USING THE FRAME ARCHITECTURE FOR PLANNING INTEGRATED INTELLIGENT TRANSPORT SYSTEMS

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Abstract

The potential complexity and size of Intelligent Transport Systems (ITS) requires that they be implemented through a system engineering approach based on the use of ITS Architectures. These enable a high level set of "views" of the proposed ITS implementation to be obtained early in its lifecycle so that many of the details and implications can be checked and, if necessary, changed at significantly less cost than if the need for a change is only found when some/all of the development work has been completed. The FRAME Architecture has been created for use as the starting point for any deployment of ITS, and a methodology for its use has been developed. This methodology is now supported by two FRAME Architecture Tools. The FRAME Architecture is currently being extended to include cooperative systems.

Keywords
ITS Architecture, System Architecture, System Engineering

1. Introduction

There are two main factors that have a profound impact on the success or otherwise to the implementation of Intelligent Transport Systems (ITS) services. The first is that the implementation of ITS services often requires the deployment of many components. These components are often provided by more that one supplier, and in some cases do not actually exist at the time of their specification. This means that some components will need to be developed, which adds a degree of uncertainty to the success of the implementation of the services. In addition, once the ITS services have been implemented the components may be owned and/or operated by different organisations, which usually need to have some level of interaction and co-operation.

The second factor that impacts on the implementation of ITS services is that the components must provide the services that the end users require in a consistent and coherent manner. Thus end users must be able to use the same services in the same way regardless of the part of the geographic area served by the ITS implementation in which they are delivered. Another aspect of this factor is that it must not be apparent to end users that the components are owned and/or operated by different organisations and/or provided by different suppliers.

In order to achieve all these aims simultaneously and successfully, it is necessary to have a consistent high level view of how all the components fits together, and how they will all be managed. In addition the design and development of the components themselves will often need expertise from a number of different domain experts. The former is the subject of System Architecture [1], the latter of Systems Engineering [2].

2. ITS Architectures

The need for Intelligent Transport System (ITS) Architectures was recognised in the early 1990's, when the number of possible applications and services that ITS could provide increased greatly. However, instead of producing unique architectures for each deployment, it was also realised that it would be much more efficient to have a Framework Architecture, from which individual ITS Architectures can be developed. The principal advantages of doing this are:

- It is quicker, and therefore cheaper, to produce a suitable ITS Architecture from a Framework Architecture.
- Each derived ITS Architecture has the same properties as the Framework Architecture from which it has been produced. This facilitates the use of similar equipment in different deployments, and thus extends their potential market.

The first Framework Architecture to be produced was the National ITS Architecture for the USA, which was first published in 1996 [3]. This was followed in 2000 by the European ITS Framework Architecture produced by the European Commission funded project KAREN [4]. Since their publication both architectures have been (and still are) under continuous review and development as the scope and content of ITS services, and the expectations of the stakeholders, have changed.

Although these two Framework Architectures have many similarities there are also a number of differences, the most prominent of which are:

- Certain services, in particular those connected with commercial freight vehicles, have very different objectives.
- The US National ITS Architecture shows the relationship between physical components, and users choose those components that they need to satisfy their requirements. However, the European ITS Framework Architecture shows the relationship between functions only, and users first choose those that they need to satisfy their requirements, and then make their own decisions as to how they will be allocated to physical components.

The reason for the first difference is obvious – some things are done quite differently on each side of the Atlantic! The reason for the second difference is that the same thing is sometimes done in different ways in different European Member States, and one way to ensure that they can all be modelled using the European ITS Framework Architecture is to permit the same functions to be put into different physical locations in different countries.

The rest of this paper describes the use of the European ITS Framework Architecture, now known as the FRAME Architecture after the projects that have maintained it since 2001.

3. Intelligent Transport System Lifecycle

Systems engineering is the activity of specifying, designing, implementing, validating, deploying and maintaining socio-technical systems [5]. The systems engineering process is often depicted using the V-model system lifecycle (see Figure 1). This model emphasises the need to ensure that the system is both built correctly, and that it satisfies the aspirations of all its stakeholders.

