.8.: Detailed business process for short-term RWW basic mode implementation in Germany

The actual Road Works Warning service consists of several elements. First a map matching of the trailer position takes place. This is required both to improve the GPS signal as well as converting the WGS84 (World Geodetic System 1984) coordinates into the location referencing system used by the traffic control centre. Afterwards, the lane closed by the trailer is determined. Given that the GPS position has no lane accuracy and the arrow sign configuration is not completely explicit regarding lanes this information can only be determined in the traffic control centre with support of a map. (There will be no map available on the trailer.) In the next step, multiple trailers are combined with each other – in case that several lanes are blocked by the short-term road works several trailers are required, in the traffic control centre they are merged into one road works object. These processing steps are followed by two optional operations: if a road works management data base is available the data from the trailer and the static data from the database are merged. This might lead to an enhanced description of the road works. And finally, an optional plausibility check by an operator might follow. All computations together lead to an enhanced and validated set of Road Works Warning parameters. They are passed back to the road works safety trailer.
Finally, the road works safety trailer converts the content in vehicle-understandable messages and broadcasts the information via ETSI ITS G5. In the vehicles, the service results are prepared for presentation and are finally presented to the driver.

Parallel to the dissemination of the information to the road works safety trailers the information is as well provided through other means. The road works information will be available via the MDM, service providers might sign up for this content and develop their own services. They might broadcast the information via cellular network, Digital Audio Broadcast (DAB) or other communication bearers.

The business process for the Road Works Warning service in **stand-alone** operation is slightly different from the one depicted in basic mode Figure 8.8. In stand-alone mode, no connection to the traffic control centre is possible therefore only a limited set of functionalities is available (Figure 8.9). All preprocessing activities are canceled and the service activities are reduced to the generation of messages for the vehicles. In stand-alone mode only communication with the vehicles via ITS G5 is possible, the data is not published via the MDM and service providers have no access to this data for their services.

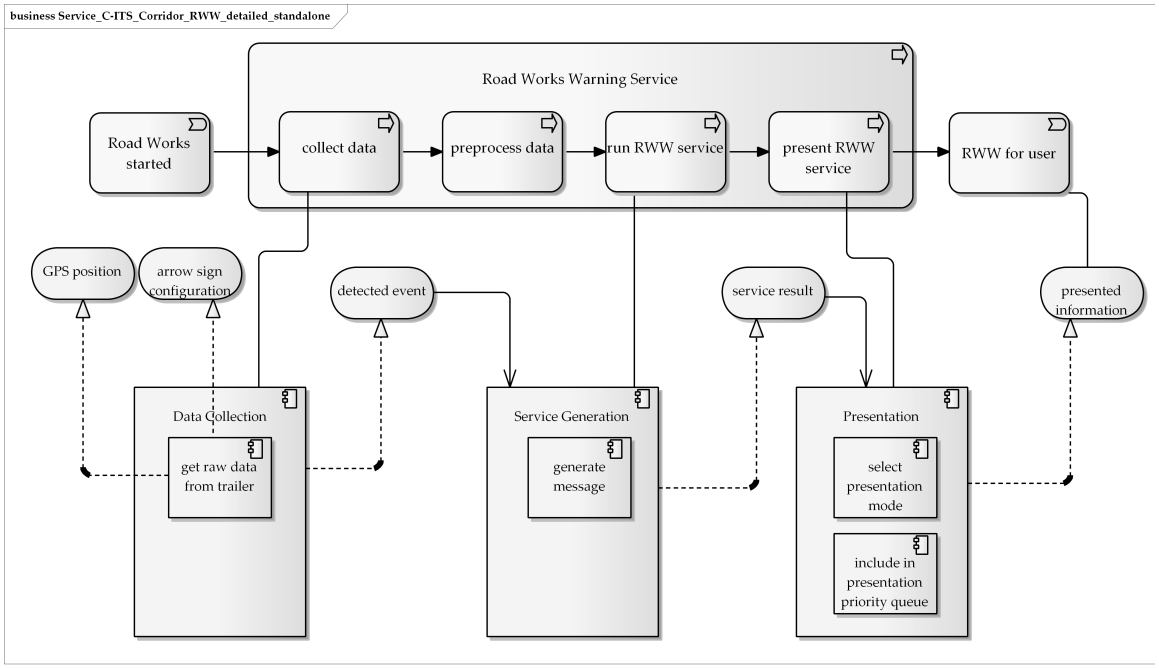

Figure 8.9.: Detailed business process for short-term RWW stand-alone mode implementation in Germany

In general, the stand-alone service should be active only rarely. Once active and connected to the traffic control centre a trailer might continue to broadcast the enhanced set of information received when being in basic mode as long as the road works is not closed and started again or major changes of the road works configuration take place (e.g. changed configuration of arrow signs). In such a situation missing cellular connections may be bypassed without switching back to the stand-alone mode. In consequence, the stand-alone mode will only be in use right after a road works was started and in case that there are major problems with the cellular network link to the traffic control centre.

Concluding the detailed description of Road Works Warning use case, sequence diagrams were developed to show the timely course of actions for this service. The sequence diagrams (Figures 8.10 and 8.11) additionally highlight the main difference between the basic and stand-alone use case that were already touched before.

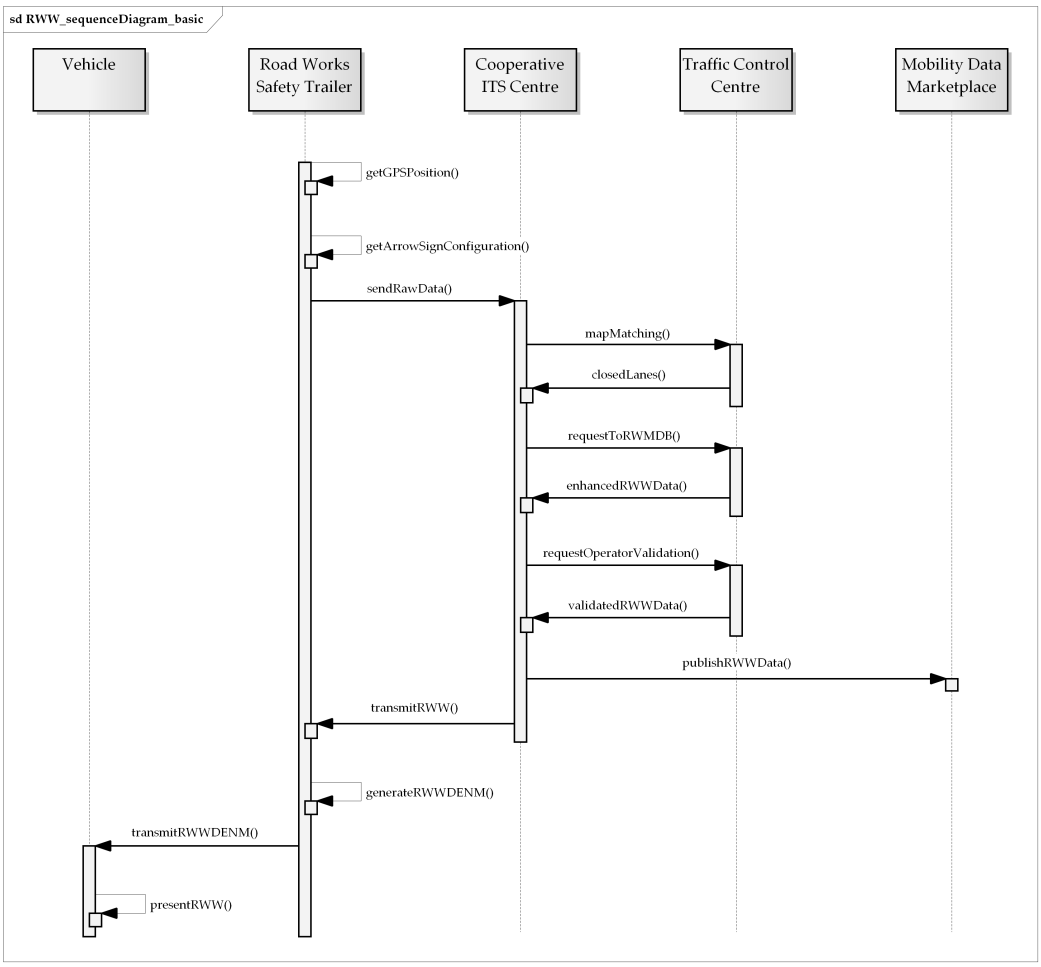

Figure 8.10.: Sequential flow for RWW service in basic mode (UML sequence diagram)

8.7.3. Road Works Warning modules and their assignment to components

The detailed description of the business process in the previous chapter shows that the service Road Works Warning is built up of a large number of smaller units. Partially, they were already used in the pre-C-ITS implementation of Road Works Warning that did not use the ITS G5 broadcast (legacy road works position in a systems like DORA [1]). Accordingly, they can be taken from the Modular Construction System. Modules that are additionally required will be registered with the Modular Construction System so that they are available for any upcoming implementation.

[1]System for **D**ynamic **PO**sitioning of Short Term **R**o**A**dworks

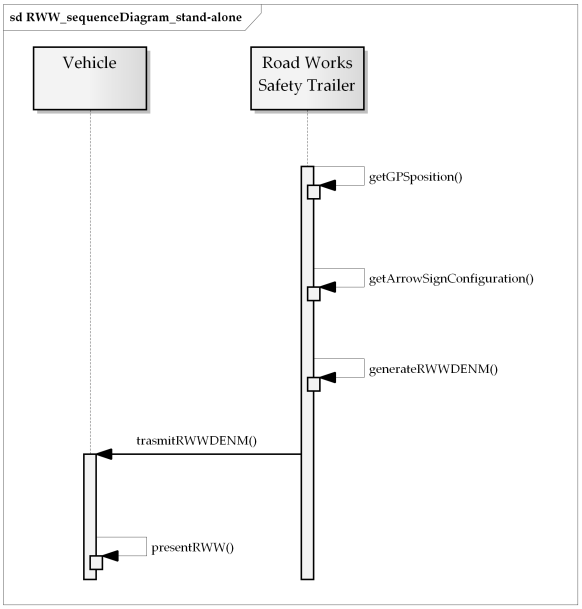

Figure 8.11.: Sequential flow for RWW in stand-alone mode (UML sequence diagram)

This chapter comprises first a list of modules which are required to implement the Road Works Warning service (8.7.3.1). This is complemented by the actual assignment of modules to components (8.7.3.2) what is closely linked to the description of the technical viewpoint.

8.7.3.1. Modules

Table 8.2 indicates which modules are already existing or need slight modifications and which new (additional) modules are required. The modules are described more detailed in Table 8.3, a description that is detailed and precise enough for an implementation can be found in the deliverables of the project groups on ICS – Cooperative ITS Central Station (PG2) [C-ITS Corridor and Hessen Mobil Straßen- und Verkehrsmanagement, 2016] and IRS – Cooperative Roadside Infrastructure (PG4) [Kühnel et al., 2015].
The specifications will be publicly available as soon as they are approved for tendering.

Module	**Description**	**Legacy ITS RWW**	**C-ITS RWW**
Module 1a	Retrieve the position information	X	
Module 1b	Retrieve the arrow sign configuration	X	
Module 1c	Generate a message with the retrieved content that can be sent through cellular network	X_m	

Module	Description	Legacy ITS RWW	C-ITS RWW
Module 2a	Retrieve the status of technical components of the road works safety trailer (e.g. battery status and others)	X	
Module 2b	Generate a message with the component status / error message	X_m	
	Transfer of data through cellular network is not wrapped into a module as this is a standard task fulfilled by cellular network operators. The Road Works Warning service only uses this functionality.		
Module 3	Filter content and error messages (messages from Modules 1c and 2b)	X	
Module 4a	Generate new Road Works Warning data object		X
Module 4b	Update Road Works Warning data object		X
Module 4c	Merge Road Works Warning data objects (road works with more than one road works safety trailer)		X
Module 4d	Archive / Delete Road Works Warning data object		X
Module 5a	Map matching of road works safety trailer position	X_m	
Module 5b	Determine position on traffic control centre map		X
Module 5c	Determine lane that is closed by road works safety trailer		X
Module 6	Combine multiple road works safety trailers working at the same construction site (closing multiple lanes) and retrieve their relative positioning		X
Module 7a	Get data from RWMDB		X
Module 7b	Combine / Merge data from the road works safety trailer with data from the RWMDB		X

Module	Description	Legacy ITS RWW	C-ITS RWW
Module 8a	Generate a message with the improved / updated content of the Road Works Warning object that can be sent through cellular network		X
Module 8b	Generate a message with the improved / updated content from the traffic control centre that can be passed to service providers and other road operators (both via MDM)		X
	See above – the transfer of the message via cellular network is not described here in detail.		
Module 9	Update the received content with current position and time stamp (optional – only in case that the trailer changed its position in the meantime)		X
Module 10	Generate message that can be sent through ITS G5		X
Module 11	Broadcast the message to the recipients (via ITS G5)		X
Module 12	Prepare the message for presentation		(X)
Module 13	Present the information		(X)

Table 8.2.: Modules for RWW service
grey modules actually belong to the service that provides operational information about the road works safety trailer to the road operator, this information is collected within the Road Works Warning service
X_m stands for 'needs slight modification'
(X) modules are not in focus, they are in the responsibility of the vehicle manufacturer and brand specific

The modules listed in Table 8.2 provide the following general features:

Module	Title and Description
1a	Retrieve the position information The road works safety trailer is equipped with a GNSS component. This is used to identify the position of the trailer and code it in WGS84 coordinates.
1b	Retrieve the arrow sign configuration

Module	Title and Description
	The road works safety trailer has a sign board that is closed when the trailer is not active. When the short-term road works is started the sign board is opened. On the sign board are two signs, a metal sheet sign with an arrow that may point to the bottom left, bottom middle and bottom right and a LED sign that can display an arrow pointing to the bottom left, the bottom right or a cross. The possible arrow sign configurations are described in the RSA [Forschungsgesellschaft für Straßen und Verkehrswesen, 1995].
1c	Generate a message with the retrieved content that can be sent through cellular network The position of the trailer and the arrow sign configuration is put together in a message – the detailed description for this public interface can be found in section 8.7.4.
3	Filter content and error messages (messages from Modules 1c and 2b) In parallel to the Road Works Warning service various other parameters which are relevant from an operators perspective are collected. They are not part of the Road Works Warning service but are transmitted to the traffic control centre together with the data from the Road Works Warning service. The filter module separates the two types of content. Partially, the data of the operational phase might be of relevance for the Road Works Warning service.
4a	Generate new Road Works Warning data object When a trailer becomes active and first sends its position and data to the traffic control centre a new data object is initiated.
4b	Update Road Works Warning data object The trailer sends new or updated information (new position, changed configuration of arrow signs), this requires an update of the already existing data object. Alternatively, the modules on the centre side generate new or updated content, this requires an update of the already existing data object.
4c	Merge Road Works Warning data objects (road works with more than one road works safety trailer) Several trailers belong to one road works, the corresponding data objects are merged into one or are linked to each other
4d	Archive / Delete Road Works Warning object The road works is finished when the sign board is closed. The road works data object is deactivated and moved into an archive for logging purposes.
5a and 5b	Map matching of road works safety trailer position

Module	Title and Description
	Determine position on traffic control centre map The WGS84 coordinates determined by the trailer are converted into the traffic control centre location referencing system and the position of the trailer is determined. Eventually the position is corrected if the coordinates do not point to a location on the road network. The Road Works Warning data object is updated.
5c	Determine lane that is closed with road works safety trailer With the support of the traffic control centre map the closed lane is determined and encoded. The Road Works Warning data object is updated.
6	Combine multiple road works safety trailers working at the same construction site (closing multiple lanes) and retrieve their relative positioning A road works setup may consist of several closed lanes and therefore multiple road works safety trailers. For a complete description of a single road works it is checked whether there are other trailers blocking neighboring lanes. They are combined into one road works. The Road Works Warning object is updated.
7a	Get data from road works management data base Partially, short-term road works are already registered in the road works management data base run by the road operator. The entries in the database might provide additional information that cannot be derived from the information received from the road works safety trailer. A query to the road works management data base is issued to retrieve potential additional information.
7b	Combine / Merge data from the road works safety trailer with data from the road works management data base The data from the road works management data base is merged with the data so far collected about the short-term road works. The Road Works Warning data object is updated.
8a	Generate a message with the improved / updated content of the Road Works Warning object that can be sent through cellular network The content of the Road Works Warning data object is encoded in a suitable message format so that it can be sent to the road works safety trailer for further dissemination to the vehicles, the detailed description for this public interface can be found in section 8.7.4.
8b	Generate a message with the improved / updated content from the traffic control centre that can be passed to service providers and other road operators (both via MDM)

Module	Title and Description
	The content is as well published on the MDM so that service providers can pick it up. The Road Works Warning object is converted into a DATEX II message.
9	Update the received content with current position and time stamp (optional – only in case that the trailer changed its position in the meantime) Only in short-term mobile use case: after the road works safety trailer received the updated road works data object it updates the position with the most recently determined position (from the GNSS module).
10 and 11	Generate message that can be sent through ITS G5 Broadcast the message to the recipients (via ITS G5) The content is passed to the ITS Station, in the facility layer of the ITS Station a Road Works Warning DENM is generated.
12 and 13	Prepare the message for presentation Present the information The receiver of the Road Works Warning DENM takes the necessary steps for presentation of the content. This is not detailed here as it is not in the scope of the C-ITS Corridor. Both the preparation and presentation of the information is in the responsibility of the receiver and not part of standardization or harmonization activities.

Table 8.3.: Detailed specification of RWW modules from table 8.2

Additionally, certain processes are required to implement the security requirements, therefore the following parallel processes especially for the IT-security were implemented as modules:

Module	Title and Description
14	Request / receive new certificates and keys from a public key infrastructure
15	Establish a secure channel for the communication between the road works safety trailer and the cooperative ITS Centre or traffic control centre
16	Establish a secure channel for the communication between the cooperative ITS Centre and the traffic control centre
17	Sign messages which will be sent to the vehicles / nomadic devices

Table 8.4.: Detailed specification of security related modules

The detailed requirements for the security modules are described in the protection profile developed in PG6. This is currently still under development.

