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MASTER'S DEGREE THESIS

THE ROLE OF INFORMATION TECHNOLOGY IN THE OPERATION OF SLOVENE MOTORWAYS

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I, Andrej Grebenc, hereby certify to be the author of this Master's thesis that was written under the mentorship of Docent Dr. Jurij Jaklič and in compliance with the Act of Authors' and Related Rights - Para.1, Article 21. I herewith agree this thesis to be published on the website pages of the Faculty of Economics.

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GLOSSARY

Autopoiesis: Concept of systems theory meaning the capability of system self-production

DATEX (Data Exchange Network): Agreement between the European traffic centres to exchange traffic and travel information

EC: European Commission

ETC (Electronic toll collection): Motorway toll collection by means of electronic

EU: European Union

European ITS Architecture: Architecture of intelligent electronic transport systems

FHWA (United States): Federal Highway Authority

Framework Architecture: A theoretical architecture that serves as a basis for development of specific national, regional or local intelligent transport architecture

GIS: Geographical Information System

GPS: General Positioning System

GSM: Global System for Mobile Communications
IEC: International Electrical Commission

Inter-modal transport: A transport that uses different transportation modes (i.e. road, rail, air, sea)

ISO: International Standardisation Organisation

ITS (Intelligent Transport System): Electronically supported transport systems, consisting for example of traffic management, electronic toll collection, GPS based fleet management, in-vehicle navigation etc.

Life cycle: A complete life span of a system from conception to retirement

On-board unit: Electronic device used by drivers in order to exploit ITS services

Operation and Communication Centre: A centre of the Slovene police where all accidents are reported

PTN: Public Telephone Network

RDS (Road data services): radio service for report of traffic situation on the roads

Self-reference: A concept of systems theory where a system refers to itself and thus shows that its subsystems are of similar structure as a whole system

Software engineering: An engineering discipline that deals with the software development process

Systems engineering: An engineering discipline that is used to develop systems in a systematic way

TEN (Trans-European Network): Transport network of any kind that is of interest for European Union

TMC (Traffic Management System): computer based system for managing traffic situations so that traffic runs smoothly as possible

Toll: A fee charged to road users for using a road
Universal system: A concept in the systems theory representing the ultimate system that incorporates all other existing or in the future developed systems.
1 SUMMARY

Building complex systems requires special attention and methodology. Although Slovenia is a small country, any system having some sort of national coverage and being interconnected with neighbouring countries with a substantial number of subsystems and components, is a complex system.

The Slovene motorways are in the midst of construction and will be internationally connected. To a modern road infrastructure pertain modern national and international road transport services such as travel information, motorway traffic conditions, fleet management, electronic toll collection etc.

This thesis paves the way to a modern motorway intelligent transport system (ITS) that will be built in Slovenia in the near future.

Before building such a complex system, a sound and adequate methodology for a complete system life cycle has to be developed or selected. Given that several international efforts in the field of standardisation, method development and physical standardisation have already been accomplished or are underway, these have been considered for the development of a convenient methodology for building a Slovene motorway ITS system.

This thesis consists of four parts. The first part describes the services that motorway stakeholders, i.e. state, motorway operator and motorway users, need.

The second part is a theoretical one and deals with the general systems theory, the origins of which date back in the 1960's. This theory is a synthesis of various works in different science fields such as philosophy, biology, cybernetics, mathematics, engineering, economy, management, psychology and similar. Based on the work of many authors it was found that Bertalanffy’s and Luhmann's work were the most influential. Bertalanffy’s general systems theory has an adequate mathematical formulation. However, no adequate mathematical formulation of Luhmann’s improved general systems theory was found. That theory introduces two important notions: self-reference and autopoiesis (self-production). Derivation of
systems theory is information systems theory. Short formal information systems theory is presented in order to round the theoretical part.

The third part of the thesis deals with methodology and presents systems engineering as a tool for building complex systems. Some methods and available systems engineering knowledge recognised at international level have been looked at. Some standards that cover all aspects of systems engineering were found and studied. Within its 15288 standard, the ISO and IEC developed the most widely recognised general system engineering method. Next, it was found that transport industry’s specific method was developed within the ISO, IEC, United States’ FHWA and European communities/commission. A thorough analysis of a Slovene context for motorway ITS system has been done. Finally, a combination of international methods of systems life cycle (ISO/IEC), European ITS architecture with the amendment for motorway operations, and PMI project management method has been made. Since a future Slovene motorway ITS system will be developed as a consensus of all relevant stakeholders, some examples of motorway ITS system architectures are also presented, although in a fragmented form. The third part of this thesis concludes with an assessment of the strategic impact (cost/benefit) of the implementation of the motorway ITS system.