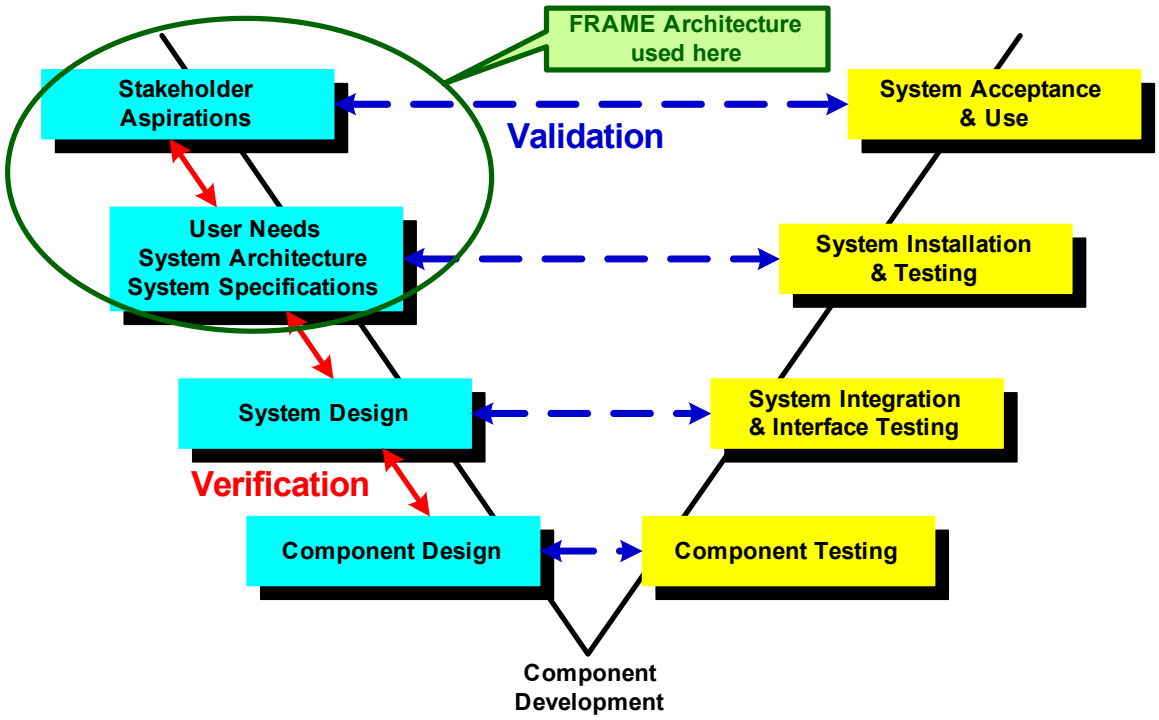

Figure 1 – V-model system lifecycle

The FRAME Architecture is used early in the lifecycle both to capture the Stakeholder Aspirations (sometimes called User Requirements), and then to produce the System Architecture, i.e. the ITS Architecture that satisfies them. The ITS Architecture is used to produce detailed system specifications that can be included in Calls for Tender for the design and development of part, or all, of the ITS that will satisfy part, or all, of the Stakeholder Aspirations.

The early part of a system lifecycle (whether used in ITS or for other forms of system implementation) is sometimes glossed over quickly so that the "more exciting and interesting" stages of design and implementation involving the use of (often new) technology can be reached as quickly as possible. The danger that exists when taking such an action is that the products in the early part of the lifecycle (Stakeholder Aspirations, User Needs, System Architecture and System Specifications) will not be complete and/or correct. Thus the resulting System Design, which will be verified against them, will also be incomplete and/or incorrect, and the system implementation may be some way up the right hand side of the V-model system lifecycle before the discrepancies begin to manifest themselves, making them much more expensive to rectify.

This increase in the cost to fix discrepancies is in fact exponential as is illustrated by Figure 2. It is sometimes called "The 10:100:1000 Rule" because the cost of correcting faults in a system increases exponentially (by about a factor of 10) during each successive stage of a lifecycle. There is some supporting evidence for this "Rule" as a result of work carried out in the US during the 1980's and 1990's by organisation such as the Software Engineering Institute at Carnegie Mellon University, in Pittsburgh.