8.7.3.2. Assignment of modules

Basically, the assignment of modules to components links the functional and the technical viewpoint. The technical viewpoint provides the hardware structure (and limitations) that need to be reflected in the implementation of the modules.
For the assignment of modules to components on a functional level the still open discussion on structural technical architecture decisions is not relevant. (For details see section 8.8)
The following allocations of modules are implemented in the German C-ITS Corridor System Architecture:

Component	Module
road works safety trailer	(1a) Retrieve the position information
	(1b) Retrieve the arrow sign configuration
	(1c) Generate a message with the retrieved content that can be sent through cellular network
	(9) Update the received content with current position and time stamp (optional – only in case that the trailer changed its position in the meantime)
	(10) Generate message that can be send through ITS G5
	(11) Broadcast the message to the recipients (via ITS G5)
Cooperative ITS Centre	(3) Filter content and error messages (messages from Modules 1c and 2b)
	(4a) Generate new Road Works Warning data object
	(4b) Update Road Works Warning data object
	(4c) Merge Road Works Warning data objects (road works with more than one road works safety trailer)
	(4d) Archive / Delete Road Works Warning data object
	(5a) Map matching of road works safety trailer position
	(6) Combine multiple road works safety trailers working at the same construction site (closing multiple lanes) and retrieve their relative positioning
	(7a) Get data from road works management data base

Component	Module
	(7b) Combine / Merge data from the road works safety trailer with data from the road works management data base
	(8a) Generate a message with the improved / updated content of the Road Works Warning object that can be sent through cellular network
	(8b) Generate a message with the improved / updated content from the traffic control centre that can be passed to service providers and other road operators (both via MDM)
Traffic Control Centre (legacy ITS)	(5b) Determine position on traffic control centre map
	(5c) Determine lane that is closed with road works safety trailer
	(7a) Get data from road works management data base
Vehicle / Nomadic Device	(12) Prepare the message for presentation
	(13) Present the information

Table 8.5.: Assignment of RWW modules to components for RWW service

8.7.4. Interfaces implemented in Road Works Warning

Before actually discussing the interfaces in detail, a data model for the Road Works Warning service needs to be developed. The data model for the Road Works Warning services covers any service related data transmitted between the involved entities, starting from the raw data to the final road works information. The data model therefore covers the whole operational business process.
For the implementation of the service, legacy ITS is considered, the same applies to the data models. Existing data models need to be considered when developing the one for the C-ITS Corridor Road Works Warning service. Relevant data models are:

- ETSI CDD [ETSI 102 894-2, 2013] for the communication with the vehicles 'their' language is used, hence it needs to be ensured that all elements required from CDD for the Road Works Warning service are included in the RWW data model.

- DATEX [DATEX II, n.d.] II and its profiles [Hessen Mobil Straßen- und Verkehrsmanagement and Freudenstein, 2013; ECo-AT and Meckel, 2015] already propose structures for Road Works Warning data objects

Both existing data models were aligned with the requirements of the Road Works Warning service, some C-ITS specific extensions were added and a proposal for a new (platform independent) data model was developed within the C-ITS Corridor (example in Figure 8.12,

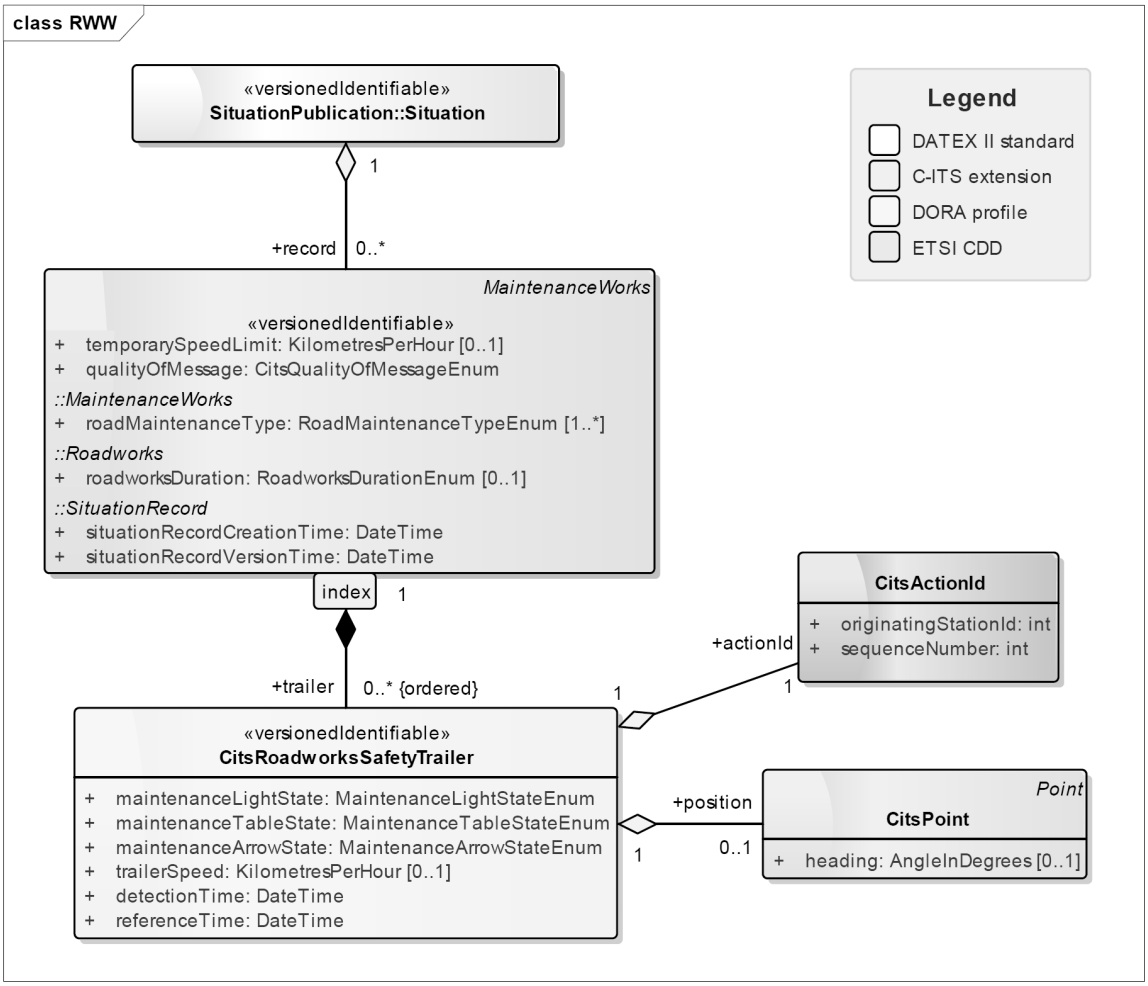

Figure 8.12.: Data model for C-ITS Corridor described in 'Road Works Warning Service (RWW) Platform-independent data model' [C-ITS Corridor, 2015a]

complete data model in respective C-ITS Corridor document [C-ITS Corridor, 2015a]).
The data model in Figure 8.12 describes one data object per Road Works Warning, the MainenanceWorks object. Besides several attributes a number of road works safety trailers can be assigned to the MaintenanceWorks object. The CitsRoadworksSafetyTrailer objects in turn are characterized with different attributes, e.g. their position, arrow sign configuration or ITS Station IDs.
The developed data model is the basis for the detailed description of each interface – only content already registered within the data model is exchanged via any interface of the Road Works Warning service.
NOTE: Not all content is transferred over every interface. Profiles of the data model for each interface are developed. This is complemented by a selection of suitable encodings (details see section 8.7.5).

With an abstract data model at hand, it is now possible to start diving into the details

of individual interfaces. Interfaces are all the links between modules described in the previous chapter. The generic description of the functional viewpoint in chapter 7 (Reference Architecture) already identified two generic and core interfaces based on the generic business process: between detection and evaluation and evaluation and presentation. For the description of interfaces in the System Architecture of the C-ITS Corridor this generic structure is picked up and slightly extended with support of the assignment of modules to components like it is described in section 8.7.3.2.

In general, the whole set of possible interfaces generated by the partition of the service into modules can be split up into two major groups. External interfaces, which later will be implemented between modules that are assigned to different components, and internal interfaces which exist between modules implemented within the same component. Whether an interface is external or internal therefore highly depends on the implementation and hence the assignment of modules to components. It is not possible to generically define which interfaces are internal and which are external.
Especially the external interfaces are important for interoperability. Components might be produced by different manufacturers, if no agreement on interfaces is made it is possible that two functionally identical components cannot replace each other. Therefore, at least the external interfaces need to be specified and harmonized. Internal interfaces are not that critical – usually, they are in the responsibility of one single entity and interoperability is not an issue.
The assignment of modules to components was described in section 8.7.3.2. This is the basis to identify which interfaces are external and internal in the System Architecture for the C-ITS Corridor.
NOTE: Other assignments are feasible as well. This might result in a different partition into external and internal interfaces. Within the C-ITS Corridor the individual countries defined similar assignments of modules, hence it is possible to (partially) harmonize the external interfaces.

From the allocation in section 8.7.3.2 the following external interfaces are derived:

a) between road works safety trailer and vehicle

b) between road works safety trailer and cooperative ITS centre

c) between cooperative ITS centre and traffic control centre

d) between traffic control centre or cooperative ITS centre and MDM

These interfaces are completed by an internal interface to a standard component, in particular between the road works safety trailer and a (standard) ITS Station which is required to communicate with vehicles via ITS G5. All other internal interfaces are hidden within components and are therefore implementation and vendor specific.

Like for the service description and the data model several legacy aspects need to be considered when describing the interfaces. Partially, the interfaces are already implemented for other implementation variations of a Road Works Warning service e.g. the traffic control centres already exchange data with the MDM about long-term road works, a DATEX

II profile is defined, protocols are agreed. Regionally, already DATEX II profiles for short-term road works are implemented. A similar background exists for the interface to / from the vehicles. The C2C-CC and ETSI already specified how communication on the ITS G5 link looks like, including message sets and the communication architecture. This needs to be considered – at least in a Day 1 implementation of the Road Works Warning service (later, new message structures might be defined).

NOTE: All interfaces described in the next chapters are harmonized as far as possible within the C-ITS Corridor. For the vehicle – infrastructure interfaces this is absolutely necessary to allow for the implementation of a seamless service across the whole C-ITS corridor without huge efforts on the vehicle side. The other interfaces are harmonized to enable benefits for procurement of equipment on the infrastructure side. Harmonization here is no mandatory requirement as the legacy backend systems which were developed in the last years are rather different. The Amsterdam Group hosts these harmonization activities.

8.7.4.1. Vehicle – road works safety trailer interface

The communication for this interface is running over the ITS G5 channel. A lot of standardization efforts have been made within ETSI and C2C-CC for this technology, resulting for example in the ITS Communication Reference Architecture [ETSI 302 665, 2010], the message sets CAM and DENM [ETSI 302 637-2, 2014; ETSI 302 637-3, 2014], various ITS G5 specific protocols. The standards are comparatively stable and C2C-CC published a basic system profile [Buburuzan, 2014] in which is stated which of the standards in which profile are implemented on day 1. These documents are the basis for the definition of the interface between the vehicle and the road works safety trailer.
The interface is discussed in the Amsterdam Group task force on Road Works Warning between the road operators and the vehicle manufacturers. The interface on Day 1, it needs to be based on the already standardized DENM [ETSI 302 637-3, 2014]. A profile for Road Works Warning was developed by the task force, this is adopted both by the road operators and the vehicle manufacturers (added to the C2C-CC Day 1 Basic System Profile) and will be implemented in the C-ITS Corridor. Other deployment initiatives were involved in the process of harmonizing the description.
The Road Works Warning profile comprises of a functional description of the different Road Works Warning use cases [Amsterdam Group Road Works Warning Task Force, 2016a] and a profile on the DENM message including the triggering conditions for road works [Amsterdam Group Road Works Warning Task Force, 2016b]. The latter document explains which fields of the DENM are used and how to transmit a Road Works Warning from the roadside infrastructure to the vehicles. The triggering conditions define when road works really starts and ends and which triggers actually lead to a Road Works Warning broadcast.
All documents are available from the Amsterdam Group website. Leader of the task force and editor of the documents was Teresina Herb. The documents are agreed between the partners involved in the Amsterdam Group task force.

The Amsterdam Group Road Works Warning DENM profile does not define which protocols are used in the layers below the facility layer. The underlying layers make use of the

protocols proposed in the ITS Station Reference Architecture [ETSI 302 665, 2010] implemented in the way how it is defined in the Basic System Profile [Buburuzan, 2014].

8.7.4.2. Road works safety trailer – Cooperative ITS Centre interface

With the cooperative ITS centre a new component is introduced. Partially, the modules now assigned to the cooperative ITS centre were already implemented in proprietary technical solutions of the legacy road works positioning system. Though, no standardization activities for this interface took place so far.
Currently, the requirements for this interface are collected, this includes both the content that will be transmitted over this interface as well as the requirements on the communication protocols. A first proposal was made in the German position paper [C-ITS Corridor, 2015b]. The three corridor countries aspire to standardize this interface.
NOTE: This interface is comparable to legacy ITS interfaces between roadside units and traffic control centre. At present the TLS standard [BASt, 2012] is used for this interface. TLS is currently updated but does not yet reflect the requirements of cooperative ITS. It is assumed that in the future the description of this interface will be integrated in a new version of TLS. This becomes as well relevant as soon as (stationary) roadside units are equipped with ITS G5 technology to broadcast services like in-vehicle signage.

The lower layers will be IP based and not implement the ITS Station Reference Architecture [ETSI 302 665, 2010; ISO 21217, 2009].

8.7.4.3. Cooperative ITS Centre – Traffic Control Centre interface

In fact, the interface between cooperative ITS centre and traffic control centre is a centre-to-centre interface. For these interfaces the DATEX II standard was developed, so only a suitable profile for short-term road works needs to be developed to transmit the road works information from the cooperative ITS centre to the traffic control centre.
Apart from complete or partial road works objects additionally service requests need to be passed over this interface: the cooperative ITS centre needs the support of the traffic control centre for the map matching module and the additional information from the road works management database. This aspect is not yet covered by DATEX II and suitable messages formats need to be defined. The missing profiles are currently under development.

Like the interface between the road works safety trailer and the cooperative ITS centre the lower layers of this interface will be IP based and not implement the ITS Station Reference Architecture [ETSI 302 665, 2010; ISO 21217, 2009].

8.7.4.4. Traffic Control or Cooperative ITS Centre – MDM interface

This interface is very similar to the legacy interface that is already used for long-term road works. All traffic control centres in Germany are supposed to support a DATEX II interface to the MDM. For long-term road works a profile was already defined [Freudenstein, 2017]. The short-term Road Works Warning profile is an advancement of this profile derived from

the generic data model. A new DATEX II profile is developed and will be standardized shortly.
NOTE: Some regional profiles for short-tem Road Works Warning exist [Hessen Mobil Straßen- und Verkehrsmanagement and Freudenstein, 2013; ECo-AT and Meckel, 2015] which need to be harmonized with a new DATEX II profile.

The interface is implemented based on IP communication.

8.7.5. Data structure(s) and encoding

The different options for the encoding of the respective data models was already briefly touched in section 7.2.3.3.1. In general, the encoding provides a transfer syntax that allows to transfer the generic platform independent description of the data model (C-ITS specific data model see section 8.7.4 and Figure 8.12) into an implementation specific description. Usually, several options for encoding the data model exist and it is depending on the requirements of the system and its services which type of encoding is finally selected.

For the interface between vehicle and infrastructure the encoding is determined by the V2V implementations. Focus of the C-ITS deployment driven by the C2C-CC is the V2V communication, V2I communication (like it takes place over this interface) needs to be in line with it as the vehicles use the same data model, protocols and encoding for this interface. The C2C-CC decided to use ASN.1 Packet Encoding Rules. To ensure interoperability the same encoding is used for the vehicle – infrastructure interface.

The other interface, for which implementations already exist, is the interface between the traffic control centre and the MDM. The implemented DATEX II protocol is encoded in XML Schema Definition (XSD).

To only two interfaces that do not exist in any legacy ITS are the ones between the road works safety trailer and the cooperative centre and between the cooperative centre and the (legacy) traffic control centre. The interface between road works safety trailer and the cooperative centre will be an air interface and therefore has to follow different requirements than the interface between cooperative centre and the (legacy) traffic control centre what will be a wired interface. Presumably, a very dense encoding will be selected for the air interface. The wired interface might use the same encoding like the traffic control centre – MDM interface (DATEX II via XSD).

8.8. Technical Viewpoint of C-ITS Corridor System Architecture

For the technical viewpoint, which describes the choice of technology (hardware) for the deployment of services and functionalities of the system, existing modules from the Modular Construction System are reused.
The technical viewpoint in general covers two main aspects. One is the assignment of modules to technical components. This is already briefly described in section 8.7.3.2. Be-

sides this generic description of the technical and physical implementation as well a set of structural implementation options is part of the technical viewpoint. This was already generically addressed in section 7.3 and is now deepened here and transfered to a practical example.

For the Road Works Warning service the following components will be part of the technical implementation:

- **vehicle** and / or **nomadic devices** equipped with an ITS Station and GNSS module. They will receive the Road Works Warning via the ITS Station, can locate themselves with the GNSS module, provide the hardware to run algorithms required for the presentation of the warning to the driver, in case that it is spatially relevant
- **road works safety trailer** equipped with an ITS Station, GNSS module and cellular communication. The road works safety trailer is involved in the event detection as it is the starting position of the road works, it is able to determine its own position with the GNSS module, identify its hardware (sign) configuration, provides the necessary hardware to pre-process the data and then communicates with the backend (cooperative ITS centre or traffic control centre). Apart from that, the road works safety trailer's hardware is designed to even locally process the detected data into a Road Works Warning – in case that the trailer is running in stand-alone mode.
- **cooperative ITS centre** provides the hardware to host especially the cooperative modules that are required for a cooperative Road Works Warning service.
- **traffic control centre** supplies the hardware to host the modules from the legacy ITS that are used to realize the Road Works Warning service. This incorporates for example database structures in which more details on Road Works activities are stored (Road Works Management Database) or suitable data structures for the map required by the Road Works Warning service.

The structure of the technical architecture is depicted in Figure 8.13.
All these components are already part of the Modular Construction System (see chapter 5 and Appendices E and F), no additional components need to be included. The functional modules are assigned to those components like it is described in table 8.5.

The detailed technical (hardware) requirements for the individual components are described in the respective project groups (as soon as the documents are publicly available they can be downloaded from the official C-ITS Corridor website [Cooperative ITS Corridor, n.d.]): the details for the road works safety trailer are in the specifications of the ITS Roadside Station (IRS) project group (PG4) [C-ITS Corridor and Hessen Mobil Straßen- und Verkehrsmanagement, 2016], the details on the cooperative centre and the necessary adaptations for the legacy traffic control centre are described in the documents of the project group ITS Central Station (ICS) (PG2) [Kühnel et al., 2015].