The fourth part shows the way towards the practical implementation of the Slovene motorway ITS system. First, it presents the actual situation of the Slovene motorway ITS system. Public information systems at various Slovene stakeholders are described and a need for the development of the new Slovene motorways operations strategy is justified. Elaboration of the Slovene motorway ITS system strategy, that shall align to operations strategy is considered.

The original contribution of this thesis is twofold. From the theoretical viewpoint, some initial steps in mathematical formulation of Luhmann’s general systems theory were made, especially in the development of the mathematical formulation of self-reference and autopoiesis. A concept of the universal system was also introduced. From the practical point of view, a promising methodological framework as a combination of internationally recognised systems engineering methods has been developed, thus enabling the efficient development of the Slovene motorway ITS system.
2 INTRODUCTION

On 01.05.2004, Slovenia became a member of the EU and is included in the EU structures.

Transport and transport infrastructure is one of priorities of the EU. Slovenia as an accession country already took part in preparatory work of the EU regarding so called Trans-European Networks (TEN). Efforts by the Slovene Government - Ministry of Transport were successful, the EU recognised that Slovenia lies at important European crossroads. the Slovene motorways belong to two important EU motorway corridors - corridor V. (Barcelona - Kiev) and corridor X. (Munich - Belgrade).

On the other hand, the Slovene Government recognised the importance of motorway infrastructure already in 1990’s when it decided to build a Slovene motorway system.

However, building the motorways is only one important part of the endeavour but information is another one.

More and more focus is given to traffic information in order to give information to travellers and transport companies to use the motorways and roads more efficiently. Transportation times should be predictable because more goods and persons will be transported in the future in Europe. For this purpose, more information is and will be needed. Strategic informational aspects for road transport participants and motorway management organisations have to be considered (Verdujin & Brugge, 2001, pp. 87-92).

Topics such as needs of “on board units”, communication of weather conditions, traffic congestions and maintenance works, traffic accidents and similar will have to be elaborated in the definition of informational needs of participants.

Another topic is motorway toll charging that is required by the EU for all trucks on Trans-European motorways and will be extended to every TEN-motorway user in the future years - possibly around 2010. Because of certain rules that the EU imposes on national authorities and because of possible congestion on certain motorways, motorway toll policies will have to be developed, where toll tariffs will have an influence on traffic corridors and toll income. Toll collection and toll payments are important for every national transport
infrastructure economy and is, therefore, covered in the thesis. This thesis develops some informational requirements for those kinds of decisions that will have to be met in the future (Official Journal of the European Union, C73, 2004).

A third topic is information providing services that may to some extent already exist, but new services will have to be developed, providing necessary information (Lyons et al., 2001, p.34-38). The exchange of information with neighbouring countries (Italy, Austria, Hungary and Croatia) will be needed. Some efforts for information exchange have already been undertaken (CENTRICO Experience. URL:http://www.datex.eu.org/article_profiles.html).

It should be mentioned that the in-process implementation of information technology in the transportation sector lags behind some other infrastructure sectors, so learning from their experience might be valuable. Although the information technology systems, subsystems and elements show similarities to some extend, differences also exist. Information technologies used in the transport sector are of a general type (communication technology, computers, databases, GIS (Maher, 1992), vehicle tracking, presentation technologies etc.), but the system architectures are different from those in the other infrastructure sectors such as energy and water supply for example (Grebenc & Wolf, 2000).

The goal of this thesis is to open development paths for the gradual development of a national motorway ITS system in Slovenia. It shows the possible way for the development, considering integration with neighbouring EU and non-EU countries.

The further goal of the thesis is to develop a methodology for national motorway ITS system for the benefit of all stakeholders. Fragmental examples from European ITS architectures (EC, 2000 b) are shown as well.

3 INFORMATION NEEDS

3.1. Services needed

The use of computers now extends into almost all fields and transport is no exception. Computer-based systems in transport
are called (EC, 2000) intelligent transport systems (ITS). They include a wide range of services using information and communications technologies. These systems deliver significant benefits to all groups involved in transport and facilitate improved operational efficiency, service reliability, infrastructure management, as well as better safety, reduced ambient impact, and information services for transport users.

Intelligent transport systems encompass (EC, 2000):

- computerised traffic management systems
- management of emergencies
- management of transport infrastructure assets
- traveller information services
- freight and fleet management systems
- electronic payment services
- support for public transport operations
- advanced in-vehicle technologies.