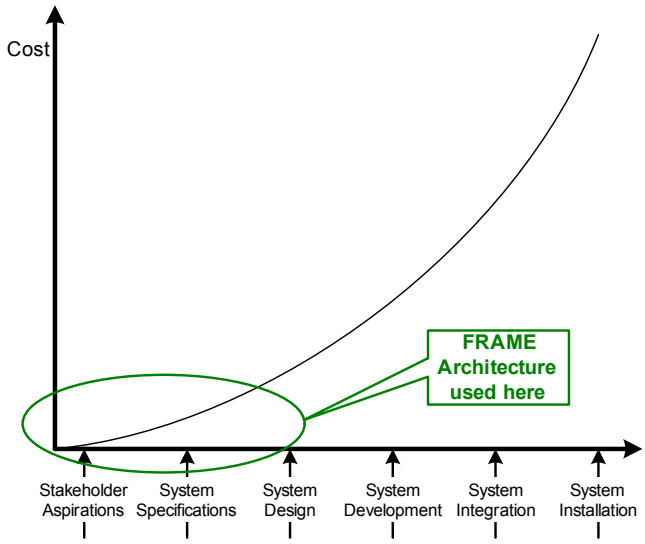

Figure 2 – The 10:100:100 rule

4. The FRAME Architecture Methodology

The authors have been using the FRAME Architecture for a number of years to create ITS Architectures for several clients. This experience has been used to formulate a systematic process that collects the Stakeholder Aspirations and then continues until the Component and Communications Specifications have been produced. This is illustrated in Figure 3.

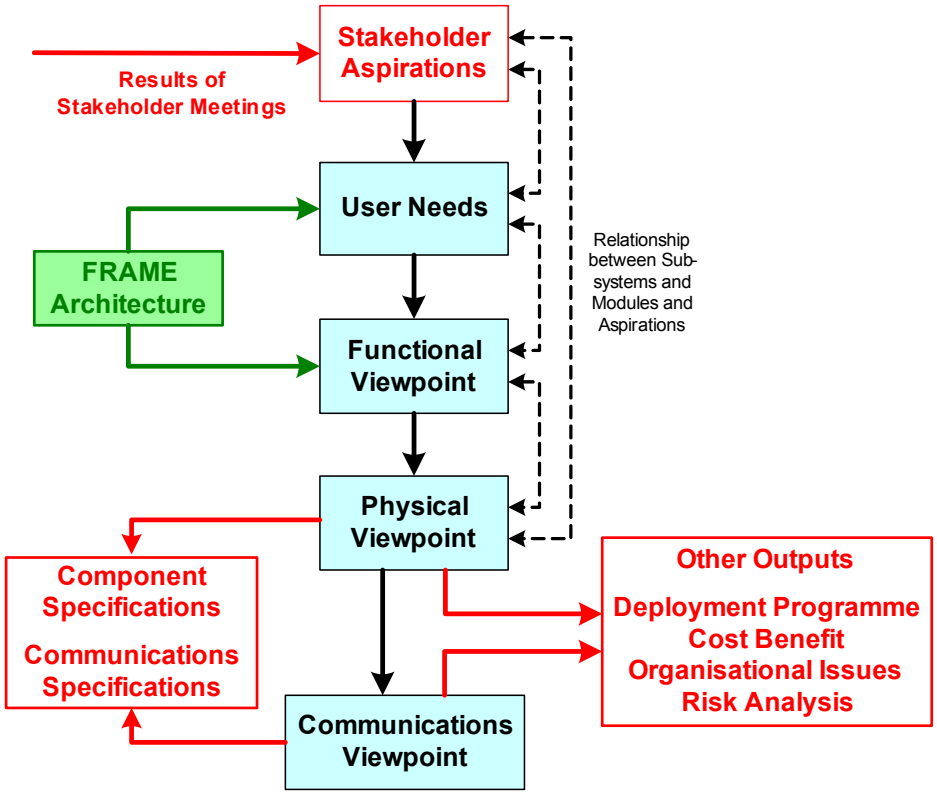

Figure 3 – The FRAME Methodology

Note that the FRAME methodology uses the term “Viewpoints” for the names of the parts that make up the FRAME and its resultant ITS Architectures. In doing this it is following the recommendations of IEEE 1471 [6]. The alternative term of “Architecture” is still used in some publications, but the authors feel that an architecture made up of viewpoints is more comprehensible than one that is made up of architectures.