Although a precise list of modules was developed in the functional viewpoint (8.7.3.1), the hardware components were identified in the technical viewpoint (8.8) and the assignment of modules to components was made (8.7.3.2) there still exist several implementation

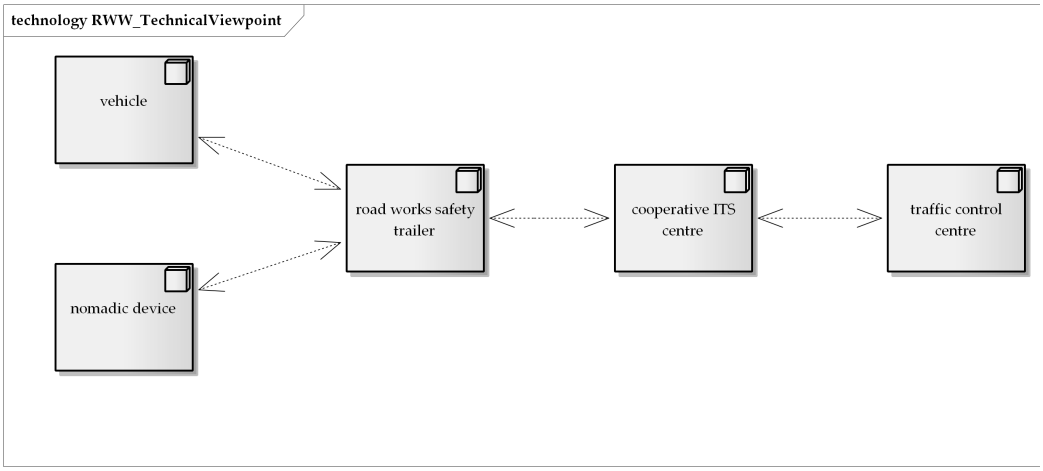

Figure 8.13.: Generic technical architecture for RWW

options for the Road Works Warning service. What leads to the conclusion that apart from the general assignment of modules to technical components additional structural decisions are needed. In an abstract way, this topic is already touched in the generic description of the technical viewpoint in section 7.3 (Reference Architecture), mentioning that some components might be implemented in a central, distributed or mixed (hybrid) scenario.
For the specific German structural decision the existing organizational structures need to be taken into account. According to the national legislation, the responsibility for the operation of highways is with the individual federal states. Hence, for the operation of any related telematic infrastructure usually the same applies. This may lead to the fact that components which from a purely academic viewpoint should exist only once in a centralized structure in fact are implemented in a distributed way. This only affects the functionalities which are assigned to the cooperative ITS centre. The legacy traffic control centers are already implemented in a distributed way, at least each federal state has one traffic control centre for traffic management on their highways and rural roads.
A cooperative ITS centre is so far not deployed but is required for the implementation of the C-ITS Corridor services and therefore is needed as well for the Road Works Warning service. Hence, the structural decision mainly affects the cooperative ITS centre and its modules. It might be integrated in the existing traffic control centers (distributed solution – Figure 8.14, right) or be implemented as another new type of traffic control centre that is jointly used by different federal states (central or mixed solution, depending on whether all agree to use one single cooperative ITS centre (central – Figure 8.14, left) or only some (hybrid – Figure 8.14, bottom).
Currently, no decision for one of the options was made. Advantages and disadvantages of the individual solutions still need to be analyzed. This includes not only technical aspects and the costs and benefits of the individual solution but as well the political position of the federal states. At the moment it is too early for such a decision, the ultimate implementation decision will be described in the final architecture document which will be available on the C-ITS Corridor website [Cooperative ITS Corridor, n.d.].
Other components besides the cooperative ITS centre are not really influenced by such a

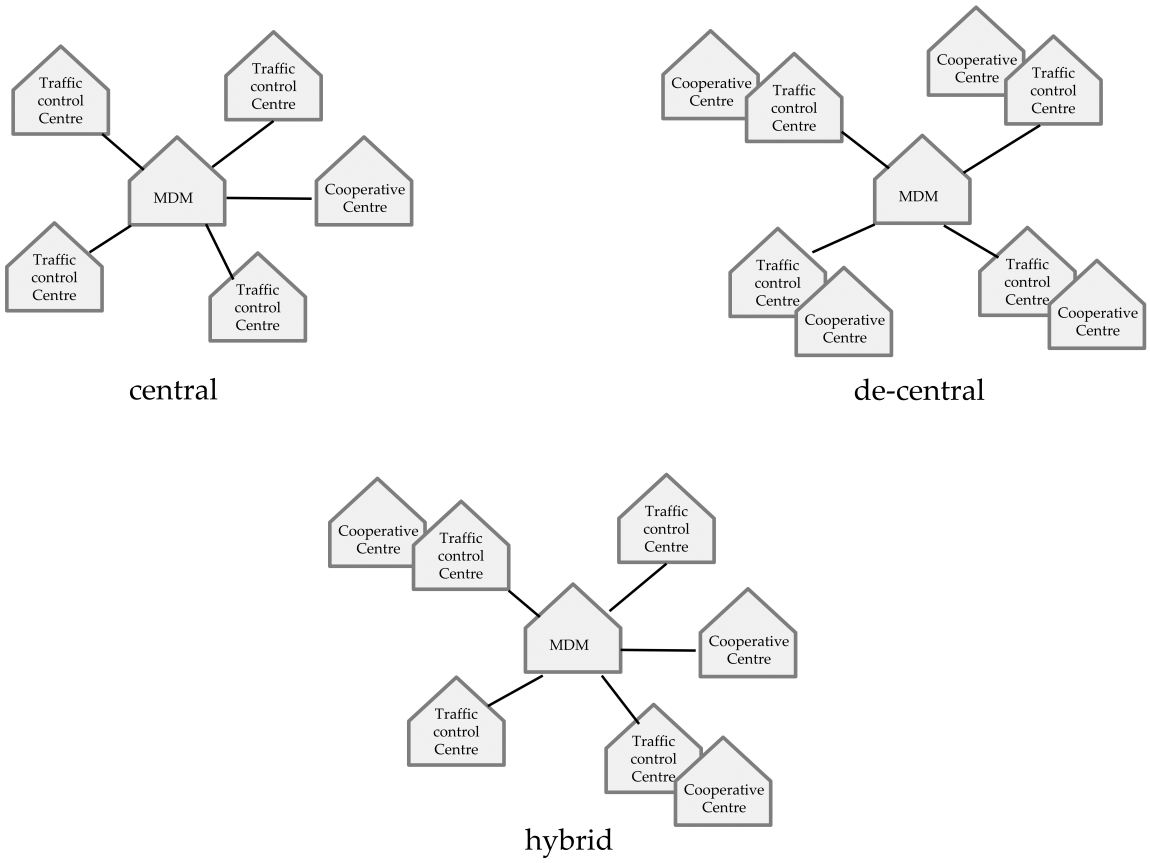

Figure 8.14.: Technical architecture options for RWW

decision and therefore do not need to be considered. The road works safety trailers will be equipped in all the federal states and they will be operated and in the responsibility of the respective road operator. The responsibility for the traffic control centers does not change only because several C-ITS services make use of their already existing functionalities. Hence, the distributed structure of the traffic control centres will be preserved.

8.9. Other aspects of C-ITS Corridor System Architecture

The description of the Reference Architecture addresses as well several so-called 'horizontal aspects', in detail those are IT-Security, Privacy and Data Quality. In the architecture, they are perpendicular to the viewpoints described in section 8.6 to 8.8 and they exist for all three viewpoints, so there are organizational, functional and technical aspects of IT-Security, Privacy and Data quality.

The horizontal aspects are incorporated differently in the System Architecture.
IT-security leads to an extra architectural description across all viewpoints: additional functionalities need to be implemented, processes are specified, roles are identified and assigned, modules are introduced, technical components are required. All these aspects

are summarized in the security architecture. There are already standards available that support these descriptions e.g. ETSI 102 940 [2012].
In the C-ITS Corridor the work on IT-security has a very prominent role and started recently with the support of experts from BSI (Federal Office for Information Security). Currently, the protection requirements for the services are identified, a protection profile will be developed. To secure the communication in the C-ITS Corridor a Public Key Infrastructure (PKI) that provides certificates needs to be established and operated. The partners from the Automotive Industry proposed to use the test PKI operated by C2C-CC. From an infrastructure perspective this is still under discussion and the IT-security experts still analyze whether the test PKI is suitable.

To adequately deal with the **privacy** aspects in the C-ITS Corridor architecture a privacy concept is developed. The privacy concept does not lead to an architecture of its own but partially has severe implications on the System Architecture as it forms the basis for additional requirements that need to be followed when implementing the C-ITS Corridor services. The Road Works Warning service is not of relevance for the privacy experts as it does not make use of any person related data. A respective analysis was already made for the legacy services which are implemented in some of the Bundeslaender.
This is slightly different for the Improved Traffic Management based on vehicle data service in which the vehicles transmit data to the roadside infrastructure which then uses this data to improve existing traffic management algorithms. Privacy issues for this use case are not yet solved so far and are still under discussion between the involved stakeholders. Hence, the System Architecture for the service Improved Traffic Management based on vehicle data is not yet described in detail as the decision on privacy have implications on the architecture design (privacy by design), the implemented modules and the structure of interfaces. It is not possible to develop a completely generic description that respects different solutions for the privacy issues. A joint privacy concept is currently developed by the project partners.

Directly part of the System architecture description are **data quality** aspects. During the specification phase, the requirements for the description of data quality throughout the whole process are identified and described. This results in additional modules that implement plausibility checks and quality control. The data quality modules are closely interwoven with other functional modules of the System Architecture, their results or indicators are linked to the respective content of the service. The data processes within the service are subject to different quality control mechanisms to ensure maximum quality of the service result. In parallel, quality indicators are attached to the content to visualize the implications of the different process steps and their evaluations. All functionalities (modules) that are required to fulfill the data quality requirements are completely integrated in the System Architecture description.

8.10. Conclusion on practical implementation of architecture in C-ITS Corridor

The description in the previous chapters provides a comprehensive description of the System Architecture which will be implemented in the C-ITS Corridor. Thereby, the final link in the approach described in section 3.1 is closed.
The C-ITS Corridor Reference Architecture was specified according to the approach developed in this thesis. It follows the principles phrased in chapter 1 as far as possible and reflects some of the typical requirements mentioned in chapter 3:
The work on the architecture for the C-ITS Corridor started before any implementation activities began. Various concepts were developed and the initial versions of the system architecture did suggested different implementation options across all viewpoints. These opportunities were discussed and evaluated with stakeholders before a decision was made. Thereby, the architecture not only documented the implementation but actively **contributed to the final design** of the system.
The architecture for the service realized on day one in the C-ITS Corridor, Road Works Warning, well implements the requirement of building a new system on top of existing systems: Road Works Warning is no new service in the C-ITS Corridor countries, there are legacy ITS components already operational today. These **existing systems were successfully integrated** in the new architecture, this was mainly enabled by the underlying modular structure.
Apart from that, the architecture is very open with respect to (new) technologies – another benefit from its modular design. Already today the structure allows to realize the service Road Works Warning with different technologies in parallel. This characteristic will be used again when new technologies are available and need to be integrated. The general design will facilitate this.

Summarizing all these aspects demonstrates that the initial requirements on an architecture are addressed by the method developed in this thesis. The application of the approach in the System Architecture for the C-ITS Corridor finally is the proof of concept for the practicability of the results.

9. Conclusion and prospects

Goal of this thesis was the development of a method for the description of an overall C-ITS architecture. To achieve that goal several intermediate steps were taken. The main results and findings are summarized in the subsequent paragraphs.

Initially a structure for the description of the overall architecture was developed. It serves as orientation framework for the whole architecture description and hence has a key role. Therefore, a **method** was introduced that collects suitable aspects from various relevant fields to provide a broad and comprehensive basis for the description of the overall architecture. The material was collected both from theoretical approaches on architecture descriptions and practical architecture implementations in projects and real systems.
In parallel, the requirements upon an overall C-ITS architecture were assembled. This comprised general requirements on an architecture frame structure and aspects specifically describing the characteristics of C-ITS.
The two threads were joined by applying the selected requirements on the collection of architecture methods and descriptions resulting in a general structure. This was again refined with C-ITS specific aspects leading to the **framework structure for the overall C-ITS architecture** which was filled with life subsequently.
The developed framework structure partially takes up architectural structures which were already under discussion for ITS architectures. One precious side effect of the detailed analysis, which is part of the process of defining the framework structure for the overall C-ITS architecture, is the serious **academic adaptation** of the whole **background behind the architecture structure**. Parts of the resulting architecture structure so far were already implicitly under discussion or in use but the background behind the structure and the interrelation between its elements were not refined. The approach described in this thesis significantly contributes to comprehensively illustrate and outline the architectural coherences.
The extensions of the basic structure, which were necessary to fulfill the requirements on a C-ITS architecture, rather relate to an evolution than a revolution. The basic structure with its three abstraction levels and the respective viewpoints is already well prepared for distributed and modular demands. Augmenting it with the **Modular Construction System** does not radically change the structure, the Modular Construction System rather emphasizes on the one hand the importance of **stability and continuity** and on the other hand of **flexibility and dynamics**.
Altogether a generic and future-proof structure was developed that cannot only be applied to many different use cases in the field of C-ITS but as well in other subsets of ITS.

Besides the development of the generic frame structure for the overall C-ITS architecture the theoretical structure was as well **put into practice to provide evidence of the applicability of the developed structure**.

Excluded from the transformation was the most abstract level, the Framework Architecture, as it is not purely C-ITS specific and currently part of the work plan of national ITS architecture expert groups. As soon as results are available they need to be synchronized with the architecture descriptions of the other levels derived from the generic framework structure.
The other elements of the overall architecture were successfully developed: the Modular Construction System was set up and filled with an initial set of modules which was expanded after the description of the Reference Architecture for C-ITS. On this solid basis the final mapping to a real world example was tackled: the System Architecture for the Road Works Warning Service implemented in the C-ITS Corridor was described. The result is currently realized, the developed architecture remained stable during the implementation phase and currently stands the first tests in preparation for daily operation. The other partners of the C-ITS Corridor developed architectures based on the same generic framework structure.
The exemplary practical implementation of the generic framework structure in C-ITS finally demonstrated and proved its applicability, the initially developed method and its result were verified. The detailed description of the **Modular Construction System, Reference and System Architecture** are valuable and useful examples for the practical application of the initially developed method and structure.

Right in the beginning of the thesis (chapter 1) two incisive **limitations to the architecture** description were made: The focus was set to the economic market phase of service operation and security and privacy aspects of an architecture were excluded. Retrospective, both decisions have no negative impact on the architecture and its applicability. Though they are not analyzed and addressed equally detailed like many other aspects of the architecture they were considered in the overall design and therefore easily can be added if necessary.
The present approach to describe an overall C-ITS architecture focused on one single out of several **market phases**. Although the service operation phase was selected, which is most concrete for the different stakeholders, the approach can be easily broadened to the preceding and following phases. First activities started with a holistic examination of different architecture aspects across all market phases. Namely the research on institutional role models, which focuses on organizational structures and aspects, stepped out with the first results. With this first test they showed that the expansion of the approach to other market phases is possible. Further verifications for other viewpoints are essential.
Although **security and privacy** were excluded both aspects were briefly touched several times. The practical realization of the architecture showed that it is not possible to completely get around these topics when describing an architecture. Where it would have been noticeable to omit those aspects they were marginally addressed. Nevertheless, these description do not fulfill the expectations on a complete analysis and description of the security and privacy topic within an overall C-ITS architecture. In the C-ITS expert community a lot of interesting activities take place, e.g. by the German Federal Office for Information Security [Wagner and Wieschebrink, 2016], in research projects like CONVERGE where experts from universities and research institutes (e.g. Frauenhofer SIT, AISEC) come together. Many conferences recently focused on these topics, various organizations and associations address the field, e.g. VDA [Verband der Automobilindustrie, 2014].

The title of the thesis suggests that the developed architecture (framework) is applicable to C-ITS only but the applied principles and resulting structures disprove this conclusion. The approach itself is sufficiently generic so that it can as well be applied beyond C-ITS. And the resulting modular design of the developed overall architecture supports any organic and non-static system which is subject to regular changes and continuous advancements. The practical application for the C-ITS Corridor showed that architectures, which are once conveyed to this fundament, can be maintained and refined without fundamental transformation of their basic structure. The **forward-looking and deliberate determination of the architecture design** like it is predetermined by the overall C-ITS architecture framework is an essential success criteria, as the impact of any necessary change of the architecture is heavily depending on its initial design decisions.
The structure developed in this thesis addresses exactly these aspects. The practical application done by the System Architecture shows that already the transformation of a legacy ITS architecture into a modular structure discloses many opportunities – one of them, the evolution towards connectivity is illustrated with the C-ITS Corridor use case.

Besides the retrospective view on what was achieved in the present thesis, a look ahead shall be taken. The thesis showed the applicability of the method and the resulting architecture through its implementation in the C-ITS Corridor project. Despite these pleasant results, there still remain two fields for follow-up activities: On the one hand they, lie within the completeness of the architecture description itself and on the other hand they concern the strategic dissemination and obligation.
Regarding the description of the architecture itself, there are still some empty fields which were not yet covered. One of them certainly is the **description of a Framework Architecture for ITS**. It was explicitly excluded in this thesis as its scope is much broader than C-ITS only. Nevertheless, the ITS framework architecture is an important element in the overall structure of the C-ITS architecture. Activities are taking place under the lead of BASt, first results are expected in 2017.
Moving down one level of abstraction inside the architecture framework one has to admit that as well the **Reference Architectures for many domains are still missing**. From the perspective of the stakeholders who are actually implementing new systems and services these descriptions are even more important, as they provide the blueprint for their System Architectures and enable the interoperability between the different System Architecture instances. Like for the Framework Architecture BASt as well started initiatives to develop Reference Architectures for selected domains (in Germany).
The specification of additional Reference Architectures in turn has positive implications on the Modular Construction System. In this thesis only the Reference Architecture for the domain C-ITS was described in detail, the modules in the Modular Construction System are mainly deduced from this Reference Architecture. But the toolbox of the Modular Construction System ideally covers many different Reference Architectures. The toolbox itself is too large and complex to be completely and independently specified in this thesis. But if many Reference Architectures and their modules are described, and their descriptions are maintained, the **Modular Construction System will grow and advance**. This in turn is the prerequisite to gain the maximum benefit out of this new architectural concept.
So one of the main conclusions is, that the results developed in this thesis need to be contin-

ued and maintained. To ensure this, the overall architecture description and its elements need to be brought to the attention of the affected stakeholders. This leads to the consequence that the topic itself needs to have a certain **obligation and attention** of those that shape the environment of architectures in ITS. Only intensive dissemination activities, active support of stakeholders implementing the architecture framework, eventually accompanied by incentives of its application, may lead to a wide spread and thereby harmonization of architecture activities in a region. Like stated earlier, the maximum benefit probably is archived with the broadest possible application. It will be the task of decision makers in the field of ITS and C-ITS to encourage the users to actually apply the principles, concepts and structures of the overall C-ITS architecture. Ideally, this gives rise to a momentum, resulting in the wide-spread application and implementation of the architecture structures initially developed in this thesis.

Finally, taking a careful **look even further ahead** reveals that there are already new technologies and challenges in the field of C-ITS and connected mobility upcoming – although the latest findings are currently just under deployment. New communication technologies are developed, new functionalities are invented, organizational structures and responsibilities change. While the system is in operation it is necessary to permanently balance which opportunities shall be reflected to keep the architecture – and to that effect the system – updated.
In addition, more and more systems will be transformed from monolithic local solutions into a cloud environment, requiring smooth architectural rearrangements. The transformation not only comes along with a spatial distribution of the system across different instances – the implementation of cloud-aware architectures demands the consistent realization of modular structures. In turn, this smoothes the way towards shared resources between different systems that enable new opportunities and synergies.
Distributed systems in this context certainly remain a stable anchor but around it new solutions and technologies will arise, existing ones will evolve and others will disappear. The modular approach for the architecture, like it is described in this thesis, enables these changes and facilitates the advancement of the architecture together with the system and its corresponding technologies in a sustainable and future-proof way.

