1

Reference ITS Architectures in Europe

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1.1 Introduction

Intelligent Transportation Systems (ITS) are complex systems which require a systematic basis for their planning and deployment processes. In view of this need, the European ITS Framework Architecture (FRAME) was set up to support ITS development and to foster their roll-out at the Member States by facilitating system integration, fostering interoperability, avoiding vendor lock-in situations and promoting the standardization of functionalities, interfaces and data models. The fast technological evolution and the growing interest in Cooperative Systems based on V2X communications unveiled new requirements uncovered by the existing architectures, leading to alternative approaches by certain research projects, which ended in an extended version of the FRAME architecture and complementary standardization processes to fulfil the needs posed by the connected vehicles and road infrastructures.

This chapter will outline the reference architectures conceived for ITS planning and deployment in Europe, their evolution through the inputs provided by major ITS projects and initiatives and some experiences from the authors when facing the definition of ITS architectures through our involvement in research projects, by following different approaches.

1.2 FRAME: The European ITS Framework Architecture

An ITS Architecture sets a framework to plan, analyse, define, deploy and integrate Intelligent Transportation Systems, allowing at the same time understanding of their business, organizational and technical implications. It is commonly depicted as a high-level design showing the
structure and operation of a certain system in a given context, which can be used as a basis for further low-level design phases.

An ITS architecture integrates three main elements:

- the functions that are required for ITS;
- the system partitioning into logical or functional entities such as subsystems, modules or components, where these functions reside;
- the information and data flows that connect these functions and physical subsystems together into an integrated system.

When talking about ITS architectures in Europe, the key reference is the European ITS Framework Architecture (often referred to as FRAME). The FRAME Architecture was created as an attempt to provide a common approach across the European Union so that the implementation of integrated and interoperable ITS can be planned. Its main objective is to foster the deployment of ITS in Europe and for that purpose, it defines a framework providing a systematic basis for ITS planning, easing integration between multiple systems and ensuring interoperability and consistency of information.

1.2.1 Background

The FRAME Architecture was created by the project KAREN (Keystone Architecture Required for European Networks), funded by the European Commission under the Fourth Framework Programme in the area of Transport Telematics and first published in October 2000. The need to keep the architecture up to date was soon identified, and this entailed a huge maintenance effort. During the following years (2001–2004), projects FRAME-NET and FRAME-S, funded by the European Commission under the Fifth Framework Programme, carried out this task successfully. As a result, not only did the architecture evolve but also user needs were updated, a methodology supported by computer-based tools was defined, a centre of knowledge created and the FRAME Forum was established so that users and stakeholders could exchange advice and experiences. Since 2006, due to the growing expectations created by the so-called Cooperative Systems based on V2X communications and strongly supported by the European Commission, the FRAME Architecture entered an adaptation process to provide support to the new set of user needs and requirements posed by connected vehicles and road infrastructures, which were not covered by the original version. The project E-FRAME (Extend FRAMEwork architecture for cooperative systems), funded by the European Commission under the Seventh Framework Programme, addressed this need between 2008 and 2011. As a result, the FRAME Architecture version 4 supporting Cooperative Systems was released in 2010.

Since the time of the KAREN project, the FRAME Architecture has been adopted and successfully used in different ways by many nations, regions, cities and projects throughout Europe. Reference best practices can be mentioned such as the French national ITS Architecture (ACTIF), the Italian national ITS Architecture (ARTIST) and other adopting nations such as Austria (TTS-A), the Czech Republic (TEAM), Hungary (HITS) and Romania (NARITS). In addition, specific ITS Architectures have been created in the UK including one for Transport
for Scotland and another for the County of Kent, while Transport for London intended to use FRAME Architecture to plan its future ITS deployments. In some cases it has also been used by R&D projects such as VIKING, EASYWAY, COOPERS and MoveUs among others, and even in pre-commercial procurement programmes such as CHARM-PCP, participated by the Highways Agency (UK) and Rijkswaterstaat (the Netherlands).

1.2.2 Scope

Strictly speaking, FRAME is not always considered as an architecture, but more a framework targeted to help European countries and regions planning their own ITS architecture tailored to their particular needs. In this sense, the experience is quite similar to the one in the USA, where the main objective of the National ITS Architecture has been to guide the ITS development and deployment throughout the country at the federal, state and local levels.