It should also be noted that the use of particular technologies or supplier products is not included in the FRAME Architecture, nor do they form any part of the specifications produced by following the FRAME methodology. This is important for two reasons. Firstly the ITS Architectures created using the methodology will not become obsolete through advances in technology, or product development, and secondly it opens up the possibility for the development of new technologies to enable particular functionality to be provided.

4.1 Stakeholder Aspirations

Stakeholder Aspirations are statements that express the expectations and desires of the various stakeholders for the services that the final ITS implementation will provide. Although they should be written by the stakeholders, experience has shown that they often need help from the architecture team. There are four classes of stakeholder, as follows:

- Want ITS – this class comprises (local) authorities and road operators who need ITS services to enable their roads to be used safely and efficiently. It also includes public transport operators and freight operators where ITS can enable them to improve the efficiency with which they move people and goods.
- Use ITS – this class comprises the end users who make use of the ITS services and/or operate the equipment. It includes travellers on a multi-modal journey as well as all classes of vehicle driver; freight shippers; pubic transport mangers and specialist system operators.
- Rule ITS – this class represents those who provide regulations and standards. It includes national governments and the various Standards making bodies.
- Make ITS – the class comprises the equipment and system manufacturers, communications providers and the system integrators.

Service providers, e.g. travel information and trip planning, may be in one or more of the Want, Use and Make ITS classes.

4.2 User Needs

It is normal to find that the Stakeholder Aspirations, when completed, have been written in a variety of styles. Sometimes they are also obscure and occasionally they are inconsistent. It is therefore necessary to re-write them in a consistent manner that is suitable for the next stage in the process. The result is a set of User Needs (or User Requirements [5]) that express the Stakeholder Aspirations in a consistent and stylised manner whose meaning is clear and whose properties are testable.

The KAREN project produced a set of about 550 User Needs to cover the ITS applications and services being considered for implementation at the end of the 1990’s, and the FRAME projects have added to them since then. Thus, when using the FRAME Architecture the architecture team normally only has to write new User Needs very occasionally, most of the time they can be selected from the existing list that is published as part of the FRAME Architecture [4].

4.3 Functional Viewpoint

A Functional Viewpoint (sometimes called a Logical Viewpoint, or even a Logical Architecture by others) shows the functionality that will be required to fulfil the User Needs, and hence the Stakeholder Aspirations. When using the FRAME Architecture the Functional Viewpoint is shown as a Data Flow Diagram that contains functions, data stores and terminators, and the data that flows between them. Each of these is provided with its own description which, in the case of functions, includes statements explaining what they do, e.g. collect data from a source outside the Architecture, and then process that data to produce the output Data Flow. Since the FRAME Architecture comprises a Functional Viewpoint that satisfies all of its User Needs, the architecture team only needs to select those parts of it that correspond to the sub-set of User Needs that have been mapped to the Stakeholder Aspirations. New functions etc. are only needed where certain Stakeholder Aspirations have required new User Needs to be added.

Another important part of the Functional Viewpoint is the Context Diagram. This shows the ITS as a single item and the links needed by the functionality within it to communicate with the entities outside it. It is useful for two reasons. Firstly it enables the system boundary to be defined showing what is inside the ITS implementation and what is not. Secondly it enables definitions to be produced of the way in which the ITS functionality expects the outside entities to behave. These outside entities are called Terminators, and either obtain data for the ITS or enable outputs to be provided to end users. The same Context Diagram is also part of the Physical Viewpoint.

Concern has been expressed [various personal communications] that the Functional Viewpoint of the FRAME Architecture has been developed using a process oriented methodology that results in User Needs and Data Flow Diagrams, rather than using an Object Oriented (OO) methodology that results in Use Cases and Object Classes (in UML). Experience has shown that the use of User Needs and Data Flow Diagrams was the correct choice for the following reasons:

- User Needs are concise statements, normally one sentence long, whilst a Use Case tells “a story” in a stylised manner. Use Cases were developed so that System Specifications would contain the detail that was necessary for the system designers, but in this lifecycle these come *from* the system architecture and are not inputs *to* it (see Figure 1). Simple, one sentence, User Needs are all that is needed for this part of the lifecycle.
- At the architectural level, most ITS implementations are best described using a pipeline model of functions, which leads naturally to a Data Flow Diagram [5]. Object models can be used for the detailed design of certain components later in the lifecycle, if required.
- Clients often like to view and pass comment on their ITS Architecture, but few of them are trained to understand object models. Experience has shown that Data Flow Models are intuitive to understand, and clients do not have any difficulty interpreting them.