Road and/or motorway transport encompasses following interest groups:

- drivers
- transport companies
- service providers
- authorities.

All groups seek to meet their own needs and/or obligations.

3.2. Drivers’ needs for services

Drivers are users of the road infrastructure. They expect and need the following provisions:

- transport of persons and goods between different locations
- predictable time for transportation
- orientation at the accesses, junctions, exist and the road itself
- transport safety
- auxiliary infrastructure (fuel stations, rest stations, car repairs etc.)
- weather and traffic information about abnormal conditions that influence the travel time and safety
- emergency services available in the case of incidents.
3.3. Transport companies’ needs for services

Transport companies earn their revenue from the transport services they provide. They aim at the most optimal use of the road infrastructure in the most economical way. They need:

- services that enable the maximum possible road throughput for their commercial vehicles
- maximum transport safety
- services for optimal usage of their fleet (in drive dispositions)
- on-the-road repair services
- services for the efficient orientation of their drivers
- services for the monitoring of professional transportation regulations
- in-drive communication services with the drivers.

3.4. Service providers’ needs

Service providers provide services to their clients on the road. They need to have some conditions fulfilled, in order to provide the services for the benefit of their customers, such as:

- access of their services to the drivers, transportation companies and authorities
- monitoring and control of the usage of their services in order to enable service charging
- customer relation management while the customers are on the road
- assurance of quality and safety of services and works.

3.5. Authorities’ needs

Authorities define policies and take care to fulfil them in the most efficient way. The systems on and at the road will enable them to fulfil their needs such as:
- providing the data for monitoring and control of the transport policies
- policy enforcement
- enabling changes in policies.

All needs form the base for a platform of needs that have to be considered and balanced during the process of stakeholder requirements analysis and stakeholder requirements specification.

4 SYSTEMS AND SYSTEMS THEORIES

4.1 Information systems within the scope of systems

As the topic of this work is information technology, it is not possible to implement any functionality without the system. In the end, information technology is incorporated in an information system.

In consideration of a general theoretical background of an information system, it becomes apparent that this background consists of the systems theory and the information system theory. The theory that is more general is obviously the systems theory, because a system is more general than information, which is a part of the system. Further elaboration will show this more clearly.

4.2 History of the research on systems

Researchers began their work on systems in the 1930’s with major breakthroughs in the 1940’s through to the 1970’s. They started to explore many domains and developed various systems theories. Later, they looked beyond these domains. Systems have attracted the interest of many sciences such as biology (Bertalanffy, 1969), cybernetics (Ashby, 1957, Wiener, Forrester), sociology (Luhmann, 1984), philosophy (Bunge; Bahm; Laszlo, 1973), mathematics (Rapoport; Mesarović, 1975; Klir 1972), physics, engineering, economy (Boulding, 1981), and management. The result of this work was a notion of a general systems theory.
Ludwig von Bertalanffy, a biologist who published a book entitled *General Systems Theory* (Wikipedia, 2004; Bertalanffy, 1969) is considered the father of the general systems theory. On the other hand, a systems philosophy was developed, which extends the knowledge of systems well beyond the material forms of the systems. It deals with the systems ontology, cognition, epistemology, ethics and even metaphysics. This philosophy is based on natural systems i.e. physical, biological and social systems (Laszlo, 1973). Despite the fact that neither Bertalanffy nor Luhmann or Laszlo consider the engineered systems in their theories, the general systems theory and philosophy can help in the understanding of the development of the systems, in drawing parallels with natural systems and learning from them.

Based on the multidisciplinary work done, it can be said that the General Systems Theory is really a multidisciplinary theory, which is the result of multidisciplinary science. Bertalanffy developed this theory as holistic. Luhmann added some new approaches and introduced a new paradigm to this field. The theory is still developing in this direction. Therefore, a definition of system should first be established.

### 4.3 Definition of a system

There are many definitions of a system. Bertalanffy (1969, p.55 and p. 83) defines the systems as:

"A SYSTEM is a set of elements standing in interrelations."

It should be emphasised that the General System Theory does not regard systems as set-ups of a fixed structure as it is seen by control theory, but inspired from evolution theory, considers systems as self-productive set-ups. Luhmann (1984, p. 60) quotes Maturana and Varela as the inventors of the concept of *autopoiesis* i.e. self-production. This concept defines the *autopoietic* system as a system that creates not only its structural links but also its elements (Luhmann, 1997, p.65). As will be shown later, this important feature is needed when an information system for the Slovene motorways comes into existence. A Slovene motorway ITS system will evolve slowly. Given that the information system of the Slovene motorways will consist of hardware, software, organisations, users, information system developers, and the motorway management and
operation employees, it is evident that the motorway ITS system will be produced and reproduced from the system itself (autopoiesis).