The most recent release of the FRAME Architecture (version 4), published in 2010 with the updates from the E-FRAME project, covers the following ITS areas:

- Electronic Fee Collection;
- Emergency Notification and Response – Roadside and In-Vehicle Notification;
- Traffic Management – Urban, Inter-Urban, Simulation, Parking, Tunnels and Bridges, Maintenance, together with the Management of Incidents, Road Vehicle Based Pollution and the Demand for Road Use;
- Public Transport Management – Schedules, Fares, On-Demand Services, Fleet and Driver Management;
- In-Vehicle Systems – including Cooperative Systems;
- Traveller Assistance – Pre-Journey and On-Trip Planning, Travel Information;
- Support for Law Enforcement;
- Freight and Fleet Management;
- Support for Cooperative Systems – specific services not included elsewhere such as bus lane use, freight vehicle parking;
- Multimodal interfaces – links to other modes when required, e.g. travel information, multimodal crossing management.

When dealing with an ITS architecture, and also with FRAME, a number of different views can be considered:

- User Needs, which are always the starting point and collect the expectations to be covered by an ITS deployment and its associated set of services. The identification of these needs may involve different stakeholders such as public transport or freight operators, system integrators, national/regional governments and every kind of traveller.
- Functional Viewpoint, which defines the functionality to be provided by the ITS in order to meet the User Needs, usually structured into functional areas and further divided into specific functions. This is represented as Data Flow Diagrams containing the functions and
showing how they relate to each other, to data stores and terminators, as well as the data that flows between them.

- **Physical Viewpoint**, which describes how functions can be grouped into physical components allocated to modules or subsystems. Hence, detailed specifications for each component can be produced.

- **Communications Viewpoint**, which describes the communications links needed to support physical data flows. Once the functionalities have been allocated to physical modules, the location of the Functional Data Flows can be inferred and also the information flow between modules, thus representing communication channels. At this level, communication specifications can be produced and the use of an existing standard, or even the need to define a new one, may be agreed.

In addition to the main architectural views, use of the FRAME Architecture enables other kind of activities such as a Deployment Study, showing how to deploy the systems and communications derived from the ITS Architecture and the way to migrate existing systems to be compliant to FRAME; a Cost/Benefit Study, helping to predict the likely costs and the expected benefits from the ITS deployment; and a Standardization Study, identifying existing applicable standards related to the European ITS Framework Architecture and future standardization needs.

### 1.2.3 Methodology and Content

A general high-level diagram showing the methodology and the different views to be considered when creating an ITS Architecture is illustrated in Figure 1.1, where the specific scope of the FRAME Architecture has been highlighted.

The FRAME Architecture is intended to be used in the European Union, it does not impose any kind of structure on a Member State and comprises only a set of User Needs describing what ITS can provide and a Functional Viewpoint showing how it can be done. The methodology is supported by computer-based tools (a Browsing tool and a Selection tool), enabling the definition of logically consistent subsets of the FRAME Architecture Functional Viewpoint and the creation of subsequent Physical Viewpoints. It is worth noting that the FRAME Architecture is technology independent and does not entail the use of any specific technology or product in order to ensure that the ITS architectures and high-level

![Figure 1.1 General methodology to create an ITS architecture and scope of FRAME architecture. © 2009 PJCL.](image-url)
requirements planned using the methodology will not become obsolete despite the evolution of technology and product development.

The KAREN project generated about 550 User Needs to cover the ITS applications and services being considered for implementation at the end of the 1990s. Since then, the FRAME-related projects have continuously updated this set of User Needs with the most recent E-FRAME project, adding about 230 User Needs related to the use of Cooperative Systems.

The FRAME Architecture can be used in a number of scenarios, being one of the most ambitious to plan large-scale integrated ITS deployment in a country or region over a number of years. By collecting the vision of the different stakeholders involved, a suitable subset of the FRAME Architecture can then be used to provide a high-level model on the way to achieve it. When creating a subset ITS architecture, the most appropriate set of functionality to deliver the required services must be selected. The system structure obtained as a result should provide enough information to develop the services and deploy the equipment needed, all of them compliant with the overall architecture concept.