Thus it can be seen that there is no need for the FRAME and OO methodologies to compete. The FRAME methodology enables non-system designers to understand and make decisions about the form of the ITS implementation at an early stage. If required its results can then be used as input to the OO methodology when necessary.

It is also worth noting that the FRAME Architecture shares its use of the process orientated methodology with the US National ITS Architecture [3].

4.4 Physical Viewpoint

Once the Functional Viewpoint is complete, the architecture team allocates each function and data store to be located, either within a sub-system (see Figure 4), or within a module that is part of a sub-system. Once this has been completed the component (sub-system or module) specifications can be created from the definitions of the functions and data stores within them.

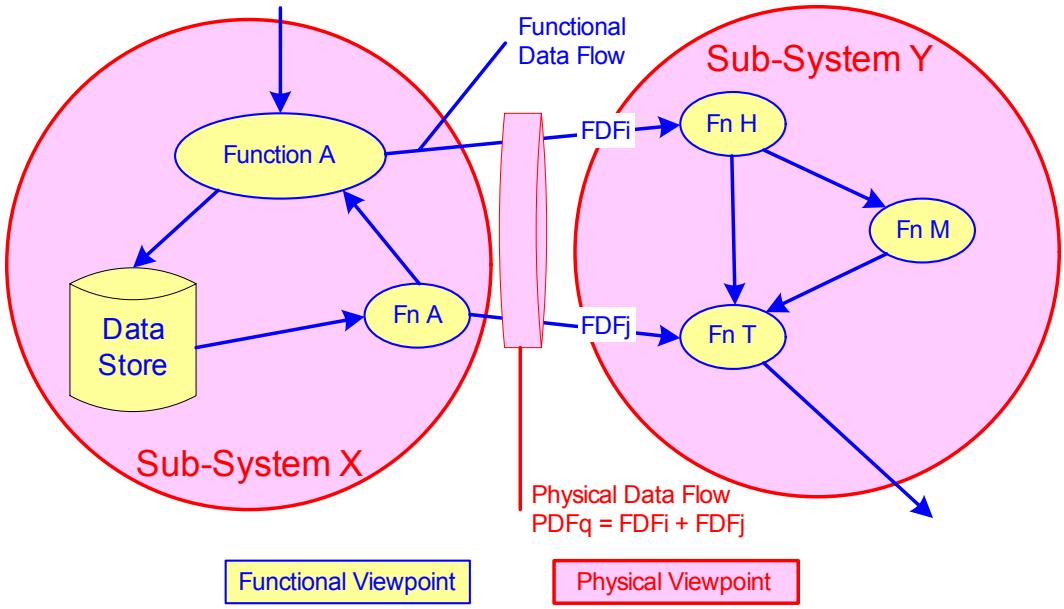

Figure 4 – Example Functional and Physical Viewpoints

The Context Diagram produced as part of the Functional Viewpoint also applies to the Physical Viewpoint. It again shows the ITS as a single item and the links needed by the functionality within it to communicate with the entities outside it.

The component (sub-system or module) specifications can be included in the tenders for the procurement of those components. As noted above, they can also provide the input to any OO methodologies that might be used for the detailed design part of the systems engineering lifecycle.

4.5 Communications Viewpoint

As can be seen from Figure 4, a consequence of allocating functions and data stores to sub-systems (and modules), is that it is immediately clear which Functional Data Flows lie within a sub-system (or module), and which Functional Data Flows pass between one sub-system and another, or between one module and another. Those that pass between sub-systems or modules make up the Physical Data Flows, and represent a communication channel between sub-systems, and/or between modules.

Since sub-systems are, by definition, located in different places (e.g. in a traffic management centre, at the road side, in a vehicle) it is possible to produce communications specifications by analysing the contents of each Physical Data Flow. This analysis may elicit that an existing Standard may be used for the communications. Alternatively the analysis can be used as the basis for defining a new Standard if the need for it can be agreed.