Appendix

A. Evaluation of architecture models for the generic overall architecture

This chapter contains the details from the selection process which was developed and applied in the Top Down Approach in chapter 3.
One element in this process is the selection of suitable theoretical models, therefore a preselection was made, the resultant models were analyzed in detail.

A.1. Selection process I

In the first part of the selection process, the selected models were analyzed with regard to criteria from the categories 'Enterprise' and 'Methodology / Method'. The detailed requirements are defined in Appendix A.1.1.

A.1.1. Selection / Evaluation criteria for 'enterprise' and 'methodology'

A.1.1.1. Part 1 – Enterprise: Definition of enterprise and architecture framework

Enterprise is defined as complex systems comprising individuals or groups that coordinate actions in pursuit of common goals [March et al., 1994].
Definition of **architecture framework** (ISO 42010 [2007]): *conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders*
Enterprise architecture defined as *architecture of a system where the system is the whole enterprise* [Bente et al., 2012]
Those definitions lead to the following requirements that the candidate architecture model needs to fulfill to be applicable for enterprise architecture frameworks:

Crit1: Covers different kinds of business organizations, public or private, large or small

Crit2: Suitable to describe whole complex, socio-technical system, including people, information, processes and technologies

Crit3: Provides distinct views of the system

Crit4: Each view described in the architecture model addresses the specific interest or concern of a distinct stakeholder group

Crit5: Provides conventions, principles and practices [this is closely linked to the second part of the selection based on 'method / methodology']

A.1.1.2. Part 2 – Methodology: Definition of methodology / method:

Methodology is defined as follows: *a system of methods used in a particular area of study or activity* [Stevenson, 2010].
Method is defined as a *particular procedure for accomplishing or approaching something, especially a systematic or established one* [Stevenson, 2010].
The Duden [Duden: Die deutsche Rechtschreibung, 2013] includes in its definition of a method that it is a *procedure based on a defined set of rules*.
This leads to the following requirements that the candidate needs to fulfill:

Crit6: Provides procedure with a defined set of rules

Crit7: Applying the procedure results in a complete architecture

Crit8: Generic – can be applied to any domain in ITS

Crit9: Procedure is systematic

A.1.2. Results of Selection Process I

The results of applying the requirements from Appendix A.1.1 on the initial set of architectures (section 3.2.4.1.1) are summarized in Table A.1, this intermediate result is the basis for the continuation of the approach in chapter 3.

Candidate	Strengths	Weaknesses
Zachman	• No limitations on use of framework • The rows in the Zachman matrix structure provide 'perspectives' – those are comparable to viewpoints and represent the view of a single stakeholder group	• No detailed description of cells in Zachman matrix included
	• Provides a neat and pure way to structure an enterprise architecture (each cell only contains one specifically limited aspect)	• Does not provide a methodology to develop an architecture – or elements missing in an existing architecture

Candidate	Strengths	Weaknesses
TOGAF	• No limitations on use of framework • Includes a subset of architectures (viewpoints): business, data, application and technology architecture • technology independent	• Abstract description lacking practical examples • No detailed description of viewpoints included
	• Provides a tested and repeatable process to develop an architecture (ADM) • The ADM supports the development of an architecture framework, architecture content, and finally transitioning, and governing the realization of architectures	• Detailed but very abstract description of methodology
Gartner	• Depending on selected framework	• No own formal framework or process to develop an architecture was published – Gartner customizes and adapts existing architecture frameworks to user needs and supports them in the implementation; similar activities from other consulting companies exist
	• Depending on selected framework	

Candidate	Strengths	Weaknesses
FRAME	• Architecture description with focus on ITS ('European ITS Framework Architecture') • Viewpoints are denominated and are addressed in the different elements of the toolbox (organizational, functional, information, communication, physical) • Technology-independent	
	• Full toolbox is provided to develop an architecture based on the individual system's requirements • FRAME offers / allows to adapt the toolbox to individual user's needs	• Different applications of the FRAME methodology are not necessarily interoperable
ISO 42010	• General description of architecture that can be used for any field of application • Conceptual model of architecture description (for one architecture level with one or more viewpoints) • Viewpoints are addressed as essential part of an architecture • Technology independent	• No specific viewpoints are denominated
	• General description of how to develop an architecture	• No method (step by step procedure) for the development of an architecture

Candidate	Strengths	Weaknesses
ISO 10746	• General description that can be used for distributed systems • Viewpoints are denominated (enterprise, information, computational, engineering, technology) • Technology independent	• Limitation to distributed systems • Aspect of business processes not included
	• Example application of standard provided in informative annex	• No normative description of method to design architecture
ISO 14813(-5)	• Both object oriented and process oriented architecture development is possible • Result of applying the standard is a general abstract architecture description, not specific for an implementation • No preference to any methodology for architecture development • Viewpoints are part of the architecture • Viewpoints are denominated (conceptual, logical / functional, physical, communication organizational), additional viewpoints are possible • Viewpoints are already roughly outlined • Technology independent	

Candidate	Strengths	Weaknesses
	• Recommendation on aspects / architecture elements that need to be considered when using either of the mentioned methodologies	• No description of methodology

Table A.1.: Analysis of strengths and weaknesses in selection process I

Summary and conclusion can be found in section 3.2.4.1.2.

A.2. Selection Process II

In the second part of the selection process, the selected models were analyzed with regard to criteria from the categories 'C-ITS' and 'others'. The detailed requirements are defined in Appendix A.2.1.

A.2.1. Selection an evaluation criteria for 'C-ITS' and 'others'

C-ITS is defined as a subset of overall ITS that *communicates* and *shares information between ITS stations* to give advice or facilitate actions with the objective of improving safety, sustainability, efficiency and comfort *beyond the scope of stand-alone systems*. [Definition C-ITS in chapter 2]
Additional characteristics of C-ITS like the topological structure of a distributed system and the need for communication between elements can as well be derived from this definition.

Char1: The architecture model follows the principles of distributed systems

Char2: Communication is a core element in the architecture model

Char3: Different technologies can be used, easy (ex)change of technologies

Char4: Concept of ITS Station can be integrated in the architecture model

Other aspects that are neither linked to the definition of enterprise architecture methodology nor to C-ITS but need to be fulfilled to have a suitable architecture model for the next process steps are additionally considered.

AddCrit1: Ensures interoperability of multiple implementations (instances) of the same enterprise architecture profile (local and temporal)

AddCrit2: Allows for extension with additional features or technologies and at the same time ensures interoperability

A.2.2. Results from Selection Process II

The results of applying the requirements from Appendix A.2.1 on the results from the Selection Process I (Appendix A.1) are summarized in Table A.2, this intermediate result is the basis for the continuation of the approach in chapter 3.

Candidate	Strengths	Weaknesses
TOGAF	• The concept of artifacts includes distributed systems	• No use of TOGAF in C-ITS known
	• The 'Content META Model' defines different elements for an enterprise architecture, core elements and extensions, the latter can be used to add features • Interoperability of different enterprise architectures is addressed in the context of the ADM, focus on certain aspects for interoperability • Different levels of abstraction are addressed (Enterprise, Architecture and Solution Continuum)	
FRAME	• Provides a C-ITS toolbox that was developed based on CVIS, SAFESPOT and COOPERS (project) results • Supports functional and technical decomposition like in distributed systems	• Changes in technology requires new or updated toolboxes, this may lead to a loss of interoperability

Candidate	Strengths	Weaknesses
	• Implementations based on the same toolbox are interoperable • Modifications of the toolbox to adapt the toolbox to specific local requirements, additional features, new technologies are possible	• Modifications of the toolbox which are necessary to adapt the toolbox lead to a loss of interoperability between different versions of the toolbox • Toolbox is specific for local requirements and in most cases needs customization / adaptation to user's needs
ISO 10746	• Description itself is completely implementation and technology independent	• No use of ISO 10746 in C-ITS known
		• Application of standard leads to requirement specific ODP architecture instantiation, interoperability then is no longer guaranteed • Standard provides general description, any adaptation results in an implementation specific architecture (system architecture)

Table A.2.: Analysis of strengths and weaknesses in selection process II

Summary and conclusion can be found in section 3.2.4.1.3.

B. Evaluation of C-ITS projects for generic overall architecture

B.1. Analysis of different C-ITS projects

This chapter contains the details from the selection process which was developed and applied in the Bottom Up Approach in chapter 3.
One element in this approach is the selection of suitable C-ITS projects and the subsequent analysis of these projects. The criteria for this analysis are described in section 3.2.4.2.3, the results are summarized in Tables B.1 to B.4.
Additional details on the selected projects can be found in Appendix B.2.
The results from Tables B.1 to B.4 are discussed in section 3.2.4.2.3, the approach is continued based on these results in chapter 3.

	MARZ & TLS	**NERZ**	**MDM**	**VDV Kernapp.**
what level is addressed	Reference Architecture	Reference Architecture	Reference Architecture	Reference Architecture
what layers are addressed	(Organizational) Functional Technical	(Organizational) Functional Technical	~~Organizational~~ Functional Technical	Organizational Functional Technical
details beyond organizational, functional, technical	The organizational viewpoint is only briefly touched	The organizational viewpoint is only briefly touched		
where is it applied	Realization of telematic units (e.g. variable message signs)	Individual Bundeslaender realize their Traffic Management Centres based on this architecture	Actors active in road transport	Actors active in public transport
	Germany, similar descriptions in Austria and Netherlands	Germany	Germany	Germany
special requirements, additional remarks	–	The architecture (and software) is published as Open Source	–	Defines interfaces and data structures for eTicketing

Table B.1.: Summary of ITS architecture analysis based on Boltze and Krüger [Boltze and Krüger, 2011; Krüger et al., 2013] (part 1)
(Text) only limited material was available to confirm this finding from Krüger [2013];
~~Text~~ no material was available to confirm this finding from Krüger [2013]

	DELFI	**OCIT**	**OTS**	**RVWD**
what level is addressed	Reference Architecture	Reference Architecture	Framework Architecture Reference Architecture	Reference Architecture
what layers are addressed	Organizational Functional Technical	~~Organizational~~ Functional Technical	Organizational Functional Technical	Organizational Functional ~~Technical~~
details beyond organizational, functional, technical	The organizational viewpoint is only briefly touched			
where is it applied	Actors active in public transport Germany	Actors involved in traffic signals Germany	Actors involved in traffic signals Germany	Actors involved in traffic information Germany
special requirements, additional remarks	Defines interfaces to exchange timetable data between service providers	Defines only a number of interfaces used to connect traffic signals components	Focus on interface(s) between different ITS components Close link to OCIT	-

Table B.2.: Summary of ITS architecture analysis (part 2)

	SafeSpot	**CVIS**	**COOPERS**	**FRAME** [1]
what level is addressed	All aspects covered in FRAME	Reference Architecture and System Architecture	Reference Architecture and System Architecture	Reference Architecture
what layers are addressed	Based on FRAME	Based on FRAME	Functional Physical Viewpoint based on FRAME Organizational structures for different services	Organizational Information Functional Communication Physical
details beyond organizational, functional, technical	–	The organizational viewpoint is only briefly touched	Results were turned into standard for C-ITS communication architecture	–
is the candidate still in use	No, research project closed	No, research project closed	No, research project closed	No, research project closed
where is it applied	European testsites	European testsites	European testsites	FRAME did not run own tests
special requirements	–	Focus on implementing the CALM standards , strong focus on communication	–	-

Table B.3.: Summary of C-ITS architecture analysis (part 1)

[0]and e-FRAME (C-ITS extension)

	simTD	**DriveC2X**	**COMeSafety**
what level is addressed	Reference Architecture and System Architecture	Reference Architecture and System Architecture	Reference Architecture
what layers are addressed	Functional Technical	(Organizational) Functional Technical	Functional
details beyond organizational, functional, technical	Analysis on operator model, stakeholder analysis	For organizational viewpoint only the actors were described, no roles	–
is the candidate still in use	No, research project closed	No, research project closed	No, research project closed, results standardized in ETSI
where is it applied	Germany, Frankfurt city and region	European testsites	COMeSafety did not run any tests
special requirements	–	Strong focus on communication (implementation of ETSI EN 302 665).	Strong focus on communication (implementation of ETSI EN 302 665).

Table B.4.: Summary of C-ITS architecture analysis (part 2)

B.2. Additional details on analyzed C-ITS projects

This chapter complements the analysis of existing architecture descriptions from different projects in Appendix B.1. The results are summarized in Tables B.3 and B.4.
The following sections give additional details on the considered C-ITS projects' deliverables and documents as well as the respective interpretation of the definitions for the different architecture terms. Often, the same architecture terms are used with different definitions, therefore the respective definitions are included here.

B.2.1. simTD

B.2.1.1. Reference documents for Tables B.3 and B.4

- Deliverable D21.2 Konsolidierter Systemarchtekturentwurf and other documents from work package 2 (detailed specification of communication interface, communication protocols and IT-Security)
- Deliverable D5.5 - Teil B-4 Ökonomische Analyse

All public simTD deliverable can be found under
http://simtd.de/index.dhtml/deDE/backup_publications/Projektergebnisse.html

B.2.1.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

There are no explicit definitions for the different architecture terms in the document. The terms 'reference architecture' and 'system architecture' are used with the following meaning:
Reference architecture: is used for the abstract model that describes the (simTD) system
System architecture: includes a more concrete description of the system
The simTD architecture description is very component and communication driven.

b. Implementation of architecture concept

The simTD system was implemented according to the descriptions in the architecture deliverables. The deliverables on IT-Security aspects were not completely implemented due to hardware restrictions. Only a basic security concept was realized.

B.2.2. Safespot

B.2.2.1. Reference documents for Tables B.3 and B.4

- D6.3.2 Organisational Architecture
- User Needs are defined in D7.2.1 Core Architecture Requirements and fed into the KAREN (later FRAME) architecture framework to develop the Safespot architecture
- further reading architecture deliverables are not publicly available

All public Safespot deliverables can be found under
http://www.safespot-eu.org/deliverables.html (SP 6 and SP 7)

B.2.2.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

Only documents with requirements and the description of the organizational architecture are publicly available. The documents do not include definitions for architecture terms.

b. Implementation of architecture concept

The Safespot project had several test sites in Europe. The system was implemented in France, Germany, Italy, Netherlands, Sweden and Spain. Experiences from these implementations were put to the COMeSafety Communication Reference Architecture activities.

B.2.3. CVIS

B.2.3.1. Reference documents for Tables B.3 and B.4

- D3.1 Reference Architecture
- D3.2 High Level Architecture
- D3.3 Architecture and System Specification
- D3.4 Final Architecture and System Specification

The CVIS deliverables are no longer publicly available.

B.2.3.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

There are no explicit definitions for the different architecture terms in the document. The terms 'reference architecture' and 'system architecture' are used with the following meaning:
Reference architecture: is mainly used in the context of the Communication Reference Architecture (EN 302 665 or ISO 21217).
System architecture: includes entities and relations as well as interactions between these. Additionally, it describes the core enabling services of the CVIS system.
The architecture description is very component and communication driven.

b. Implementation of architecture concept

The CVIS project had several test sites in Europe. The system was implemented in France, Germany, Italy, Netherlands / Belgium, Sweden and UK. Experiences from these implementations were put to the COMeSafety Communication Reference Architecture activities.

B.2.4. COOPERS

B.2.4.1. Reference documents for Tables B.3 and B.4

- D13-B-IR 3100-2 Report on ITS framework reference architecture
- D 3600/3700 COOPERS services and value chains, concerning operator / user behaviour, integration of services in the co-operative system

The COOPERS deliverables are no longer publicly available.

B.2.4.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

There are no explicit definitions for the different architecture terms in the document. The terms 'reference architecture' and 'system architecture' are used with the following meaning:
Reference architecture: is the architecture framework developed with the FRAME methodology and extended where COOOPERS specific requirements require this.
System architecture: is defined as the result of the implementation view that corresponds with the ODP engineering and technology viewpoint.

b. Implementation of architecture concept

The user needs of the project itself and from the services implemented in the project were collected. These user needs were fed into the FRAME concept and an architecture was derived.
The COOPERS project had several test sites in Europe. The system was implemented in France, Germany, Italy and Netherlands. Experiences from these implementations were put to the COMeSafety Communication Reference Architecture activities.

B.2.5. DriveC2X

B.2.5.1. Reference documents for Tables B.3 and B.4

- D23.1 DRIVE C2X system specification (not public)

DriveC2X activities are based on various national C-ITS projects and incorporate services and architectures developed in those national projects (examples: simTD (Germany), Score@F (France), DITCM (Netherlands))
All public DriveC2X deliverables can be found under http://drive-c2x.eu/publications

B.2.5.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

There are no explicit definitions for the different architecture terms in the document.
Only the term 'system architecture' is used with the meaning: general architecture descrip-

tion applicable on all test sites.
The term Reference Architecture is not used in DriveC2X.

b. Implementation of architecture concept

The DriveC2X project had several test sites in Europe. The system is implemented in Finland, France, Germany, Italy, Netherlands, Spain and Sweden.

B.2.6. COMeSafety

B.2.6.1. Reference documents for Tables B.3 and B.4

- Deliverable 31 European ITS Communication Architecture - Overall Framework - Proof of Concept Implementation (available online: COMeSafety2 website)
- ETSI EN 302 665 Intelligent Transport Systems (ITS) Communication Architecture (available online: ETSI website)

B.2.6.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

The project COMeSafety provides several architecture related definitions:
(Overall) System architecture: is the architecture that includes all aspects of the described system
Reference architecture: is used in the context of 'ITS Station Reference Architecture' and abstractly describes the communication stack of an ITS Station

b. Implementation of architecture concept

Results of the big European C-ITS projects Safespot, CVIS and COOPERS were aligned especially with focus on the corresponding C-ITS communication architectures.
COMeSafety collected the specifications, implementations and lessons learnt and developed the C-ITS communication architecture. The results (content of the deliverable) were passed into standardization and were standardized in ETSI EN 302 665 and ISO 21217.

B.2.7. FRAME

B.2.7.1. Reference documents for Tables B.3 and B.4

- core architecture description in deliverable D3.6 European ITS Framework Architecture Overview
- various deliverables that describe and explain the FRAME tool in detail

Main contributions to the C-ITS part of FRAME (eFRAME) came from European projects like CVIS, Safespot and COOPERS
All public FRAME / e-FRAME deliverables can be found under
http://www.frame-online.net/node/38

B.2.7.2. Additional explanation for content in Tables B.3 and B.4

a. Use of definitions

There are no explicit definitions for the different architecture terms in the documents but for the different viewpoints:
Organizational: who owns, manages and operates each physical unit and other organizational issues
Information: information that is used, its attributes and relationships
Functional: functions that create the ITS Application or Service
Communication: the requirements for communication between physical units in Each location
Physical: location of functions together with the data that flows between those locations

b. Implementation of architecture concept

The FRAME project evolved out of the KAREN project and was extended with C-ITS aspects in e-FRAME. FRAME provides an approach to develop an architecture with a defined set of viewpoints

C. ITIL v3 adaptations for organizational viewpoint

Originally, the Open Group developed within in ITIL v3 [ITIL, n.d.] a set of roles. This basic set describes all elements of a software or product life cycle including service strategy, design, transition, operation and service improvement. For all phases a set of roles was identified and described, a complete list of roles including short descriptions is available in the ITIL Wiki [Kempter and Kempter, 2016].