It can be stated that the FRAME architecture in its current version covers most ITS applications in place or considered for implementation in Europe without imposing any technical requirement on the development phase and therefore remaining technology independent. Comprehensive documentation and the tools to support its use, which are strongly recommended, are freely available [1].

1.3 Cooperative Systems and Their Impact on the European ITS Architecture Definition

Cooperative Systems based on V2X communications are still regarded as one of the most promising solutions to address the current and future needs for increased safety and road traffic efficiency. Research on Cooperative Systems in Europe started at the end of the 1980s with the PROMETHEUS project. However, the technology required was not mature enough at that time and it was not until the last decade that real investment was made in this field through different initiatives and R&D projects, always with strong support from the European Commission.

Although initial research and awareness activity was carried out in a noncoordinated manner, a significant effort was made to align and harmonize the results from the different projects in order to provide an integrated view of the architectural needs to support Cooperative Systems. In addition, the European Commission defined a Policy Framework for ITS deployment and promoted an intense activity on standardization, not only limited to the EU but also looking outside to establish a fruitful cooperation with the USA and Japan. In the last years, the projects focused on the design and development of Cooperative System prototypes have given way to the so-called Field Operational Tests (FOTs) and Pilots, targeted to large-scale deployment, validation and impact assessment.

1.3.1 Research Projects and Initiatives

The preliminary framework for the support of research and technological development in European Cooperative ITS was set by the Intelligent Car Initiative [2] in 2006, targeted to coordinate research on smarter, cleaner and safer vehicles and to create awareness of
ICT-based solutions for safer and more efficient transport. One of its pillars was the eSafety Forum, now renamed as iMobility Forum [3], which aimed to support ITS deployment specifically targeted to overcome safety needs. In particular, the eSafety Forum Communications Working Group was entrusted to provide all the information required to advise the European Commission on the deployment of a harmonized EU wide communication system for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I), paying special attention to spectrum issues, standardization and international cooperation.

On the industry side, key initiatives can also be mentioned such as the Car2Car Communication Consortium (C2C-CC) [4], an industrial nonprofit organization driven by European vehicle manufacturers and focused on V2V communication whose primary goal was to establish an open European industry standard for V2V communication systems based on wireless network components ensuring European-wide inter-vehicle compatibility. The consortium promoted the allocation of the frequency band at 5.9 GHz range for safety-critical automotive use. The C2C-CC is currently integrated in the Amsterdam Group [5], a broader stakeholder association targeted to Cooperative ITS deployment in corridors and cities, sharing knowledge and experiences with leading organizations such as CEDR (Conference of European Directors of Roads), ASECAP (European Association of Tolled Motorways) and POLIS (European Cities and Regions Networking for Innovative Transport Solutions).

Concerning research and development activity, it is worth mentioning projects such as CVIS, SAFESPOT, COOPERS, GEONET and PRE-DRIVE C2X, all funded by the European Commission under the Sixth and Seventh Framework Programmes. All of them dealt with Cooperative Systems development, prototyping and demonstration but putting the focus on different perspectives. CVIS [6] worked on a global view, developing and integrating the essential applications and enabling technologies for communications, planning and positioning in a common platform unit implementing the ISO CALM (Continuous Air-interface Long and Medium range) architecture; while SAFESPOT [7] focused on the development of a ‘Safety Margin Assistant’, a safety bubble around the vehicle in which full driver awareness to anticipate potentially dangerous situations could be achieved by means of cooperative communications; and COOPERS [8] looked for a better use of the available infrastructure capacity by using V2I communications for safety-relevant data exchange. Shortly after, GEONET [9] produced reference specifications for Cooperative Systems networking covering GeoNetworking and IPv6, which were later adopted for standardization, and PRE-DRIVE C2X [10] prototyped a common European V2X communication system and designed the necessary tools for operating a Field Operational Test with Cooperative Systems on a European level performing comprehensive assessment of the impacts.