Analysis of the Physical Data Flows that pass between the ITS and the Terminators can also lead to “standard” interfaces for end users. These can play an important part in making sure that the services provided by the ITS implementation can be used in the same way, everywhere that it is deployed.

4.6 Traceability

An important feature of the FRAME Architecture methodology is the ability to provide traceability all the way through the process (see Figure 3). It should be noted that the services contained in most ITS Architectures cannot normally be deployed all at the same time, both for reasons of cost, as well for reasons of dependability (i.e. one service may have to be established before another can be introduced). Thus those planning the implementation of the components and communications links identified by the ITS Architecture need to take account of any financial and dependability constraints that the proposed deployment may have.

Traceability can provide a relationship between the Stakeholder Aspirations and the sub-systems and modules in the Physical Viewpoint. This enables the owners of the ITS Architecture to identify quickly those components that are needed to satisfy a given set of Aspirations, and thus meet their immediate political goals. A traceability matrix of Stakeholder Needs against sub-systems (and modules) can also show whether certain Aspirations can be satisfied “for free”, i.e. having identified the sub-systems and/or modules needed to satisfy a given set of Aspirations, it may be found that it is possible to satisfy some other Aspirations without the need for extra sub-systems and/or modules.

4.7 Additional Studies

Once an ITS Architecture has been created, it can be used as the basis for certain analyses.

- Organisational Issues – most integrated ITS implementations have components and communications links that are owned and managed by more than one organisation, who must work together in a harmonious manner. Issues such as command and control, ownership of equipment and data, and priority in the use of communications links need to be identified and agreed as early as possible before deployment takes place. The ITS Architecture shows the technical relationship between components, and this can be used as the basis for discussion and agreement about such issues.
- Deployment Programme – as discussed in Section 4.6, the deployment of all the services represented in an ITS Architecture can take a number of years to complete. In addition to providing the component and communications specifications, by showing their interrelationship the ITS Architecture will help the creation of plans that get a sensible sequence for their deployment and use.
- Cost/Benefit Analysis – the ITS Architecture is a representation of all the components, data and communications links needed to satisfy some or all of the Stakeholders’ Aspirations. A cost/benefit analysis can be undertaken using the capital and operating costs of the components and communications links, and the benefits that can be assigned to their use in order to justify, or otherwise, a particular ITS implementation.
- Risk Analysis – a risk analysis can be undertaken of one or more of the above topics to ensure their validity and to plan mitigation strategies. This can be very useful for decision makers who can be helped to understand the consequences and constraints arising from the ITS implementation.

5. The FRAME Architecture Tools

The FRAME Architecture is now supported by two tools that facilitate the work that needs to be done by the architecture team [4].

5.1 The Browsing Tool

The FRAME Architecture is a large product with many thousands of elements. In addition, the Data Flow Diagrams have had to be organised in a hierarchical manner so that they are understandable. In order to provide a unified front end to the architecture team a FRAME Browsing Tool has been created that permits all the elements of the FRAME Architecture, and their interrelationships, to be viewed interactively using a standard HTML viewer. Thus, for example, it is possible to follow the passage of data from its collection by a particular part of the functionality, through fusion and processing, to its eventual use in providing a service for the end users through outputs from different functionality.

5.2 The Selection Tool

The FRAME methodology described in Section 4 is supported by the FRAME Selection Tool (see Figure 5), which contains a data base with all the elements of the FRAME Architecture.