4.4 General systems theory

First, a definition of general systems theory should be looked at.

The inventor of this concept defines in his famous book Béralanffy (1969, p. 32):

"GENERAL SYSTEMS THEORY (GST) is a theory that explores the formulation and derivation of principles that are valid for systems."

The General Systems Theory, further developed by Luhmann, defines the following important notions:

a) Systems and ambient

Systems in general do not perform only internally, but interact with the ambient. It is therefore necessary to include the ambient of the systems in the observation and analysis of systems (Luhmann, 1984, p. 35).

No literature that considers or models the UNIVERSAL SYSTEM could be found. Therefore, the universal system is defined as a set of all systems, the ultimate system. This implies that systems not existing now, but created in the future, will be surely embedded in the UNIVERSAL SYSTEM at some level.

b) Self-reference of the systems

The systems are complex entities. They consist of components. Theory of self-reference systems claims that internal division of systems occurs within the same systems framework. The consequence is that systems are decomposed into subsystems or partial systems using the same systems theory. In new systems theory this is called self-referencing (Luhmann, 1984, p.24-27, 57-61).
c) Elements of a system

Since systems are complex entities by definition, they are composed of lower level elements sometimes called components (Bertalanffy, 1969, p. 19, 38; Luhmann, 1984, p. 41).

d) Relations

Derived from the definition of the system, which components are part of, relations exist (Luhmann, 1984, p. 41). Two kinds of relations can be recognised:

- external or exogenous and
- internal or endogenous.

External relations are relations between the system and the ambient, internal relations are relations between the components of the system. Relations also build a structure of the system (Luhmann, 1984, p. 73). Classic general systems theory speaks about systems input/output, but Luhmann speaks more generally about relations.

e) Production

The concept of production has a different, broader meaning than that in industry. It is a generic notion of any kind of creation including reproduction, self-production or autopoiesis (Luhmann, 1984, p. 40). It is obvious that some elements of the system will die out during its lifetime, so a disappearance of the elements during the lifetime of the system has been. Disappearance is termed as a negative autopoiesis. Production is defined as one of the processes.

f) Conditionality

Relations influence each other by constraints, control or goal. In order to achieve some results systems will be influenced by conditions (Ashby, 1968, p. 108-118; Luhmann, 1984, p. 44). The feedback that is necessary for control of the systems in a classic systems theory is also a part of conditionality.

g) Characteristics and attributes

Systems have some characteristics. One characteristic that was intensively explored is the complexity of the systems. Some authors (Luhmann, 1984, p. 45) do not speak about the broader
notion of characteristics, but speak only of complexity. Characteristics of the systems are presented by attributes.

h) Processes

Systems are not static entities. They process material, energy and information and produce results (Luhmann, 1984, p. 67). Processes use means. Bertalanffy does not define this concept.

i) Time

Time is an important concept in systems theory. Any change in the system or the ambient happens in time. Systems dynamic happens in time (Luhmann, 1984, p 70-71).

j) Means (resources)

Means are one of the inevitable items for the operation and production of systems. Means such as material, energy and people ensure this. This is seen as true despite the fact that Bertalanffy (1969) and Luhmann (1984) do not define means or resources as an essential part of the system. On the other hand, Luhmann claims that information can be considered as a resource. Information is an essential part of relations and originates from a difference of two data entities (Luhmann 1984, p. 68-69).

Luhmann distinguishes between the classic systems theories as defined by Bertalanffy, Wiener, Forrester and others and a new systems theory based on paradigms in social science. The classical systems theory is based on control systems metaphor and deals with flows, states, inputs/outputs, feedback and transfers (Bertalanffy, 1969, p. 42-44,161-163; Luhmann 1997, p. 104-105). The classical theory does not include the autopoiesis and self-referencing of the systems.

4.5 Mathematical formulation of the systems theory

4.5.1 Mathematical formulation of the classic systems theory

The question of an exact and consistent representation of the systems theory calls for a mathematical (i.e. compact and formal) representation.
A mathematical formulation of the classic systems theory is presented by Bertalanffy (1969, p. 56-75) in a rather narrow engineering manner by partial differential equations. Mesarović and Takahara (1975) represented it by the set theory and developed a good mathematical formulation, based on the classic control systems theory. The approach by wymore (1967, p. 30) and Resconi & Wymore (1997, p. 202) is to develop mathematically a top-down general systems approach, based on set theory for the classic systems theory.