1.3.2 Pilots and Field Operational Tests

As an evolution of the first R&D projects, which provided prototype implementations of Cooperative Systems allowing early testing of draft standards, Pilots and Field Operational Tests are intended to bridge the gap from demonstrations to system roll-out. For that purpose, it was deemed important to collect sound and valid data on the performance and cost–benefit ratio of these systems. Large-scale pilots and Field Operational Tests play an important role by providing comprehensive data on the performance and user acceptance of Cooperative Systems.
Some representative Field Operational Tests at national and regional level can be mentioned such as SIM-TD in Germany, SCORE@F in France, SPITS in the Netherlands, Easy Rider in Italy, TSN in Norway and SISCOGA in Spain, among others. As for the pilots, the most representatives at the moment are COMPASS4D [11], aimed to deploy three Cooperative ITS services (Red Light Violation Warning, Road Hazard Warning and Energy Efficiency Intersection Services) in seven European cities and CO-GISTICS [12], intended to deliver five Cooperative ITS services targeted to sustainable mobility of goods in seven European logistic hubs.

1.3.3 European Policy and Standardization Framework

As research activity evolved and the results from the different projects were released, the European Commission identified the need to set a Policy Framework for the development of ITS in Europe. In this sense, two major actions were taken:

- Directive 2010/40/EU: Framework for the Coordinated and Effective Deployment and Use of Intelligent Transport Systems [14]. It is a key instrument for the coordinated implementation of ITS in Europe, aimed to establish interoperable and seamless ITS services while leaving Member States the freedom to decide which systems to invest in.

Regarding standardization, the European Commission issued the Mandate M/453 [15] under the 2010/40/EU Directive, inviting the European Standardization Organizations to prepare a coherent set of standards, specifications and guidelines to support European Community wide implementation and deployment of Cooperative ITS. The results of the European research and development projects as well as the Field Operational tests were included in the standardization process. Coordinated by the COMeSafety initiative [16], these projects developed a harmonized ITS communications architecture [17], which was provided to ETSI and ISO and resulted in published standards. The first standards package, the so-called ‘Release 1 specifications’ [18], produced by ETSI and CEN, has been adopted and issued in 2014.

In addition, international cooperation on standardization activities has been addressed since 2010 with the USA and Japan, searching for global harmonization of standards for Cooperative Systems. A joint ITS technical task force has been established between ETSI and the US Department of Transportation, while a Memorandum of Cooperation has been signed with the Japanese Ministry of Land, Infrastructure, Transport and Tourism.

1.3.4 Impact on FRAME Architecture

After an initial phase of research, development and prototyping in isolation, Cooperative Systems are reaching a fair maturity level to make steps towards integration with any other ITS application or service, since they need to interact with other elements to exchange information, e.g. a traffic management system.
Thanks to the E-FRAME project, the current FRAME Architecture (version 4) contains all the applications and services that were considered by CVIS, SAFESPOT and COOPERS projects and can therefore show how this integration may be achieved. Analogously, when a Physical Viewpoint has been created and the corresponding communications requirements are identified, the work of COMeSafety and the projects contributing to the standards produced by CEN and ETSI as a result of Mandate M/453, can be used to define the communications links in detail.

The measures and priority areas defined in the ITS Action Plan demand the delivery of specific ITS services and applications throughout Europe, which need to be supported by one (or more) architectures. These architectures can be now defined by using a subset of the current FRAME Architecture. By following the methodology, applicable existing standards or new standardization needs can be identified. As a result, a technology-independent view of each service or application can be generated, ensuring interoperability between products from different manufacturers, avoiding vendor lock-in situations and facilitating the further merging of several ITS architectures, even coming from different Member States, since they will be compliant with FRAME elements and terminology.

1.4 Experiences in ITS Architecture Design

In this section, part of our experience in the definition of ITS architectures is explained through our involvement in two R&D projects funded by the European Commission: Cybercars-2 and MoveUs. These projects are radically different, since they were conceived and carried out at different moments in the ITS evolution timeline. The resources available were not the same and therefore, different approaches for architecture definition were required and put into practice.