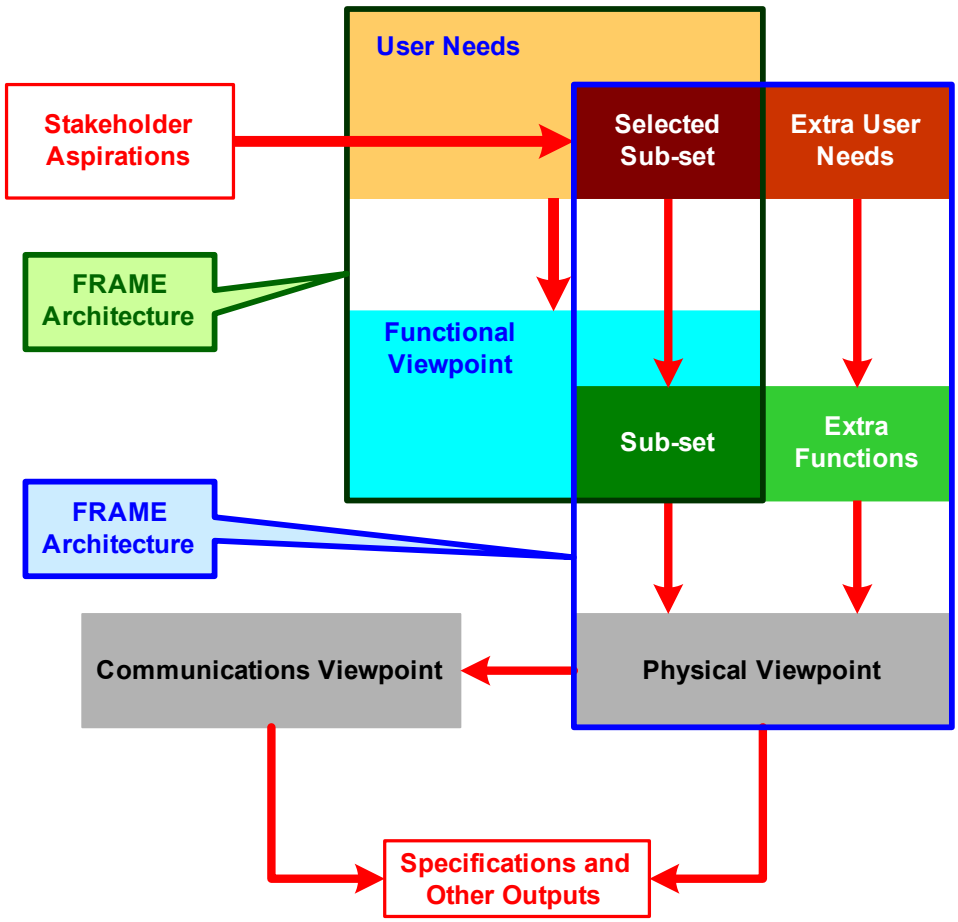

Figure 5 – Use of the FRAME Selection Tool

The Tool does not perform any selections automatically, but it does support the architecture team in its use of the methodology in the following ways.

- The team selects those User Needs that reflect the Stakeholder Aspirations.
- The tool will then guide the architecture team to those parts of the Functional Viewpoint that help to satisfy those User Needs.
- The FRAME Architecture does not claim to satisfy what is contained in every possible Stakeholder Aspiration, i.e. there may not always be a User Need to support (either totally or in part) every detail of every Aspiration. In order to provide this support it may be necessary to create and add extra User Needs and hence Functional Viewpoint elements to the Selection Tool data base.
- Since the mapping from User Needs to Functions is not an exact science, the Tool will probably report some logical inconsistencies as a result of the initial selection of User Needs and Functional Viewpoint elements (e.g. a data flow with only the function at one end selected). The architecture team can then modify the selection to include further elements, or remove some of those already selected, until there are no logical consistency errors, and they are satisfied that their selection fully represents the Functional Viewpoint needed to satisfy the Stakeholder Aspirations.
- Once a Functional Viewpoint is considered acceptable, it can be used as the basis for one or more Physical Viewpoints. The architecture team does this by allocating functions and data stores to individual sub-systems, and to modules within them if required. Modules are used to partition the functionality in sub-systems so that, for example, the functionality for traffic management can be separated from that for parking management.
- Once a Physical Viewpoint has been completed one of the reports available from the Selection Tool can be used to provide the starting point for an analysis of the Physical Data Flows. This leads to the creation of the Communications Viewpoint, which shows the characteristics of the links required between each of the sub-systems and modules, plus those with the Terminators.

Thus, although the Selection Tool does not have any intelligence to make decisions on behalf of the architecture team, it does perform much of the detailed work of recording all the decisions taken by them. Experience has shown that it is not normally necessary to produce a Data Flow Diagram of the Function Viewpoint since all the information required to produce a Physical Viewpoint is held within the data base. The Tool permits more than one Physical Viewpoint to be created from a Functional Viewpoint so that the advantages and disadvantages of different component configurations, physical locations and deployment scenarios can be explored.