Waymore defines the system as a set

\[ Z = \{S, P, F, M, T, \sigma\} \quad (1) \]

where

- \( S \) is a non empty set of states of the system
- \( P \) is a non empty set of input states of the system
- \( F \) is a set of input functions
- \( M \) is a set of transition functions defined on \( S \) with values in \( T \) is a time scale of the system
- \( \sigma \) is a function defined on \( F \times T \) with values in \( M \)

4.5.2 Mathematical formulation of Luhmann's systems theory

The mathematical formulation of the classic systems theory is based on Bertalanffy's systems theory. Luhmann developed a new systems theory that includes self-referencing and autopoiesis (self-production). A new, mathematical model is needed for Luhmann's systems theory. A small contribution towards the mathematical formulation of the Luhmann's system theory can be made.

Based on the concepts of Luhmann's systems theory from the above paragraph, the definition of the General Systems Theory is as:

\[ S_b = \{E_b, A_b, R_b, P_b, C_b, M_b, t\} \quad (2) \]

as a basic system that is represented by an initial set of elements, ambient, conditionalities, relations, means, processes and time, where
\( S_b = \text{basic system with simple structure} \)
\( \quad (\text{composed of elements}) \)
\( E_b = \text{basic set of elements of the system. Element is the smallest unit that has no further structure.} \)
\( A_b = \text{basic set representing ambient of the system} \)
\( R_b = \text{basic set of relations within the system and with the ambient} \)
\( P_b = \text{basic set of processes the system performs. Processes of self-production (autopoiesis) are part of this set.} \)
\( C_b = \text{basic set of conditionalities of the system} \)
\( M_b = \text{basic set of means the system uses or needs from inside of the system or the ambient} \)
\( t = \text{time} \)

The general development (this includes autopoiesis) of the initial system \( S_0 \) into a new system \( S_1 \) should be considered. This development happens through the process. Means are used (consumed) from the system \( S_0 \). First they are used from its internal structure (i.e. from elements at this level of the system), then from the ambient \( A_0 \). To simplify this development it can be established that the change happens in such a way that a new subsystem is created. It is evident that this can always be achieved. The simplest creative change is the creation of a new element in the initial system. This process can be accomplished through the following steps:

a) the creation of two subsystems: the first subsystem will be created, so that the old system will become a new subsystem and another subsystem will be created with only one element;

b) the transfer of the second subsystem (having only one element) into the first subsystem with the deletion of the second subsystem;

c) the transfer of the remaining subsystem into the new system.

The mathematical expression of this process can be described as follows:

\[
P_{01}: S_0 = \{E_b, A_b, R_b, P_b, C_b, M_b, t\} \rightarrow S_{01} = \{E_{01} = S_b, A_{01}, R_{01}, P_{01}, C_{01}, M_{01}, t\} \cup S_{02} = \{E_{02}, A_{02}, R_{02}, P_{02}, C_{02}, M_{02}, t\}
\]

(3)

\[
P_{02}: S_{02} = \{E_{01} = S_b, A_{01}, R_{01}, P_{01}, C_{01}, M_{01}, t\} \cup S_{02} = \{E_{02}, A_{02}, R_{02}, P_{02}, C_{02}, M_{02}, t\} \rightarrow S_{03} = \{S_b \cup E_{02}, A_{03}, R_{03}, P_{03}, C_{03}, M_{03}, t\}
\]

(4)
\[ P_0:S_0 = \{ S_0 \cup E_{02}, A_0, R_0, P_0, C_0, M_0, t \} \rightarrow S_1 = \{ S_0, A_1, R_1, P_1, C_1, M_1, t \} \]
\[ \& \quad S_0 = \{ E_{02}, A_{02}, R_{02}, P_{02}, C_{02}, M_{02}, t \} \rightarrow -\exists \]

where \(-\exists\) represents non existence and where
\[ S_0 = S_b \cup E_{02}. \]

It was demonstrated that the process
\[ S_b = \{ E_b, A_b, R_b, P_b, C_b, M_b, t \} \rightarrow S_1 = \{ S_0, A_1, R_1, P_1, C_1, M_1, t \} \]
led to the self-referenced system. With induction, it can be generalised:
\[ S_{i+2} = \{ S_i \subseteq E_{i+2}, A_{i+2}, R_{i+2}, P_{i+2}, C_{i+2}, M_{i+2}, t \} \]