On the one hand, Cybercars-2 belongs to the wave of projects related to Cooperative Systems heavily invested on since 2006. At that time, the FRAME architecture was not yet ready to cover the requirements posed by this kind of systems, so an alternative methodology was used taking as a reference the ongoing initiatives and the flagship projects in this field. On the other hand, MoveUs is a still ongoing project dealing with the provision of personalized mobility services in the context of Smart Cities aiming to trigger behavioural changes towards sustainable mobility habits. In this case, the FRAME Architecture has been used as main reference in combination with other approaches and tools available, thus enabling all the functionalities to be covered and providing richer and more complete results at the design phase.

1.4.1 Cybercars-2: Architecture Design for a Cooperative Cybernetics Transport System

Cybercars-2 (Close Communications for Cooperation between Cybercars 2) was a project funded by the European Commission under the Sixth Framework Programme between 2006 and 2008. It was conceived as an evolution from its predecessors, CyberCars and CyberMove, which dealt with the development and evaluation of Cybernetic Transport Systems (CTS) comprising a number of individual driverless vehicles with the capability to travel on existing road infrastructure without the need for dedicated ways. However, the prototype vehicles developed in those projects were designed for low-demand road traffic environments and were neither able to communicate nor cooperate with each other. Hence, the main challenge for
Cybercars-2 was to empower these vehicles with the ability to cooperate through Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication links in order for the CTS to enable higher traffic flows and improved network efficiency.

One of the main project tasks was to define, develop, deploy and test a Cooperative Cybernetic Transport System Architecture able to provide: interconnectivity and interoperability between different types of driverless vehicles, compatibility with ADASE (Advanced Driver Assistance Systems in Europe) Architecture and increased road traffic efficiency and safety. Since consortium partners brought their own driverless vehicles to the project, featuring different system architectures, great effort was invested on adapting the existing vehicle control architectures to the Cooperative Vehicles’ Communication Architecture paradigm.

With these objectives in mind, specific cooperative communication needs were identified in the context of interoperability, operational safety, reliability and compatibility with ADASE Architecture. In particular, the following steps were made:

- The system architecture for each component of the CyberCars-2 fleet of vehicles (fully driverless Cybercars and Dual-Mode vehicles, manually or automatically driven) was analysed in depth.
- The Cybercars-2 Architecture was defined: use cases, Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication requirements were identified and a proposal for a communications architecture based on protocol layers was developed.
- The main requirements for compatibility between Cybercars and vehicles compliant with ADASE Architecture in terms of functionality, security and safety were identified, articulated and examined.
- Enhanced Safety Certification procedures applicable to the scope of Cooperative Cybernetic Transport Systems were defined.
- A small-scale Cooperative Cybernetic Transport System was demonstrated in La Rochelle (France) in September 2008; it comprised a simplified Control Centre and a fleet of Cybercars and Dual-Mode vehicles driving in an 8-shaped test track.

At the same time frame, numerous R&D activities focusing on vehicular communications were undertaken under the umbrella of the European Commission and EU member countries. Many of them explored the use of V2V/V2I communication technologies for different application fields and purposes, e.g. improved safety or enhanced traffic efficiency. Representative examples are European projects PReVENT, CVIS, SAFESPOT and COOPERS, already introduced.

According to the project objectives and to the status of research activity on Cooperative Systems, it was soon agreed that the architecture to be proposed by CyberCars-2 project should be:

- focused on the safety application field, because the aim was to perform cooperative manoeuvres safely;
- mainly based on robust, low-latency and reliable V2V communications, which is the most efficient way to exchange information between the vehicles, since cooperative manoeuvres are time-critical actions;
- compliant with the architecture supported by any of the key reference projects previously mentioned, in order to achieve the highest possible degree of compatibility.
As a result, the SAFESPOT architectural approach was chosen as a reference for Cybercars-2 architecture design for the following reasons:

- It enabled advanced detection of potentially dangerous road traffic situations and made drivers aware of the surrounding environment.
- It was implicitly aligned to Car2Car-Communications Consortium Reference Architecture, which was focused on the creation and establishment of an open European industry standard for Car-to-Car communication systems based on wireless networking technologies.
- Being compatible with the ISO CALM architecture, it offered a standardized set of air interface protocols and parameters for medium and long range, high-speed ITS communication.