In the Top Down Approach for the organizational viewpoint the ITIL v3 roles are adapted to the requirements of C-ITS. Therefore, a first step analyzed which of the respective roles are important for C-ITS. Focus of the present description is the operation and management of C-ITS, strategic development activities as well as the design phase are not in scope and therefore excluded from the list of roles.
After this pre-selection, the remaining roles were restructured. Partially, the ITIL v3 roles are very detailed and cover many different aspects of an organizational architecture – at the same time some of the roles are rather broad and general. Table C.1 provides the initial list (first and second column) and the subsequent modifications. The third column indicates the pre-selection of those roles that should be part of the C-ITS organizational architecture. The forth column provides the original ITIL v3 description of the individual roles, the fifth column provides the modification of this description for C-ITS. The sixth column indicates to which high-level role the respective role later will be assigned – most of the roles from ITIL actually contribute to the high-level management role. Finally, the last column provides additional explanations on the previous selection and modification process.

Result of the Top Down Approach is the following set of ITIL v3 roles that are later merged with the results of the Bottom Up Approach (Appendix D):

- Financial Manager
- Service Catalogue Manager
- Service Level Manager
- Service Owner
- Technical Analyst
- Risk Manager
- Capacity Manager

- Availability Manager
- Information Security Manager
- Compliance Manager
- [new] Homologation Manager
- [modified] C-ITS Architect
- Change Manager
- Project Manager
- Configuration Manager
- Test Manager
- System / Service Operator
- Access Manager
- [new / modified] Service Recipient

	ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Service Strategy	Business Relation Manager	no	responsible for maintaining a positive relationship with customers, identifying customer needs and ensuring that the service provider is able to meet these needs with an appropriate catalogue of services			too detailed covered through [C-ITS] Service Level Manager
	Demand Manager	no	responsible for understanding, anticipating and influencing customer demand for services			too detailed covered through [C-ITS] Capacity Manager

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Financial Manager	yes	responsible for managing an IT service provider's budgeting, accounting and charging requirements	optional – depending on type of C-ITS service (e.g. free safety related traffic information vs. commercial services) responsible for managing budgeting, accounting and charging in the context of the C-ITS service	System Management	
IT Steering Group (ISG)	no	sets the direction and strategy for IT Services			strategic responsibilities are covered through role Policy Framework

	ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
	Service Portfolio Manager	no	decides on a strategy to serve customers in cooperation with the IT Steering Group, and develops the service provider's offerings and capabilities			strategic responsibilities are covered through role Policy Framework
	Service Strategy Manager	no	supports the IT Steering Group in producing and maintaining the service provider's strategy			strategic responsibilities are covered through role Policy Framework
Service Design Management	Service Level Manager	yes	is responsible for negotiating Service Level Agreements and ensuring that these are met	is responsible for negotiating C-ITS Service Level Agreements and ensuring that these are met	System Management	
	Service Owner	yes	is responsible for delivering a particular service within the agreed service levels	is responsible for designing and delivering a particular C-ITS service within the agreed service levels	System Management	

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Service Design Manager	no	responsible for producing quality, secure and resilient designs for new or improved services			design of service is outside scope
Applications Analyst	no	manages applications throughout their lifecycle			focus on operation of service
Technical Analyst	yes	is a Technical Management role which provides technical expertise and support for the management of the IT infrastructure	is a Technical Management role which provides technical expertise and support for the management of the C-ITS infrastructure	System Operation	
Risk Manager	yes	is responsible for identifying, assessing and controlling risks			

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Capacity Manager	yes	is responsible for ensuring that services and infrastructure are able to deliver the agreed capacity and performance targets in a cost effective and timely manner	is responsible for ensuring that C-ITS services and infrastructure are able to deliver the agreed capacity and performance targets	System Operation	
Availability Manager	yes	is responsible for defining, analyzing, planning, measuring and improving all aspects of the availability of IT services	is responsible for defining, analyzing, planning, measuring and improving all aspects of the availability of the C-ITS system	System Operation	
IT Service Continuity Manager	no	responsible for managing risks that could seriously impact IT services			too detailed covered through [C-ITS] Risk Manager

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Information Security Manager	yes	is responsible for ensuring the confidentiality, integrity and availability of an organization's assets, information, data and IT services	is responsible for ensuring the confidentiality, integrity and availability of the system, information, data, C-ITS services and the user	System Management	
Compliance Manager	yes	is to ensure that standards and guidelines is followed, or that proper, consistent accounting or other practices are being employed	is responsible to ensure that standards guidelines, laws and regulations for C-ITS are followed and applied	System Management	
Enterprise Architect	yes	is responsible for maintaining the Enterprise Architecture (EA), a description of the essential components of a business, including their interrelationships	is responsible for designing and maintaining the implemented C-ITS Architecture, including architecture viewpoints	System Management	renamed to [C-ITS] Architect

	ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
	Supplier Manager	no	responsible for ensuring that value for money is obtained from all suppliers			too detailed
Service Transition	Change Manager	yes	controls the lifecycle of all changes	is responsible for all change activities including collection of change requests, handling of change requests and application of changes	System Management	
	Change Advisory Board (CAB)	no	advises the Change Manager in the assessment, prioritisation and scheduling of changes			too detailed
	Emergency Change Advisory Board (ECAB)	no	sub-set of the Change Advisory Board who makes decisions about high impact emergency changes			too detailed

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Project Manager	yes	is responsible for planning and coordinating the resources to deploy a major release within the predicted cost, time and quality estimates	is responsible for planning and coordinating the resources (including software, hardware) to deploy, operate and maintain C-ITS	System Management	
Application Developer	no	responsible for making available applications and systems which provide the required functionality for IT services			design of service outside scope
Release Manager	no	responsible for planning and controlling the movement of releases to test and live environments			too detailed

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Configuration Manager	yes	is responsible for maintaining information about configuration items required to deliver IT services.	is responsible for maintaining information about infrastructure / equipment / hardware required to deliver C-ITS services	System Operation	
Knowledge Manager	no	ensures that the IT organization is able to gather, analyze, store and share knowledge and information			too detailed
Test Manager	yes	ensures that deployed releases and the resulting services meet customer expectations, and verifies that IT operations is able to support the new service.	ensures that deployed C-ITS services meet requirements and fulfill their specification, no unexpected behavior or errors	System Management	

	ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Service Operation	1st Level Support	no	register and classify received incidents and to undertake an immediate effort in order to restore a failed IT service as quickly as possible			too detailed
	2nd Level Support	no	takes over incidents which cannot be solved immediately with the means of 1st Level Support			too detailed
	3rd Level Support	no	services are requested by 2nd Level Support if required for solving an incident			too detailed
	Major Incident Team	no	concentrates on the resolution of a major incident			too detailed
	Incident Manager	no	responsible for the effective implementation of the incident management process and carries out the corresponding reporting			too detailed

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Problem Manager	no	responsible for managing the lifecycle of all problems			support is required but not that detailed
Service Request Fulfilment Group	no	specializes on the fulfillment of certain types of service requests			too detailed
Service / System Operator	yes		System Operator	System Operation	
Access Manager	yes	grants authorized users the right to use a service, while preventing access to non-authorized users	is responsible to only grant the right to use a C-ITS service to authorized users and prevent access to non-authorized users	System Operation	
IT Operations Manager	no	takes overall responsibility for a number of service operation activities			subsumed under [C-ITS] System Operation
IT Operator	no	performs the day-to-day operational activities			subsumed under [C-ITS] System Operation

	ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
	Facilities Manager	no	responsible for managing the physical environment where the IT infrastructure is located			subsumed under [C-ITS] System Monitoring
Service Improvement	CSI Manager	no	responsible for managing improvements to IT service management processes and IT services			service improvement is out of scope
	Process Architect	no	responsible for maintaining the process architecture (part of the Enterprise Architecture), coordinating all changes to processes and making sure that all processes cooperate in a seamless way			service improvement is out of scope
	Process Owner	no	responsible for ensuring that a process is fit for purpose			service improvement is out of scope
Outside IT Org.	Customer	yes	buys IT services	buys IT services	Service Recipient	Modified name and combined with Service User into one role

ITIL v3 Roles	Relevant for C-ITS	Original ITIL v3 description [Kempter and Kempter, 2016]	Modified C-ITS description	assigned to high-level role	Comments / Notes
Service User	yes	uses one or several IT services on a day-to-day basis	uses one or several C-ITS services on a regular basis	Service Recipient	Modified name and combined with Customer into one role

Table C.1.: ITIL V3 roles – analysis for Top Down Approach of organizational viewpoint

D. Identification of roles and responsibilities based on selected service processes

Part of the approach to develop the organizational viewpoint of a Reference Architecture for C-ITS was a Bottom Up approach based on selected C-ITS services. For this approach the service first was described in detail based on the TISA value chain [TISA Executive Office, 2012]. The resulting process description was then used to identify potential corresponding actors for each individual process step. This was not only done for one specific potential deployment scenario but for various options, where each of them is realized by different sets and combinations of actors. Basis for the considered scenarios are those that are as well discussed in the Matrix Report [Lotz et al., 2012]. The assignment of actors to process steps is the base for the identification of roles and corresponding responsibilities and therefore the resulting organizational structure.
The subsequent chapters describe this approach in detail.

D.1. Identification of general process description

Basis for the description of the general process is the TISA value chain [TISA Executive Office, 2012].

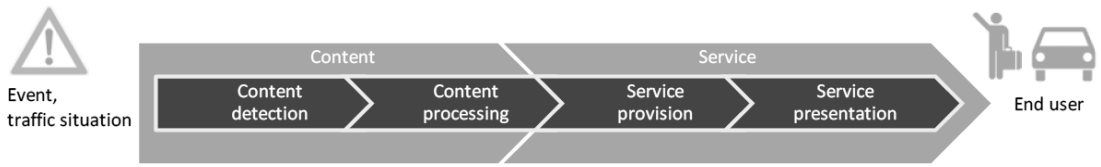

Figure D.1.: TISA value chain [TISA Executive Office, 2012]

Each element in the general basic process description of the TISA value chain (Figure D.1) is detailed in the TISA position paper [TISA Executive Office, 2012] what leads to Figures D.2 to D.4. The detailed elements are adopted for the definition of the general process description in this document.

Consolidating the Figures D.2 to D.4 from the TISA position paper and developing a process description that incorporates both the high-level and detailed process steps results in the following process chain (Figure D.5):
The elements from the abstract TISA value chain (Figure D.1) are the large black framed blocks in the front, the details from Figures D.2 to D.4 are grey framed, more in the background. The (possible) communication-related process steps (data, content, service deli-

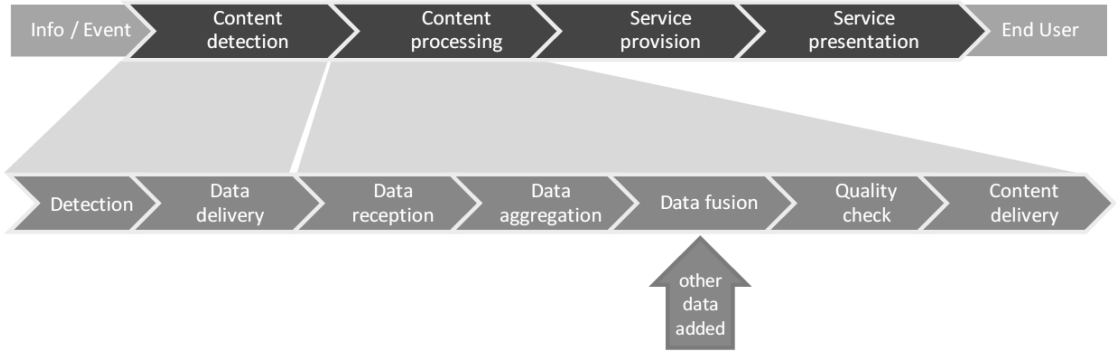

Figure D.2.: TISA value chain – details on content detection and processing [TISA Executive Office, 2012]

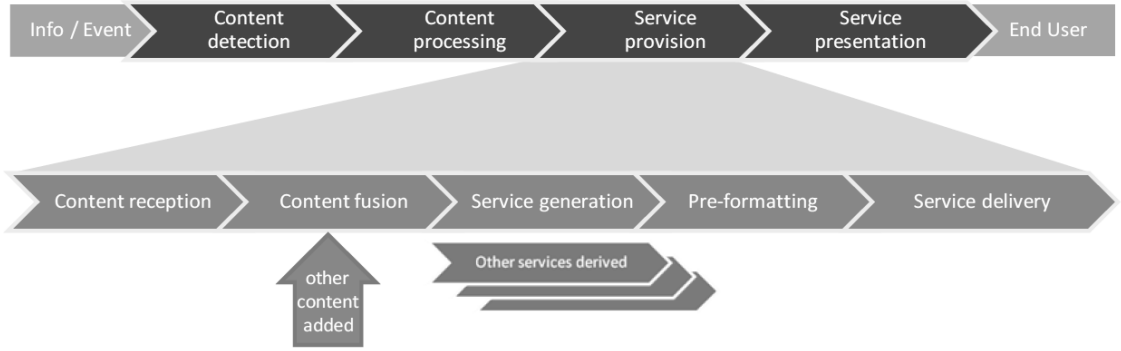

Figure D.3.: TISA value chain – details on service provision [TISA Executive Office, 2012]

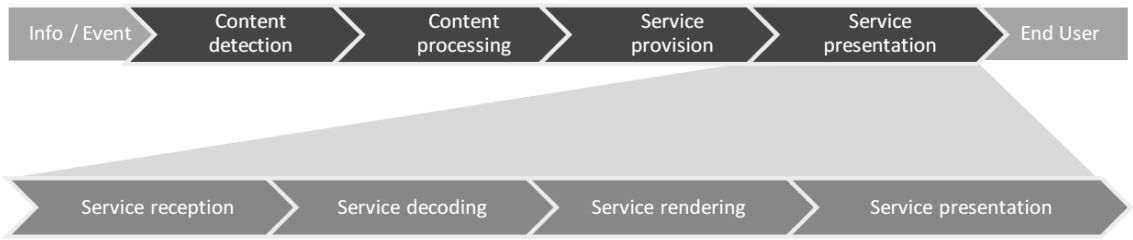

Figure D.4.: TISA value chain – details on service presentation [TISA Executive Office, 2012]

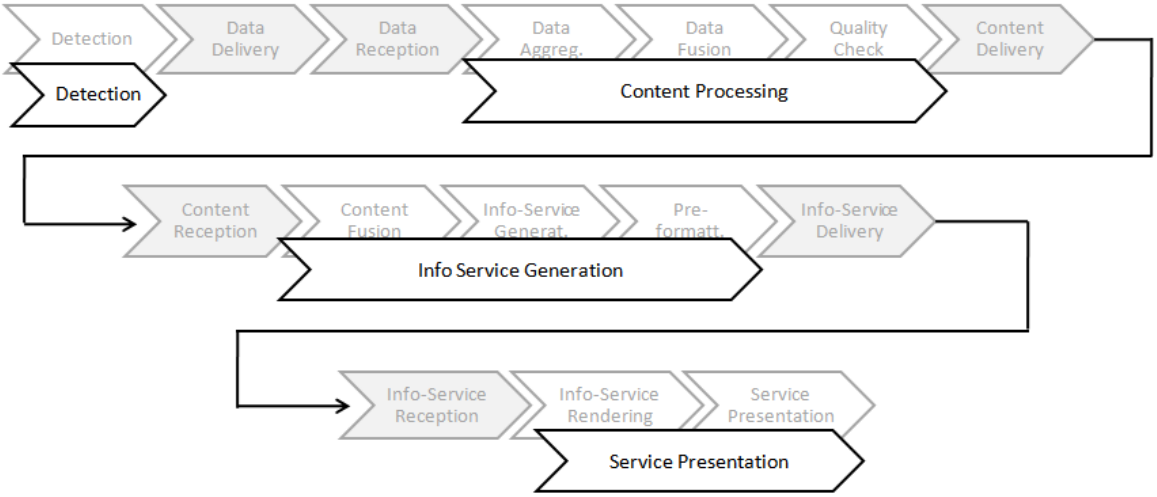

Figure D.5.: Consolidated process chain based on TISA value chain [TISA Executive Office, 2012; ISO 17427, 2013]

very and reception) have a grey background.

The Matrix report [Lotz et al., 2012] uses a slightly simplified version of the TISA value chain, in which only the high level elements 'detection', 'evaluation' and 'presentation' are considered. A unique mapping of both can be achieved by combining the steps 'content processing' and 'info-service generation' from Figure D.5 into one step called 'evaluation'. For the description of the different scenarios which will be considered in this approach (Appendix D.2) the more general structure in line with the Matrix report will be used. This is sufficient to identify all relevant scenarios. For the identification of roles and responsibilities and the therefore undertaken assignment of actors to individual process steps (Appendix D.4) the detailed part of the process chain from Figure D.5 is applied to grab the full level of detail and subtleties in the organizational structure.

D.2. Scenarios

The Matrix report discusses the selected service and its different implementation variations based on seven different scenarios: (classical) road traffic management based on variable message signs and other classical roadside infrastructure, public traffic information services that is free of charge, private commercial traffic information services, driver assistance systems (in the vehicle), vehicle to vehicle communication based systems, local vehicle to infrastructure communication based systems and vehicle to infrastructure communication based systems including a traffic control centre. Each scenario describes a potential implementation variation of the selected service(s) (in the Matrix report: traffic information service for Hazardous Location Warning), composed of the organizational, functional and technical aspects. The various implementation variations are distinct systems – there is no interdependency between different scenarios and therefore different implementations. Contrasting scenarios might exist in parallel – depending on the imple-

mentation they might be built on the same raw data, content or evaluation method.
In general, the individual scenarios are oriented on the three-part process used in the Matrix report focusing on the high-level process steps 'detection', 'evaluation' and 'presentation'. Those generic process steps are used as structuring element for the scenarios to which the service specific process is mapped. Actors are assigned to the single process steps.

The idea of scenarios is applied for the description of the organizational viewpoint for C-ITS. The number of possible scenarios is depending on the number of process steps and the contemplable actor groups.
NOTE: The same scenarios can be used for a more detailed description of the functional and technical viewpoint (see sections 7.2 and 7.3).

D.3. Identification of stakeholders and actors

For the implementation of C-ITS, various players from different industries that did not collaborate so far will have to cooperate to realize one or more of the numerous implementation scenarios of ITS services.
Stakeholders are not necessarily active participants in C-ITS – they only have an occasional interest in the deployment and/or operation of C-ITS itself. Hence, the group of stakeholders incorporates the following entities: national/regional authorities (e.g. government, ministry), interest groups (e.g. user), lobby groups (e.g. industry), industry associations. A list of examples can be found in ISO 17427 [ISO 17427, 2013].
The large number of actors and stakeholders which are active in service operation related processes (which will be analyzed in detail in the subsequent chapter) can be structured into the following core actor groups:

- vehicle
- infrastructure / roadside

The vehicle group consists of all actors that are somehow linked to the vehicle itself or any mobile devices (that might be used within the car). Examples are vehicle manufacturers and suppliers, mobile device manufacturers.
The infrastructure and roadside group of actors is closely linked to the roadside infrastructures. Examples are road operator, manufacturers, maintenance staff.