Consideration can now be given to the limit of the self-referencing system. The formula shows that each next system includes all internally created subsystems. The ultimate system is one system that includes all inward systems. This system is limited by the existence of an ultimate ambient. Namely, if an ambient does not exist, the system does not exist either. As previously defined, the outmost system that has an ambient is the UNIVERSAL SYSTEM. If indices are not given to the expression of the system, the UNIVERSAL SYSTEM gets the form:
\[ S = \{ S_i \subseteq E, A, R, P, C, M, t \} \]

while
\[ S_b = \{ E_b, A_b, R_b, P_b, C_b, M_b, t \} \]

is the formula of the smallest i.e. the basic system. Notations of the universal system are as follows:

- \( S = \) outermost systems
- \( S_i = \) set of all subsystems
- \( E = \) set of the elements of the system
- \( A = \) set representing the ambient of the system
- \( R = \) set of relations within the system and with the ambient
- \( P = \) set of processes the system performs. The process of self-production (autopoiesis) is a part of this set.
- \( C = \) set of the conditionalities of the system
M = set of the means the system uses or needs from within the system or the ambient

\( t = \text{time} \)

The definition of the set \( S \) is recursive. This assures the self-reference defined by Luhmann's systems theory. The outermost system is defined as the UNIVERSAL SYSTEM. All other systems are, or will be, embedded in the universal system in the future.

As shown, this mathematical formulation corresponds to the specifics of Luhmann's systems theory. This formulation represents self-referencing, self-production (and, as added in this thesis the deletion), ambient, elements and relations (that imply structures), conditionalities (that include rules of governance and contingencies), processes and means (called resources).

Next, the interrelations in the system and between the system and the ambient can be analysed and expressed in mathematical formulas:

a) changes in the elements of the universal system and the ambient

The elements of the universal system and its ambient constitute the UNIVERSAL SET. There is no system and ambient outside the universal system.

\[ E \cup A = U, \quad U \text{ is the set of universe} \quad (11) \]

a1) Changes of single elements in the set \( E_i \)

Elements in the system can be:

- created

\[ E_{i+1} = E_i \cup e_{n+1} \text{ where } e_{n+1} \text{ denotes a new element} \quad (12) \]

- or deleted

\[ E_{i+1} = E_i \setminus e_i \text{ where } e_i \text{ denotes a deleted element.} \quad (13) \]

a2) Cumulative changes in the set \( E_i \)

The set \( E_i \) could have the following changes:
- no creation of new elements or creation of new components is equal to the deletion of old components (or new subsystems)

\[ N(E_{t+1}) = N(E_t) \]  \hspace{1cm} (14)

where \( N \) is the number of elements;

- the expansion of the system i.e. the creation of new components is larger than the deletion of old components.

\[ N(E_{t+1}) > N(E_t) \]  \hspace{1cm} (15)

- contraction of the system i.e. creation of new components is smaller than the deletion of old components

\[ N(E_{t+1}) < N(E_t) \]  \hspace{1cm} (16)

b) Changes in the ambient

Process in the system may or may not cause changes in the ambient. It can be defined that:

- the process that causes no change in the ambient. It is a process with internal influence. The mathematical formulation is:

\[ p_i: S_i = \{E_i, A_i, R_i, P_i, C_i, M_i, t\} \rightarrow S_{i+1} = \{E_{i+1}, A_{i+1}, R_{i+1}, P_{i+1}, C_{i+1}, M_{i+1}, t\} \]

& \( A_{i+1} = A_i \hspace{0.5cm} \ldots \hspace{0.5cm} \) process with internal influence \hspace{1cm} (17)

This implies the following statements:

- no elements in the ambient are changed
- no conditionalities in the ambient are changed
- no relations in the ambient are changed
- no means in the ambient are changed
- no processes in the ambient are changed
- the process that causes single change or combination of changes in the ambient. It is a process with external influence. Mathematical formulation is:

\[ p_i: S_i = \{E_i, A_i, R_i, P_i, C_i, M_i, t\} \rightarrow S_{i+1} = \{E_{i+1}, A_{i+1}, R_{i+1}, P_{i+1}, C_{i+1}, M_{i+1}, t\} \]

& \( A_{i+1} = A_i \hspace{0.5cm} \ldots \hspace{0.5cm} \) process with external influence \hspace{1cm} (18)

This implies the following statements or their combinations:
- elements are changed in the ambient
- conditionalities are changed in the ambient
- relations in the ambient are changed
- means in the ambient are changed
- processes in the ambient are changed

c) Changes in the relations

Relation is a way in which two or more items are connected or associated. Two types of relations can be distinguished:

- internal to the system and
- external between the system and the ambient.