6. Extensions for Cooperative Systems

The E-FRAME project is currently extending the FRAME Architecture to include the functionality that will be needed for the implementation of cooperative systems. The definition of this functionality is being based initially on the combined requirements produced by the three Cooperative System Integrated Projects, COOPERS, CVIS and SAFESPOT. The requirements produced by other Cooperative Systems projects may also be included if they are available before the E-FRAME project finishes in 2011.

In addition E-FRAME is also assisting the COMeSafety and PRE-DRIVE C2X projects who are defining a “European ITS Communications Architecture” [7] for use with cooperative systems.

The manner in which it is envisaged that the results of this work will fit together is shown in Figure 6. This figure also shows that an important result of the work being carried out by these projects is input to the work of the CEN and ETSI standards organizations.

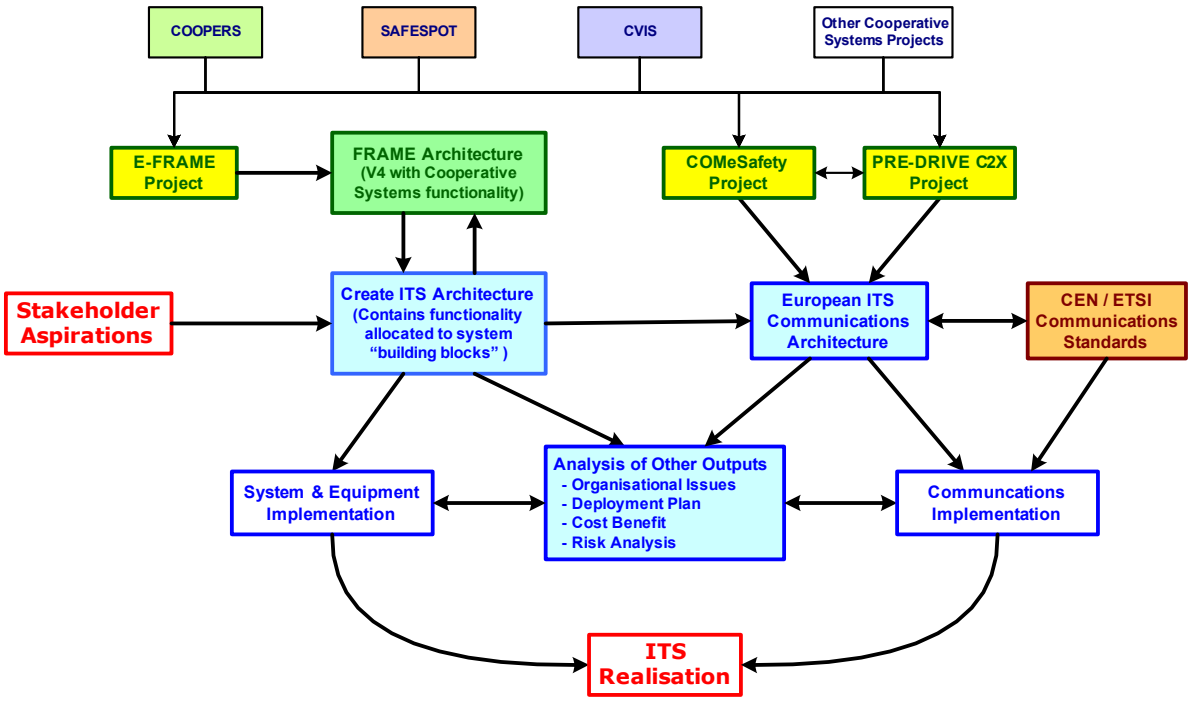

Figure 6 – ITS implementation process with inputs from the cooperative systems projects

7. Conclusions

The implementation of ITS is becoming increasing complex, and thus more difficult to achieve successfully. The FRAME Architecture methodology has been developed according to standard system engineering practices and it should be used in the early stages of the system lifecycle.

Although targeted at Europe, the FRAME Architecture can be used anywhere. This is because not only does it comprises only User Needs and a Functional Viewpoint, both of which can be extended if required, but it is also independent of any technology or existing product designs. Physical Viewpoints can be created according to the requirements of the architecture team.

The FRAME Architecture is currently being extended to include the functionality needed for cooperative systems.

8. Acknowledgments

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