D.4. Scenario options

Finally, combining the number of scenarios from the D.2 (n = 3 process steps) with the information from Appendix D.3 (n = 2 high-level abstract actor groups) leads to a total of eight scenarios (m^n with m = 2 and n = 3).
The respective combination of actors and core process steps is depicted in the header of each scenario description.
Focusing on System Operation only and generally considering only three process steps in

the generic value chain, leads to the following possible scenarios in which the representatives of the actor groups vehicle and infrastructure are assigned to the individual process steps (Table D.1):

Scen. no	Detection	Evaluation	Presentation	Comments
1	Vehicle	Vehicle	Vehicle	Classical V2V scenario
2	Vehicle	Vehicle	Infrastructure	
3	Vehicle	Infrastructure	Vehicle	
4	Vehicle	Infrastructure	Infrastructure	
5	Infrastructure	Vehicle	Vehicle	
6	Infrastructure	Vehicle	Infrastructure	Not realistic, discarded
7	Infrastructure	Infrastructure	Vehicle	
8	Infrastructure	Infrastructure	Infrastructure	Legacy ITS scenario, see [Lotz et al., 2012]

Table D.1.: Possible scenario combinations

The scenarios summarized in Table D.1 are described in detail in the subsequent chapters. All descriptions follow the same structure that consists of

- actors and stakeholders involved in the scenario – this is as well reflected in the name of the scenario
- description of use case(s) including illustrating figure
- assignment of actors to the generic process for the different implementation scenarios (use cases)

D.4.1. Scenario 1 - C-ITS: Vehicle - Vehicle - Vehicle

Stakeholders and actors involved in Scenario 1: vehicles only

In this context vehicle stands both for built-in (devices permanently connected to the vehicle) as well as aftermarket devices. Aftermarket (or mobile) devices are as well any cell or smart phone, navigation device and such equipped with the necessary technology to run C-ITS services.

Figure D.6 summarizes the stakeholders and actors involved in such a scenario. The dark grey vehicle acts as sender and is responsible for data collection. Either the dark grey or light grey vehicle is processing and evaluating the data. The light grey vehicle finally is the receiver of the results and presents the information to the driver.

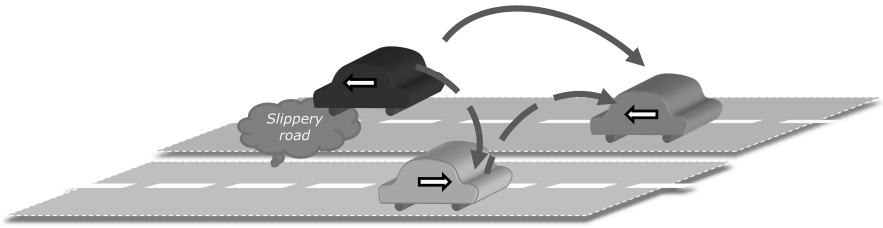

Figure D.6.: Scenario 1 – detection, evaluation and presentation realized by vehicles

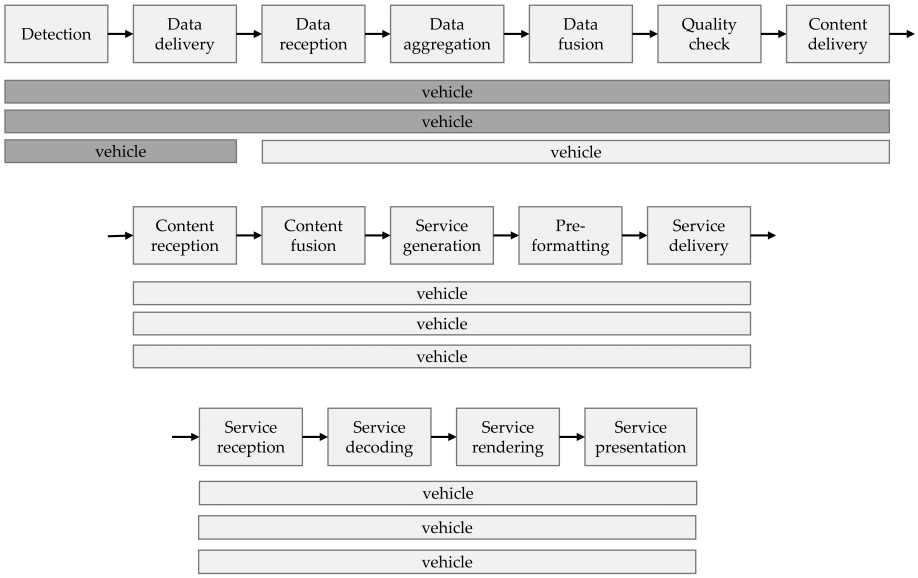

Figure D.7.: Actor assignment for implementation variations of Scenario 1 – ITS G5 communication only

The selected stakeholders and actors allow for three (six) different implementation variations regarding the assignment of actors to the individual roles (Figures D.7 and D.8). All process steps take place in the vehicle, depending on the implementation the split between the involved vehicles is different.
The implementation of the scenario based on the ITS G5 technology is depicted in Figure D.7. In ITS G5 the communication between involved actors comprising of delivery and reception of data / content / service are in the responsibility of the sending and receiving actor.
In case that the vehicles communicate with each other not through ITS G5 but cellular networks, the tasks data delivery and reception, content delivery and reception and service delivery and reception are in the responsibility of a cellular network service provider. This is depicted in Figure D.8.

All implementation variations – independent of the applied communication technology

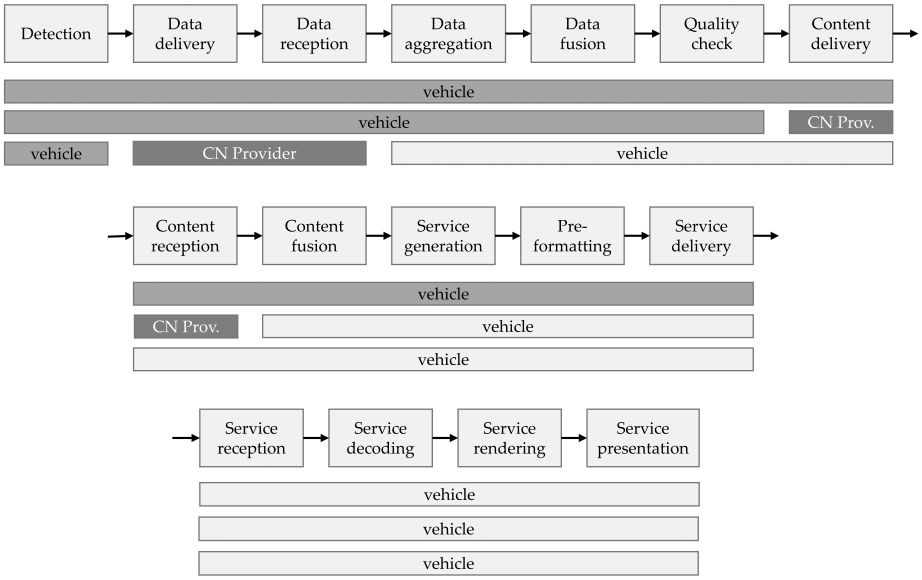

Figure D.8.: Actor assignment for implementation variations of Scenario 1 – cellular network communication only

– are interpretations of the scenario in Figure D.6.

D.4.2. Scenario 2 - C-ITS: Vehicle - Vehicle - Infrastructure

Stakeholders and actors involved: vehicles and road infrastructure

Figure D.9 summarizes the stakeholders and actors involved in such a scenario. The dark grey vehicle acts as sender and is responsible for data collection and afterwards is processing and evaluating the data. The result is then passed to the road infrastructure where the information is presented to the driver.
The selected stakeholders and actors allow for one implementation variation regarding the assignment of actors to the individual roles.
The use case in Figure D.9 actually offers both the involvement only of a roadside unit with ITS Station (=service reception) and sub centre (= preprocessing of received content before presentation) as well as a (central) traffic control centre. The traffic control centre might undertake the tasks of a supervisory authority in this context. As this is not part of the generic process chain, this fact is not reflected in Figure D.10. Which solution will be implemented is depending on the policies applicable for the service implementation.

For the scenario (Figure D.9) other presentation options besides VMS are likely, one example is the broadcast of information via (digital) radio. They are not explicitly listed here – mostly they will be in the responsibility of the same actor. To allow for additional actors the respective interface is considered in the final merge of results and analysis of roles (see Appendix D.5).

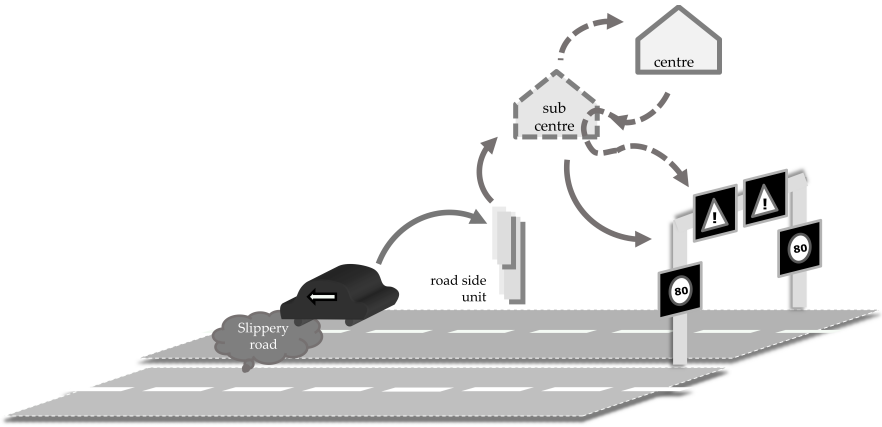

Figure D.9.: Scenario 2 – event detection by vehicle, evaluation of event in vehicle, presentation on roadside infrastructure (e.g. VMS)

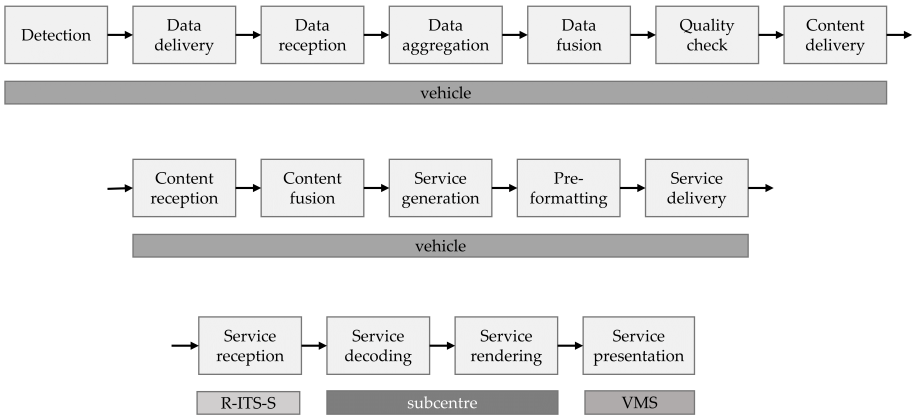

Figure D.10.: Actor assignment for implementation variation of Scenario 2

D.4.3. Scenario 3 - C-ITS: Vehicle - Infrastructure - Vehicle

Stakeholders and actors involved: vehicles and road infrastructure

Figure D.11 summarizes the stakeholders and actors involved in such a scenario. The dark grey vehicle acts as a sender and is responsible for the data collection, the light grey vehicle is the receiver and presents the information to the driver. The collected data is transmitted to the road infrastructure for processing and evaluation before it is broadcasted back to the vehicles.
For Scenario 3 multiple implementation variations are possible depending on where in the roadside infrastructure the processing and evaluation of the data takes place. The different options are depicted in Figures D.11 and D.12.

One of the options in Figure D.11 is based on a ITS G5 communication scenario with a roadside unit with ITS Station. For the other option in Figure D.11 the roadside equipment

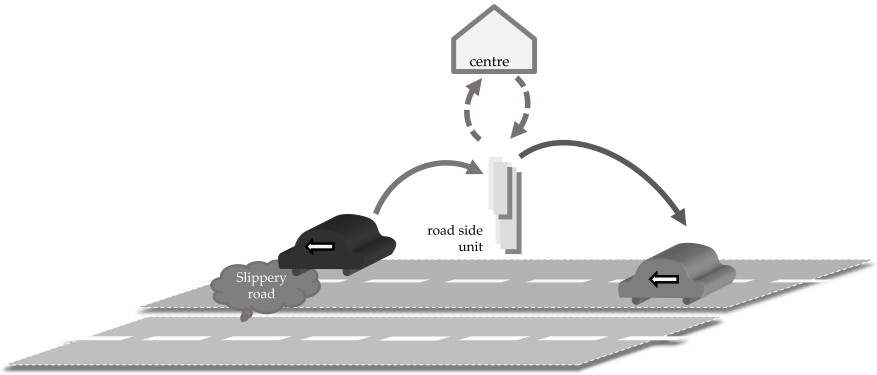

Figure D.11.: Implementation options of Scenario 3 realized with ITS G5 technology

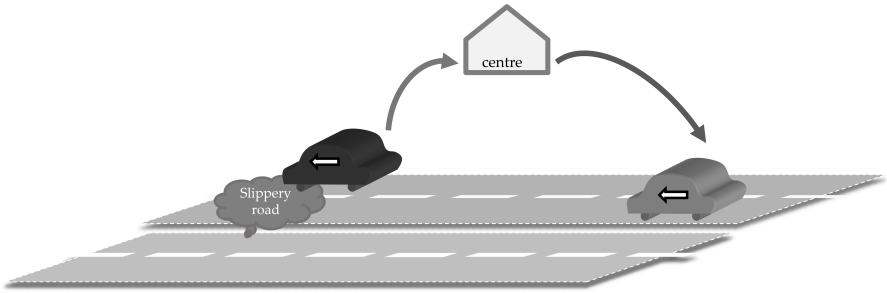

Figure D.12.: Implementation option of Scenario 3 realized with cellular networks

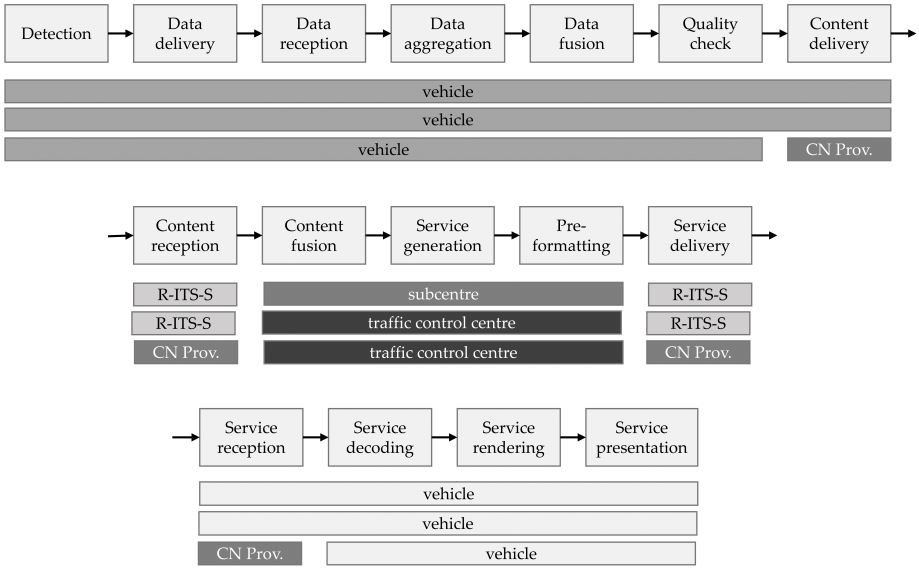

Figure D.13.: Actor assignment for implementation variations of Scenario 3

is connected to the backend system via Ethernet or fiber optics (dashed arrows) and runs the evaluations in the traffic control centre.
But C-ITS is not limited to ITS G5 communication, therefore even long-range communication directly to the traffic control centre is possible – this is depicted in Figure D.12.

The selected stakeholders / actors allow for three different core implementation variations regarding the assignment of actors to the individual roles (Figure D.13). Additionally, mixtures in the road infrastructure block are possible, realizing a segmentation of the required evaluation tasks between the subcentre and traffic control centre. All implementation variations are interpretations of the scenarios in Figures D.11 and D.12.

Currently, a direct link via cellular networks between the traffic control centre and the driver (e.g. vehicle, mobile device) is not possible. A service provider is needed to facilitate this communication. The possible actor assignments (Figure D.13) reflects this through the entity that is responsible for the content / service delivery and reception.

D.4.4. Scenario 4 - C-ITS: Vehicle - Infrastructure - Infrastructure

Stakeholders and actors involved: vehicles and road infrastructure

Figure D.14 summarized the stakeholders and actors involved in such a scenario. The dark grey vehicle acts as a sender and is responsible for the data collection. The collected data is transmitted to the road infrastructure for processing and evaluation before it is presented to the driver by the roadside infrastructure.