Relations exist also without the process, but they are established and changed by a process.

Mathematical expression defines a relation as:

Let X and Y be two sets. Let these two sets be associated, denoting

- \( R(X,Y) \) where \( X,Y \in E \) or \( X,Y \in A \).  

This is a general relation between the system and the ambient. This is a mutual open relation.

If

- \( R(X,Y) \) is defined, where \( X,Y \in E \),

then there is a closed relation within the system;

and if

- \( R(X,Y) \) is defined, where \( X,Y \in A \),

then there is closed relation within the ambient.

Systems with open relations are called open systems and those with closed relations are called closed systems.

Changes of the relations are creation and deletion.
d) Processes as the agents of changes

Let the process as an agent of change in the system or in its ambient be defined as:

\[ p_i: S_i = \{ E_i, A_i, R_i, P_i, C_i, M_i, t \} \rightarrow S_{i+1} = \{ E_{i+1}, A_{i+1}, R_{i+1}, P_{i+1}, C_{i+1}, M_{i+1}, t \} \]  \hspace{1cm} (22)

A process can have different impact on the systems sets.

e) Changes in conditionalities

Relations between the system and the ambient can imply changes in the system's conditionalities. The system sets new conditionalities if the ambient or the system changes. The change of conditionalities is achieved by the process. The process may or may not cause changes. The mathematical expression can be written as:

\[ p_i: S_i = \{ E_i, A_i, C_i, R_i, M_i, P_i, t \} \rightarrow S_{i+1} = \{ E_{i+1}, A_{i+1}, C_{i+1}, R_i, M_i, P_i, t \} \]  \hspace{1cm} (23)

Where

\( C_i = C_{i+1} \) states that the process does not change the conditionalities and

\( C_i \neq C_{i+1} \) states that the process does change the conditionalities

There are two categories of conditionalities:

- constraints that suppress the influence and
- enhancements that support the influence.

Both can be used in the governance of the system.

f) Changes of the means

Except in the case of no change (no creation and no deletion), means are consumed. This can be expressed as:

- no means consumed: \( M_{i+1} = M_i \)
- means consumed: \( M_{i+1} < M_i \)  \hspace{1cm} (24)

In total, the quantity of the means of the next instance of the universal system can only be equal to or less than the quantity of the means in the previous instance. In the process of the creation of new means, some other means will be consumed. The
same is true if the process requires only a change in the form of means. In general:

- the form of means can change within the system
- means can be acquired from the ambient (also from other systems that exist in the ambient)

The balance of means within one system holds. The quantity of means before and after the process is equal

\[ Q(M_{i+1}) = Q(M_i) \] (26)

where \( Q \) denotes the quantity.

This new mathematical formulation is only the first step. The mathematical relations, norms, and other mathematical apparatus will need to be developed. The theoretical framework of the systems developed above will assist in the understanding of what systems are, what they consist of and what are their characteristics and behaviour in general. It will support decisions in the development of an information system for Slovene motorways. Some formal methods will be needed to connect the theoretical framework with the practical development of the information system. Methods that will bring about an information system for Slovene motorways can now be considered.

### 4.6 Information systems theory — a definition of the information system

Information systems are particular instances of general systems. They have their own structure and ambient. Theories of information systems have been developed (Alter 2000, 2001) and the formalisation of the theory of information systems has recently appeared (Wand and Weber, 1990; Mora et. al. 2003). The development of the formal theory of information systems relies on the formal methods of the general systems theory (Mesarović and Takahara, 1975).

Similarly, to the introduction of the formalisation of the general systems theory, the formal information system theory will be briefly presented. Mora et.al. (2003, p. 21-25) formally define the information systems as:
An Information Systems IS is a general system denominated as SG(IS), which fulfills the following conditions:

a) it is part of a business process system SII(BP) and corresponds to the Information Subsystem ISS(BP) of it

b) it has at least four subsystems of general type
   b1) SG(Technology)
   b2) SG(Procedures)
   b3) SG(Information Workers) and
   b4) SG(Information Resources)
       denominated as SG(T), SG(P), and SG(IW) and SG(IR)

c) it has at least the following set relation: procedures, applications, user-actions, information, support, outputs, inputs, data, accesses and information delivering.

It seems that the work of Mora et. al. (2003) goes in the same direction as the development of formal general systems theory in this thesis. Further work beyond the scope of this thesis is needed to analyze the similarities and differences of both formal theory approaches.