The methodology adopted to define the project communication requirements was based on the available reference from Vehicle Safety Communications Project (VSC) in the USA. As a result, spreadsheet tables were produced in which the columns represented the driving manoeuvres to be performed cooperatively by the vehicles, while the rows listed the set of communication parameters identified (e.g. message size, allowable latency, communication range), and suitable target indicators were given for each parameter. Other references from European projects were also taken into account, such as the communication requirements for an intersection scenario provided by INTERSAFE, a PReVENT subproject.

The main building blocks involved in the CyberCars-2 Architecture were: (a) the vehicles (both, driverless and dual-mode vehicles), which exchanged messages containing useful data to perform cooperative manoeuvres safely; (b) the control centres located at dedicated environments but not necessarily close to the roads, from which traffic was controlled and the vehicle fleet efficiently monitored; and (c) the infrastructure elements, which occasionally helped to improve system efficiency, e.g. transmitting a Differential GPS correction to achieve higher positioning accuracy, or monitoring and supervising the traffic flow from a control centre.

Built in line with SAFESPOT Reference Architecture, the Cybercars-2 Architecture consisted of three subarchitectures or viewpoints, namely:

- Functional Architecture, derived from system requirements and aimed at fulfilling user needs; it comprised functional modules, data structures and interfaces and is illustrated in Figure 1.2;
- Physical Architecture, describing the way in which the required functionality and system requirements are fulfilled;
- Communication Architecture, defining links between the Physical Architecture components and identifying suitable communication protocols to enable the data flows from one component to another.

Concerning communications, as one of the examples of safety-critical applications, the Cybercars-2 Architecture supported ongoing efforts from the European industry (C2C-CC) and standardization bodies (ETSI ERM TG37) for specifically protected frequency band allocations at 5.9 GHz range to guarantee European-wide inter-vehicle compatibility. More specifically, the Cybercars-2 Architecture dealt with three types of communication channels:

- Short-Medium range V2V/V2I communication channels delivering the data required by the vehicles to perform cooperative manoeuvres safely;
Reference ITS Architectures in Europe

• Short-Medium range V2I/I2V communication channels delivering either support information to the vehicles (e.g. Differential GPS correction) or information on the network status and traffic flow to/from an infrastructure unit nearby;
• Long range V2I/I2V communication channels delivering information on the network status and traffic flow to a remote infrastructure unit (V2I) and control commands back to the vehicles in order to improve traffic efficiency.

The layered communications protocol architecture proposed, also based on SAFESPOT approach, is illustrated in Figure 1.3.

In conclusion, it can be stated that the Cybercars-2 Cooperative Communication Architecture enabled communication between driverless vehicles of different kinds, keeping the alignment with some of the most relevant architectural approaches existing at that time, fostering interoperability and allowing architecturally different vehicles to perform driving manoeuvres safely in cooperation with each other. These results would contribute to improve driving safety as well as traffic efficiency in Cybernetic Transport Systems deployed in dedicated environments such as city centres, airports or theme parks.

Shortly after the end of Cybercars-2, the E-FRAME project started, which contributed to extending the FRAME architecture to include Cooperative Systems by collating system requirements from key projects in the field into a set of requirements in the format of FRAME User Needs. SAFESPOT, the main architectural reference for Cybercars-2, was one of the selected projects.

1.4.2 MoveUs Cloud-Based Platform Architecture

MoveUs (ICT Cloud-Based Platform and Mobility Services: Available, Universal and Safe for All Users) is a project funded by the European Commission under the Seventh
Intelligent Transport Systems Framework Programme between 2013 and 2016 in the context of Smart Cities. It aims to benefit from the huge potential of combined ITS and ICT to radically change the European users’ mobility habits by offering intelligent and personalized travel information services, helping people to decide the best transport choice and providing meaningful feedback on the energy efficiency savings obtained as a result. Recommendations supported by incentives will be provided to foster ‘soft’ mobility modes and the use of shared and public transport modes (buses).

Information from a wide variety of transport modes and mobility systems such as public buses, car/bike sharing systems, traffic management systems, equipped vehicles to measure traffic density, and users’ smartphones will be integrated and processed in a cloud-based, high-capacity computing platform that will allow to measure ‘the pulse of urban mobility’ from a global perspective; to obtain valuable information on how traffic density evolves and how public transport is used; and to learn how individual users can move along the city in a more eco-friendly way, thus improving energy efficiency.