Like for the scenario 2 and 3 different structural implementations on the infrastructure side

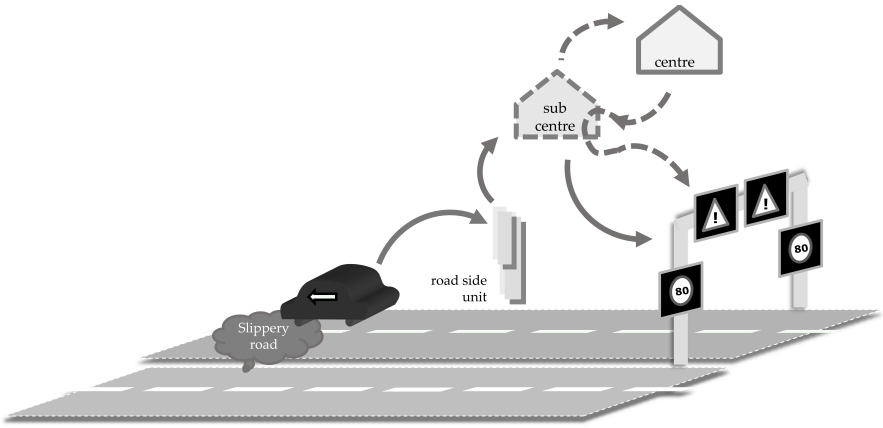

Figure D.14.: Implementation option of Scenario 4 realized with ITS G5 technology

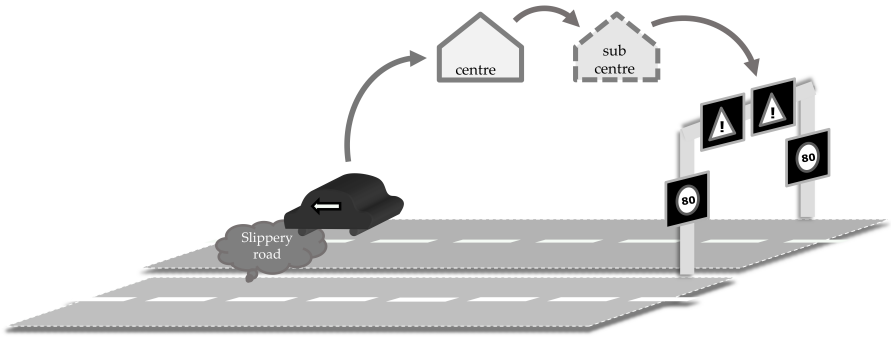

Figure D.15.: Implementation option of Scenario 4 realized with cellular networks

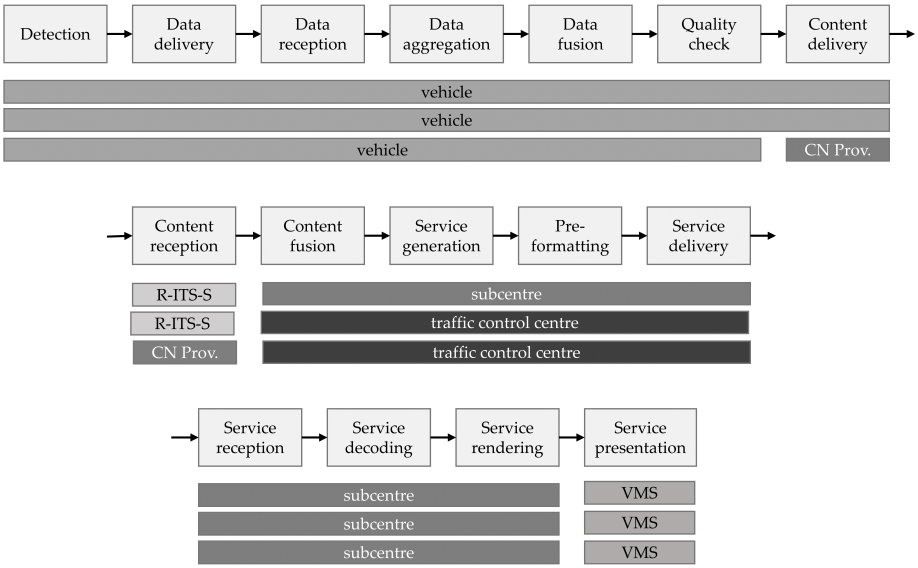

Figure D.16.: Actor assignment for implementation variations of Scenario 4

are possible. It might involve a roadside unit with ITS Station conveyed variation with a subcentre only or a subcentre backed up by a traffic control centre (Figure D.14). Alternatively, the vehicles might communicate directly with the traffic control centre through cellular networks (Figure D.15).
Like already mentioned in the description of scenario 2 multiple presentation options are possible. They are not explicitly mentioned here.

Similar like in scenario 3, the selected stakeholders / actors allow for three implementation variations regarding the assignment of actors to the individual roles (Figure D.16).

Currently, a direct link via cellular networks between the driver (e.g. vehicle, mobile device) and the traffic control centre is not possible. A service provider is needed to facilitate this communication. The possible actor assignments (Figure D.16) reflects this through the entity that is responsible for the content delivery and reception.
Besides providing pre-processed content for the processing and evaluation (see Figure D.16) it is as well possible that the vehicles serve as source providing only raw data. In this case the assignment of road infrastructure actors would already start with the 3rd / 4th element in the process chain. The pre-processing steps data reception, data aggregation, data fusion, quality check and content delivery would be assigned to the roadside infrastructure. The subsequent process steps would be operated – like before – by actors from the road infrastructure.

D.4.5. Scenario 5 - C-ITS: Infrastructure - Vehicle - Vehicle

Stakeholders and actors involved: vehicles and road infrastructure

Figure D.17 summarizes the stakeholders and actors involved in an ITS G5 based implementation of such a scenario. The road infrastructure collects the data and then broadcasts it to the light grey vehicle via the roadside unit equipped with an ITS Station. The content is processed and evaluated in the light grey vehicle before it is presented to the driver.

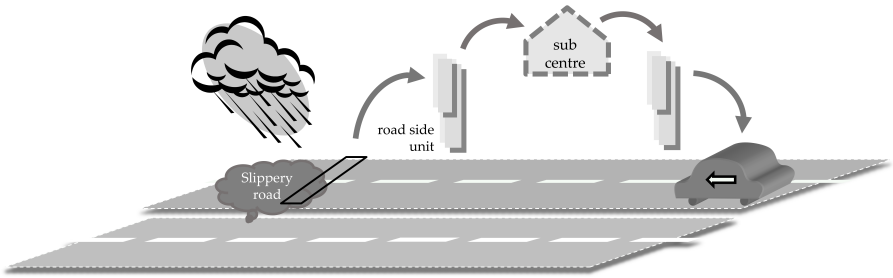

Figure D.17.: Implementation option of Scenario 5 realized with ITS G5 technology – detection of event with roadside sensors, evaluation in subcentre and presentation in vehicle

Alternatively the scenario might be realized with cellular networks (Figure D.18). This has no implications on the detection by the road infrastructure. The result is directly sent from

the (sub)centre to the light grey vehicle for evaluation and presentation.

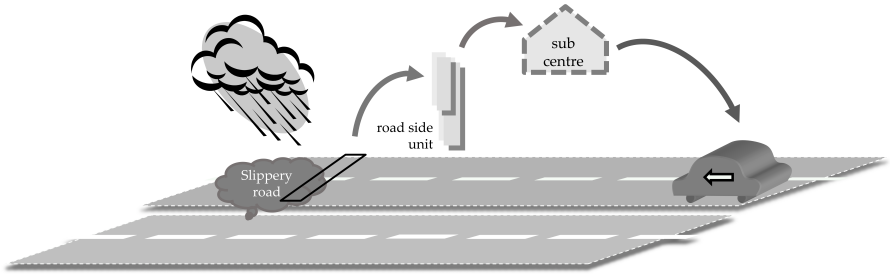

Figure D.18.: Implementation option of Scenario 5 realized with cellular networks- detection of event with roadside sensors, evaluation in subcentre and presentation in vehicle

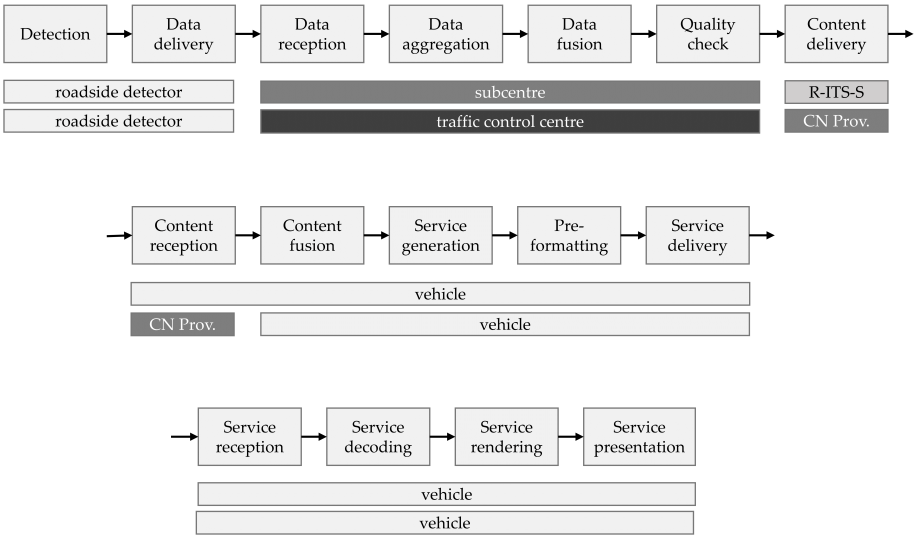

Figure D.19.: Actor assignment for implementation variations of Scenario 5

The selected stakeholders and actors allow for two implementation variations regarding the assignment of actors to the individual roles (Figure D.19). Either the road infrastructure broadcasts the collected content via ITS G5 to the vehicles or sends it via cellular networks. For the latter variation, a direct link via cellular networks between the traffic control centre and the driver (e.g. vehicle, mobile device) is required what is currently not possible. A service provider is needed to facilitate this communication. The possible actor assignments (Figure D.19) reflects this through the entity that is responsible for the content delivery and reception.

D.4.6. Scenario 6 - C-ITS: Infrastructure - Vehicle - Infrastructure

In this scenario roadside infrastructure sensors detect the event, the data is evaluated in the vehicle, finally it is presented on the roadside infrastructure. Due to boundary conditions applicable to the infrastructure actors this scenario is not likely to be implemented. It is therefore not further detailed and illustrated.

D.4.7. Scenario 7 - C-ITS: Infrastructure - Infrastructure - Vehicle

Stakeholders and actors involved: vehicles and road infrastructure

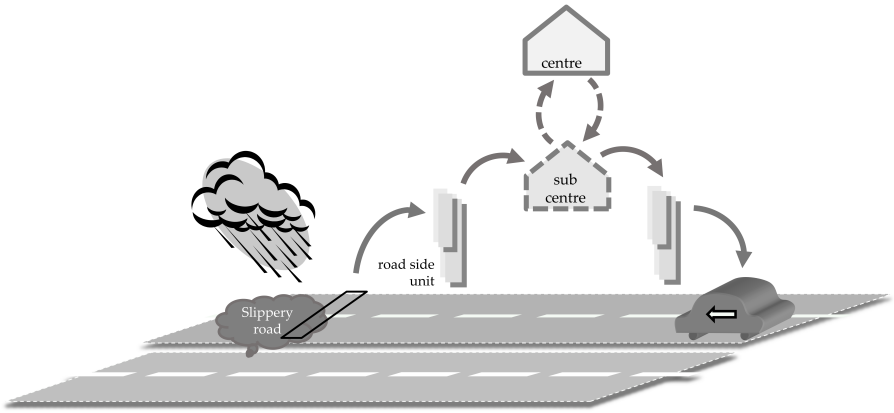

Figure D.20.: Implementation option of Scenario 7 realized with ITS G5 technology – detection and evaluation by roadside infrastructure, presentation in vehicle; from the roadside infrastructure only the subcentre is involved

Figure D.20 summarizes the stakeholders and actors involved in such a scenario. The data is collected by the road infrastructure and its sensors and is afterwards processed and evaluated. The result is broadcasted to the vehicles via a roadside unit with ITS Station. The light grey vehicle receives the information and presents it to the driver. Like for the scenario 2, 3 and 4 different structural implementations on the infrastructure side are possible. It might involve only a subcentre or a subcentre backed up by a traffic control centre. Alternatively the traffic control centre might communicate directly with the vehicles through cellular networks (Figure D.21).

The selected stakeholders / actors allow for three implementation variations regarding the assignment of actors to the individual roles (Figure D.22). Either the road infrastructure broadcasts the service result via ITS G5 to the vehicles or sends it via cellular networks. For the latter variation a direct link via cellular networks between the traffic control centre and the driver (e.g. vehicle, mobile device) is required what is currently not possible. A service provider is needed to facilitate this communication. The possible actor assignments (Figure D.22) reflects this through the entity that is responsible for the service delivery and reception.

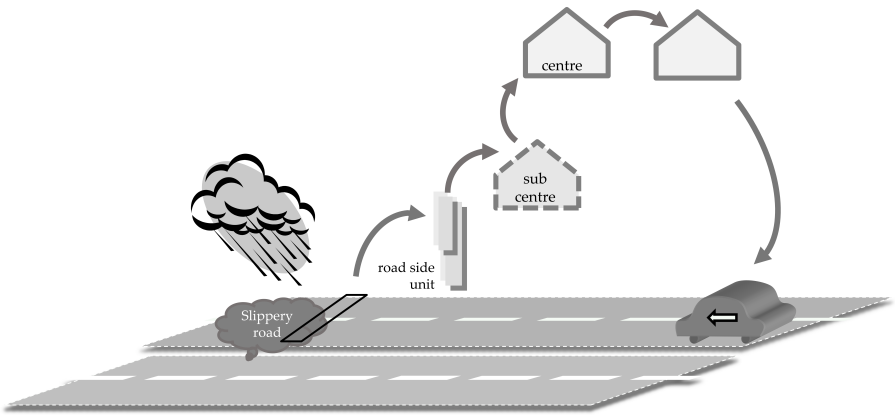

Figure D.21.: Implementation option of Scenario 7 with cellular networks

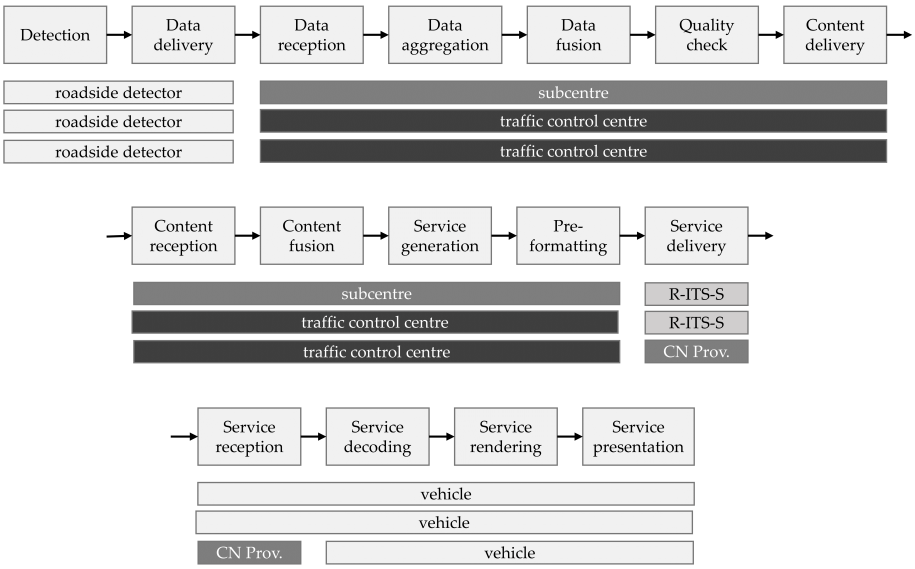

Figure D.22.: Actor assignment for implementation variations of Scenario 7

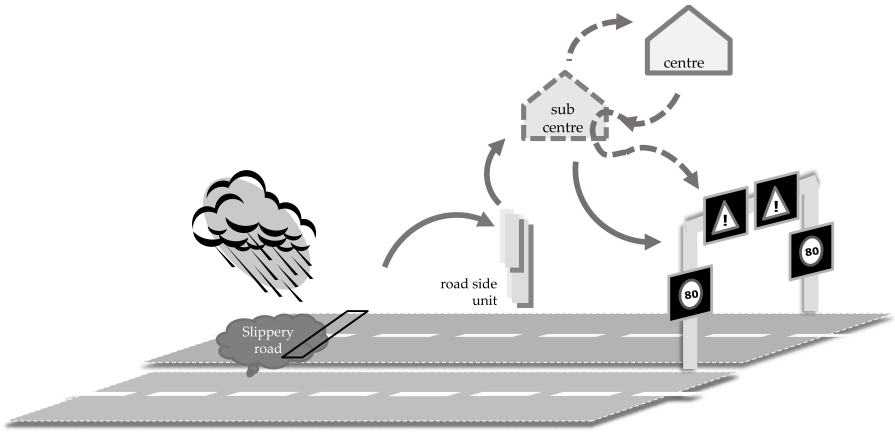

Figure D.23.: Implementation option of Scenario 8 – detection, evaluation and presentation by roadside infrastructure

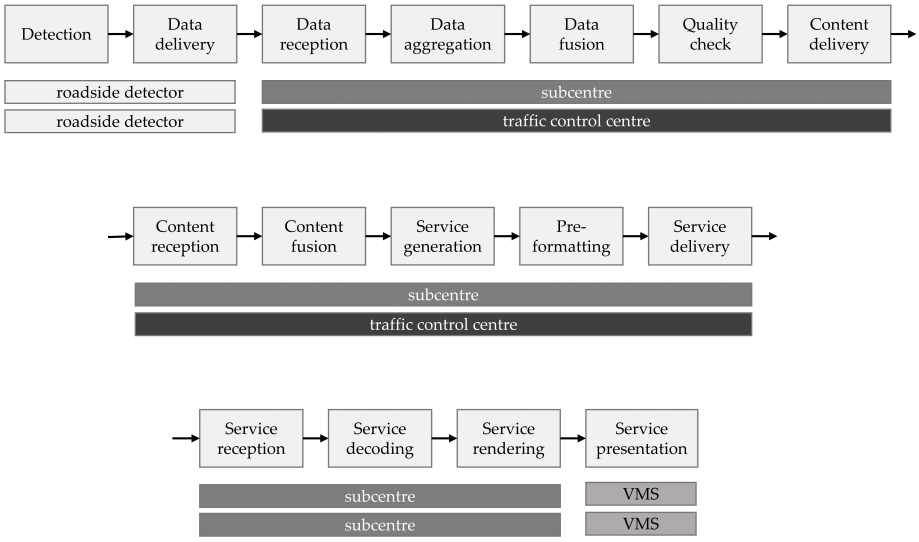

Figure D.24.: Actor assignment for implementation variations of Scenario 8

D.4.8. Scenario 8 - C-ITS: Infrastructure - Infrastructure - Infrastructure

In fact, scenario 8 is not a typical C-ITS scenario because in most cases it only will be realized by one single stakeholder and therefore does not require any cooperation between stakeholders – what in turn is a key feature of C-ITS. Comparing this with the apparently very similar vehicle only scenario (D.4.1) the V2V scenario in turn is in most cases cooperative, as the vehicles involved in this scenario belong to different actors and therefore require cooperation.

For scenario 8 it is assumed, that multiple actors are involved for the realization of this service, all coming from the road infrastructure domain. Figure D.24 depicts the two potential implementation variations.

One key element to realize such a scenario with multiple infrastructure stakeholders is the MDM, that will serve as a platform in the exchange of data and information between different actors from the field of road infrastructure. The MDM is not explicitly included in the Figures D.23 and D.24 but has a crucial role in enabling the transitions between data delivery and data reception, content delivery and content reception or service delivery and service reception. It facilitates interactions and exchange of data or information between stakeholders over the internet.

D.5. Merging the scenario results

For the generic description of roles, the results from assigning different actors to the individual process steps in the various scenarios from Appendix D.4 are merged. Therefore, the different implementation variations are put on top of each other. The overlay allows to identify the organizational interfaces that the individual scenarios share. Figure D.25 summarizes the actor assignment of the scenarios 1-8 (details in the respective sections).