The project has a pan-European approach, engaging three different smart-city pilots placed in Madrid, Tampere and Genoa, where the platform and the personalized mobility services will be deployed and tested in 2016.

In view of the project’s ambitious goals, the definition of an architecture supporting the cloud platform operation and the delivery of mobility services envisaged, with a predominant role of ITS, entailed a huge effort. The main objective was to define a comprehensive architecture for the MoveUs cloud-based platform, the specifications of its core facilities and the high-level interfaces between the different platform components. The methodology
adopted to define the specifications of this platform integrated insights and approaches from different engineering fields: traffic engineering, data analytics, software architecting and cloud-based computation deployment. Each view focused or emphasized specific aspects: functionality, performance and openness, allowing third parties access to exploit the information and extend the platform. As key challenges, the demanding real-time requirements, the vast amount of data to be handled, the scalability and availability needs and finally, the compliance of security/privacy normative are worth mentioning.

The concept of ITS reference architecture was present during this work by analysing existing solutions and by adopting and adapting selected best-practices and knowledge. The advantage of using a standard or de-facto reference architecture as a basis relies on interoperability, avoidance of vendor lock-in situations and in general, on the consistency of information delivered to end users while manufacturers and designers focus on added value (design optimization) aspects. For that reason, FRAME was initially chosen as ITS Reference Architecture in the context of MoveUs.

FRAME defines a methodology which starts from a well-defined set of functions, users, datasets and ends in a set of data stores and data flows ensuring consistent links. The FRAME Browsing and Selection tools were used by the three city pilot teams and worked fine at some stages of the process. However, some divergences identified between the common needs and requirements considered by FRAME and some of the peculiarities offered in MoveUs (e.g. incentive management, energy efficiency assessment and service customization), not explicitly addressed before, forced us to slightly adapt the methodology workflow and introduce alternative tools such as Enterprise Architect to produce the Data Flow Diagrams (DFD). Excel spreadsheets were also produced to handle a complete definition of requirements and functions in the three city pilots. Finally, the project extended this basis with the introduction of a service view, a view on the mobility-domain in terms of services linked to the functions that those services perform.

Hence, the final methodology adopted for the MoveUs platform architecture design covered the following steps:

1. Analysis of key references in the domain. ITS reference architectures and R&D projects with similar challenges were studied and their commonalities and differences with MoveUs identified.
2. Analysis of MoveUs requirements and use cases (producing Sequence Diagrams and Forms).
3. MoveUs Functional Architecture definition (Data Flow Diagrams). A sample is illustrated in Figure 1.4.
   a. elicitation of user needs per city pilot (according to FRAME methodology);
   b. elicitation of terminals (actors and external systems) per city pilot (according to FRAME methodology);
   c. selection of candidate functionalities (supported by FRAME tools);
   d. decision on what can be re-used; alignment and identification of remaining gaps.
      Identification of functions, data stores, data flows and terminators.
      At this stage, in order to ensure a common functional view of the whole system between different project tasks running at the same time, the resulting functionalities were mapped into MoveUs high-level functions.
4. Definition of the MoveUs platform Service Viewpoint.
Figure 1.4 Sample of data flow diagram produced for MoveUs trip planning functionality [20].

Figure 1.5 MoveUs operational scenario [20].
5. Technical/Application architecture definition (comprising subsystems and modules).
   a. subsystems containing elements of the functional architecture (functions, data stores) and communicating with another subsystem or terminators;
   b. modules; aggregation of related functions.
6. Mapping functionalities/services vs. modules.
7. Detailed functional description for each module.
8. Physical/deployment viewpoint definition.

At the time of writing, the architecture design for the MoveUs platform has not been fully completed yet, though the final steps are being undertaken. The process has remained technologically neutral so far and will produce its final results at the beginning of 2015, paving the way for the implementation phase. The current MoveUs operational scenario (a high-level architectural view), showing the main actors and roles, architecture elements and information flows is illustrated in Figure 1.5.

References

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