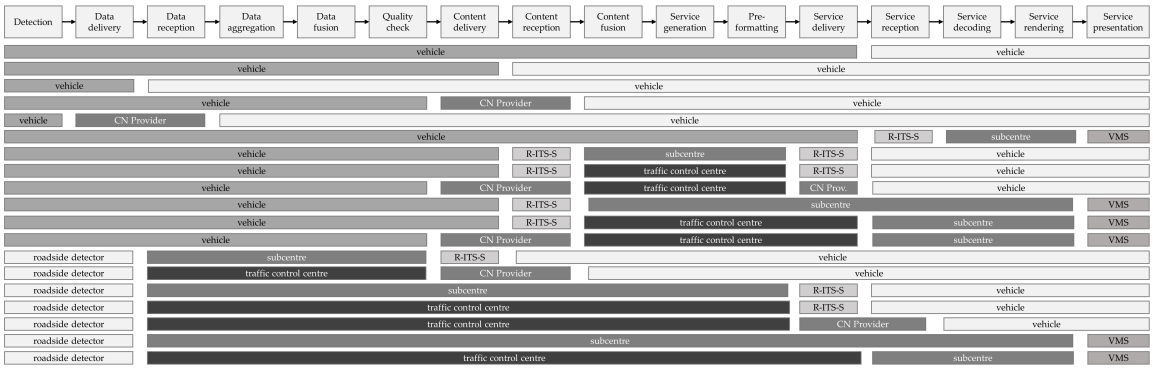

Figure D.25.: Summary of all implementation variations for the considered scenarios from Appendix D.4

Those interfaces implemented recurrently in different scenarios are potential points of intersections between different core roles. The rather scenario specific spots for cuts in the process chain are those of optional subroles. Examining the results from Figure D.25 above more closely shows that there exists an interdependency between the identified interfaces and the communication technology implemented in the respective underlying scenario variation: In scenarios implementing cellular network communication, mainly the interfaces marked with the white diamond in Figure D.26 occur. In scenarios implementing ETSI ITS G5 communication mainly the interfaces with the grey diamond occur.
The only interface identified that is not linked to communication but though occurs in several scenarios is the one between service rendering and service presentation. In the final description, this will not lead to an additional role but is reflected in the subroles defined for this part of the process chain.

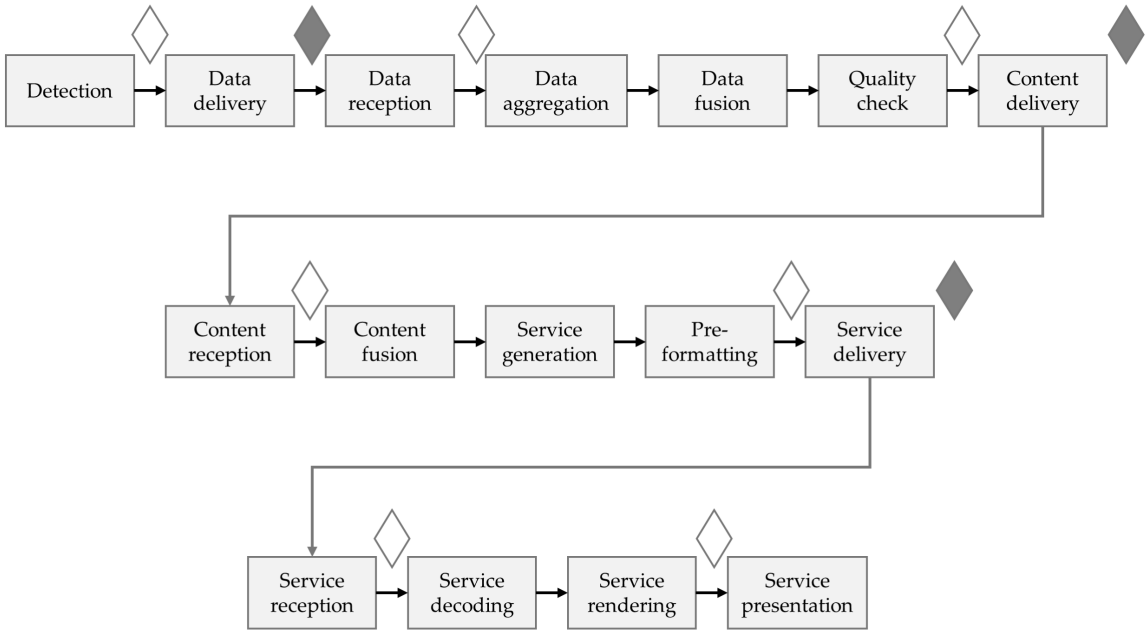

Figure D.26.: Generic description of interfaces identified through organizational bundling of process steps

Generalizing these findings shows that the communication aspect has a prominent impact on the assignment of roles within the process chain. Leaving out this issue, there is a rather clear structure within the mappings of the different scenarios. Mostly, the responsibilities can be bundled into content related, pre-processing related, service related and presentation related tasks. Depending on the ultimate implementation of the communication channel, the communication task either has its own actors or is allocated to the sender and receiver. Figure D.26 depicts both options (grey diamonds, white diamonds).

D.6. Identifying roles

Summarizing the results of the previous chapter leads to the following set of roles derived from the process describing the service operation for the service Hazard Location Warning:
Content Provision: covering the process steps Detection, Data aggregation, Data fusion, Quality Check
Service Provision: covering the process steps Content Fusion, Service generation and Pre-formatting
Presentation Provision: covering the process steps Service Decoding, Service Rendering, Service Presentation; this role might additionally be split up between those preparing the presentation and the actual presentation
Communication Manager: links the previously mentioned roles and covers (data delivery and reception) content delivery and reception and service delivery and reception

The identified roles might be split up into sub-roles, only covering some of the mentioned process steps. Actors may be assigned to one or several roles and subroles.

E. Modules derived from the Matrix report

The approach to identify modules for the Modular Construction System is rather similar to the approach originally developed in the Matrix report [Lotz et al., 2012]. In fact the Matrix report represents the methodical starting basis for the overall architecture developed in this thesis (chapter 4). Hence, the modules identified in the Matrix report might be integrated into the Modular Construction System after thorough assessment.
Given the fact that some time passed between the development of the basic concept of the Matrix report and the adoption of the idea for a Modular Construction System, it is suggested to run a qualifying examination across the modules. In the meantime some advancements of the original concept took place.
The following sections provide the samples from the Matrix report, sorted according to their assignment to viewpoints. Where appropriate the modules are brought in line with the current situation and architecture comprehension.
NOTE: The following sections comprise only a list of relevant modules, a detailed description of the single modules can be found in the Matrix report. The description in the Matrix report does not follow the template described in section 5.5.1.

E.1. Organizational modules

The organizational modules are rather similar to those later defined in ISO 17427 [ISO 17427, 2013] and used in the Reference and System Architecture (chapter 7 and chapter 8).

Content / Detection provider

(Data) Evaluation provider

Presentation provider

Communication network provider

Though the modules above partially re-emerge in the Reference Architecture an advancement is clearly visible. The tailoring of responsibilities slightly changed and the scope of the organizational viewpoint was broadened. Compare with section 7.1 and Appendix F.

E.2. Functional modules

The functional modules of the Matrix report are grouped along the value chain and are assigned to the categories 'detection', 'evaluation', 'presentation' and 'communication'.

E.2.1. Detection modules

Roadside detector (induction loops, overhead sensors, video etc.)

Built-in vehicle device as sensor with GPS coordinates

Mobile device as sensor evt. use of apps with GPS coordinates

Mobile device as sensor (Floating Phone Data) with cellular networks positioning

Police or driver as sensor / detector

E.2.2. Evaluation modules

Evaluation in subcenter or traffic control centre (public or private)

Evaluation in editorial department of radio station (public or private)

Evaluation in roadside infrastructure (e.g. roadside station / unit)

Evaluation in built-in vehicle device

Evaluation in mobile device

E.2.3. Presentation modules

Presentation on dynamic sign or regulation with traffic signal controller

Presentation on built-in vehicle device (visual, acoustic or haptic)

Presentation on mobile device (visual or acoustic)

E.2.4. Communication modules

The modules directly related to the functional process are complemented with communication related modules. The Matrix report differentiates between interfaces and protocols.

Communication bearers

Fiber optics or copper cable (only for stationary sensors)

Cellular networks (2., 3. and 4. generation)

Analogue broadcast, Digital broadcast

ETSI ITS G5 (future)

Data models and communication protocols

TLS [BASt, 2012]

Alert-C protocol of TMC

RDS-TMC (Standard: ISO 14819-Series)

TPEG (Standard: ISO 18234-Series for TPEG1, ISO 21219-Series for TPEG2)

DATEX II (Standard: CEN TS 16157 Series)

CAM – Cooperative awareness message (Standard: ETSI TS 102637-2)

DENM – Decentralized environmental notification message (Standard: ETSI TS 102637-3)

In general, the functional modules identified in the Matrix report and the Reference Architecture are mostly congruent.

E.3. Technical modules

Vehicle

Roadside station / unit

Subcenter and traffic control centre (public, private)

Vehicle, roadside, central, personal ITS Station

Cellular networks

(Radio) broadcast

F. Modules derived from C-ITS Reference Architecture

Modules identified when developing the C-ITS Reference Architecture are collected in the following sections.
NOTE: The following sections only provide a list of relevant modules, a detail description could be developed according to the approach described in chapter 5. Template in Table 5.1.

F.1. Organizational modules

The organizational structure developed in chapter 7 can be translated into modules. The high level roles are used as additional structure for the organizational modules.

F.1.1. System Operation

Communication manager
Risk manager
Capacity manager
Availability manager
Technical analyst
Configuration manager
IT-operations manager
Access manager

F.1.2. System Management

Service catalogue manager
C-ITS architect
Change manager
Test manager
Service level manager
Compliance manager
Financial manager
Service owner
Project manager
Information security manager

F.1.3. Functional Operation

F.1.3.1. Generic functional operation

Content provider

Service provider

Service recipient

F.1.3.2. Specific functional operation

Traffic participant

Infrastructure operator

Manufacturer

F.1.4. Policy Framework

Non-regulatory policy institutions

Authority

Standardization

Security certificate body

F.2. Functional modules

Section 7.2 identified the business process as one element of the functional architecture which does not lead to specific modules but instead provides the structure for the functional modules in the Modular Construction System. The resulting categories are 'detection', 'evaluation', 'presentation' and 'communication'.
This structure is complemented by the other functional categories already used to subdivide the description of the functional viewpoint in section 7.2.

F.2.1. Detection modules

Mobile data collection with video, radar, lidar, geo-referencing based on GPS sensors or cellular networks

(Mobile) detection of events by a driver or maintenance staff

Movement profiles generated by mobile devices based on GPS sensors or cellular networks (floating phone, floating car data)

Stationary detection with video, radar, loop detectors, overhead sensors, bluetooth

F.2.2. Evaluation modules

The modules in the category 'evaluation' identified by the Reference Architecture are rather generic compared to those mentioned in the Matrix report.

Merge of different data sources for further processing according to public policies

Merge of different data sources for further processing according to private policies

Evaluation of data based on public policies

Evaluation of data based on private policies

F.2.3. Presentation modules

For the modules in the category 'presentation' identified by the Reference Architecture applies the same like for those in the previous category. They are rather generic compared to those mentioned in the Matrix report.
The modules might be detailed, e.g. the presentation of results according to public policies can be realized with stationary presentation on variable messages signs or broadcast by public radio stations.

Presentation (rendering) of results according to public policies

Presentation (rendering) of results according to private policies

Presentation on mobile device or in vehicles

Presentation on stationary facilities

F.2.4. General functional modules

Data aggregation

Data fusion

Plausibility check

Quality control

Map matching

F.2.5. Communication modules

The 'communication' category subsumes modules required for the description of interfaces. Addressed aspects are data models, communication protocols and communication bearers.

Data models (OSI 5-7)

DATEX II

TPEG

ETSI CDD

TLS

IVI

OCIT

DELFI

new C-ITS Corridor data model

Usually, each of the data models comes along with a set of possible encodings, they are not included here.

Communication Protocols

OSI 4: UDP, TCP

OSI 3: Geo-Networking, IPv6 Networking, CALM Fast, IP, IPSec

Communication bearers (OSI 2)

Cellular networks

ITS G5 ad-hoc networks

Ethernet

Fiber optics networks

Infrared

F.3. Technical modules

Vehicles

Nomadic devices (smartphones, navigation devices)

Road works safety trailer

Roadside unit

Traffic control lights

Traffic control centre

Cooperative ITS centre

(Cooperative) ITS Stations

Acronyms

ADM Architecture Development Method. 13, 61, 65, 73, 203, 207

ASECAP Association of toll road operators. 25, 26

ASN.1 Abstract Syntax Notation One. 15, 188

BASt Federal Highway Research Institute, Bundesanstalt für Straßenwesen. 18, 48, 50, 76, 119, 120, 160, 161

BMVI Federal Ministry of Transport and Digital Infrastructure, Bundesministerium für Verkehr und Digitale Infrastruktur. 160–162

BPMN Business Process Modelling Language. 11

BSI Federal Office for Information Security, Bundesamt für Sicherheit in der Informationstechnik. 161, 162

BSP Basic System Profile. 146

C-ITS cooperative ITS. vii, viii, 1–7, 10, 12, 16, 19–29, 31, 33, 34, 36–46, 48–52, 54–58, 60–68, 70–74, 76–78, 80–84, 103, 109–120, 122–124, 126–130, 132, 134, 136, 138, 140–146, 148–150, 152–156, 158–160, 162–164, 169, 175–178, 183, 185, 187, 188, 190, 195, 196, 198, 206–233, 235, 238, 240, 241, 243, 245, 247, 248, 250, 259, 260, 262, 264

C2C-CC Car2Car Communication Consortium. 25, 26, 122, 146, 162, 185, 186, 188, 191

C2X Car2X. 22, 116

CALM Communications in Cooperative Intelligent Transport Systems. 144, 145, 212, 262

CAM Cooperative Awareness Message. 68, 70, 145, 256

CB citizens band. 159

CDD Common Data Dictionary. 68, 70, 142, 143, 145, 183, 261

CEDR Association of road directors and road authorities. 25, 26

CEN European Committee for Standardization. 8, 19–21, 23, 155, 162

CENELEC European Committee for Electrotechnical Standardization. 20

DAB Digital Audio Broadcast. 173

DATEX Data exchange specifications for traffic management and information. 68, 70, 142, 143, 145, 180, 183, 185, 187, 188, 256, 261

DELFI Continuous electronic timetable information, Durchgängige ELektronische FahrplanInformation. 49, 211, 262

DENM Decentralized Environmental Notification Message. 68, 70, 145, 165, 169, 181, 186, 257

DORA System for Dynamic Positioning and Road Works, Dynamische Ortung von Arbeitsstellen. 164

DOT Department of Transport. 16, 27

DSCR Dedicated Short Range Communication. 68

EC European Commission. 17

EFC Electronic Fee Collection. 14

ETSI European Telecommunications Standards Institute. 16, 19–21, 23, 67, 68, 142, 144, 155, 162, 185, 186

EU European Union. 17, 18, 21, 25, 49, 162

FGSV Forschungsgesellschaft für Straßen- und Verkehrswesen. 14, 42, 47, 52, 61, 64, 67, 71, 72, 123–125, 148

GNSS Global Navigation Satellite System. 164, 178, 181, 188

GPS Global Positioning System. 137, 172, 256, 260

He-VPZ Hessian traffic sign plan catalogue, Hessischer Verkehrszeichenplan-Katalog. 165, 169

HMI Human Machine Interface. 77

I2V infrastructure2vehicle. 122, 123

ICS ITS Central Station. 189

ICT Information and Communication Technology. 16

IEC International Electrotechnical Commission. 14

IP Internet Protocol. 145, 187, 262

IPSec Internet Protocol Security. 145, 262

IPv6 Internet Protocol version 6. 145, 262

IRS ITS Roadside Station. 189

ISO International Standardization Organization. 8, 14, 19, 21, 23, 155, 162

IT Information Technology. 8, 11, 45, 60, 77, 111, 128

ITIL IT Infrastructure Library. 60, 61, 111, 219, 221–233

ITS Intelligent Transport System. vii, 1–3, 7, 8, 10, 14–21, 23, 25, 27, 29, 33, 38–42, 46–51, 58, 61, 67–70, 73, 76, 77, 80, 81, 83, 85, 86, 90, 92–94, 102, 103, 112, 116, 117, 122, 123, 125–127, 140–150, 176–178, 181, 183, 185–189, 192, 195–197, 204, 206, 210, 211, 217, 240, 242, 243, 245, 247, 249, 257, 262

ITS G5 European profile for Intelligent Transport Systems operating in the 5 GHz frequency band. 20, 25, 68, 145, 152, 154, 157, 161, 165, 166, 169, 173–175, 178, 181, 182, 185–187, 241, 243, 244, 246, 247, 249, 252, 256, 262

ITU-T International Telecommunication Union - Telecommunication Standardization Sector. 14

IVI In-Vehicle Information. 145, 262

LDM Local Dynamic Map. 145

MARZ Leaflet for the furnishing of traffic control centers and sub-centers, Merkblatt für die Ausstattung von Verkehrsrechnerzentralen und Unterzentralen. 48, 49, 210

MDM Mobility Data Marketplace, Mobilitätsdatenmarktplatz. 49, 165, 173, 174, 177, 180, 183, 185, 187, 188, 210, 250

MoU Memorandum of Understanding. 153, 154

NERZ Association of users of the uniform central computer software for traffic management systems, Verein der Nutzer der einheitlichen Rechnerzentralensoftware für Verkehrsleitsysteme. 48, 210

OCA Open Traffic System City Association e.V. 145

OCIT Open Communication Interface for road Traffic control systems. 49, 145, 211, 262

ODP Open Distributed Processing. 10, 14, 15, 27, 45, 60, 64, 67, 68, 71, 72, 208, 216

OSI Open System Interconnection. 67, 126, 144, 145, 262

OTS Open Traffic System. 49, 145, 211

PKI Public Key Infrastructure. 191

Polis Association of cities and regions in Europe. 25, 26

RDS-TMC Radio Data System - Traffic Message Channel. 70, 145, 256

RM-ODP Reference Model Open Distributed Processing. 123–125, 148

RSA Guidelines for safety of working places at streets, Richtlinie zur Sicherung von Arbeitsstellen. 156, 157, 164, 165

RSU Road Side Unit. 70

RVWD Framework directive for the traffic information service, Rahmenrichtlinie für den Verkehrswarndienst. 49, 211

RWMDB Road Works Management Data Base. 177

RWW Road Works Warning. 97, 162, 165–168, 170–178, 181, 183, 189, 191

SAE Society of Automotive Engineers. 155

SWOT Strengths Weaknesses Opportunities Threats. 112

TCP Transmission Control Protocol. 145, 262

TEN-T Trans-European Networks - Transport. 18

TISA Traveller Information Services Association. 77, 80, 92, 112, 123–126, 169, 235, 237

TLS Technical Terms of Delivery for Road Stations, Technische Lieferbedingungen für Streckenstationen. 48, 49, 142, 145, 187, 210, 256, 261

TOGAF The Open Group Architecture Framework. 8, 11, 13, 15, 40, 41, 43–45, 52, 61, 64, 65, 71–73, 123–125, 148, 203, 207

TPEG Traffic and travel information via transport protocol experts group. 70, 71, 142, 145, 256, 261

UDP User Datagram Protocol. 145, 262

UML Unified Modeling Language. 11, 12, 14, 64, 163, 167, 168, 170

V2I vehicle2infrastructure. 22, 122, 123, 188

V2V vehicle2vehicle. 122, 123, 129, 146, 188

VDV Association of German Transport Companies, Verband Deutscher Verkehrsunternehmen. 49, 210

VMS Variable message sign. 242, 243

WGS84 World Geodetic System 1984. 172, 178, 179

XSD XML Schema Definition. 188

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