4.7 Conclusion of the formal theories

In this way, the conclusion of the formal theoretical part of the general systems theory and the formal part of the information systems theory could be reached. Thus it has been shown that the formal theoretical approaches are on the way, but they are based on different verbally defined theories (Bertalanffy, 1969; Luhmann, 1984,1997; Sachs, 1976).

5 SYSTEMS ENGINEERING

5.1 Definition of the systems engineering

Systems engineering is a methodology that facilitates the process of creating a system. There is no existing information system for Slovene motorways, and one will need to be set up in the future. The international community, which is constantly building such systems, has carried out excellent work through
its standardisation bodies in developing a methodology which can be applied in practice.

Bertalanffy (1969, p.91, 104-105) regards systems engineering as an important tool for scientific planning, design, evaluation and construction of human-machine systems. He sees systems engineering as a tool that enables the creation of systems by humans. His definition derives from the research perspective. Nevertheless, this field has developed since the time he wrote his book.

A modern, broadly accepted definition of systems engineering can now be looked at. There are many such definitions, but the one by the IEEE, a reputable standardisation organisation from the United States, is given here:

"Systems engineering is "an interdisciplinary, collaborative approach to derive, evolve, and verify a life cycle balanced systems solution which satisfies customer expectations and meets public acceptability." (IEEE 1220, 1994)"

5.2 Overview of the standardisation efforts in systems engineering

Research shows that extensive work on systems engineering is being carried out at the ISO, IEC and IEEE. Software is a special, sophisticated and important technology forming part of the information system. This too will be considered in this work.

International standards for systems engineering methodologies are not developed within one organisation, however, efforts towards harmonisation are being made. Therefore, it is not sufficient to refer to only one organisation and method, but it is necessary to use a combination of methods and standards.

5.3 Methodology for building a Slovene motorway ITS system

An information system for Slovene motorways is a technical system that should be built to assure the smooth operation of
motorways, traffic and quality travelling. To build such a system appropriate methods should be used.

The discipline dealing with system’s construction and operation is called systems engineering.

Now, there are many approaches to obtaining a systems engineering methodology. The following ways have been identified:

a) to develop its own systems engineering methodology, specific for systems engineering of the motorway ITS system;
b) to look for some well known methodology developed at university or industry and adapt it to the Slovene motorway ITS system;
c) to look for industry, national and international standards or standardised methodologies of systems engineering appropriate for information systems;
d) a combination of the approaches b) and c).

5.3.1 Analysis of approaches based on criteria

Ad a) Developing systems engineering methodology suitable for a Slovene motorway ITS system would be justifiable if the system was so unique that no other method could be used. This would be a costly endeavour for a single project. However, given that the project is not unique and the development of a new methodology would be too costly, it is suggested that this approach is dropped.

Ad b) To draw on some methodology developed by a university or an industry might be viable, especially for specific approaches that such a methodology could have been developed for traffic and/or transportation systems. Systems architecture methodologies exist in the US, the European Union and some European countries (Spenze, 2004). Therefore, it makes sense to explore their adequacy for the Slovene motorway ITS system.

Ad c) To refer to industry or international standards is another approach. There are quite a few standardisation organisations.

Here is a brief analysis of standardisation organisations:
The Slovene SIST (Slovenski institut za standardizacijo) has no systems engineering methodology (Katalog SIST, 2003).

The CEN and CENELEC are two of the European standardisation organisations. They have no standards for systems engineering.

The ISO and IEC as international standardisation organisations and the US standardisation organisations IEEE, EIA, ASME and Military standards present a good base for the selection of appropriate standards. However, there are many standards by these organisations that work on similar items. In order to select the right set of standards, a compatibility of standards and a future development thereof have to be taken into account.

Sheard and Lake (1998) and Doran (2000) analysed the international and the US systems engineering standards and found that some organisations stopped or will stop and merge its activities. The most promising for the future are ISO and IEEE. ISO/IEC 15288 - System Life Cycle Processes standard has the broadest scope of systems engineering, while IEEE 1220 - Application and Management of Systems Engineering Process covers the systems engineering aspect in the greatest depth (see Figure 1, page 24).

Special values of the ISO/IEC 15288 standard are life cycle processes that consist of:

a) Concept process
b) Development process
c) Production process
d) Operations process
e) Support process
f) Decommissioning or disposal process.

In this way, the whole life of a system is methodologically covered.

IEEE also has a set of software engineering standards that are especially important for the software. In general ISO 9001, ISO 9003 (for software) and ISO 14000 standards may be applicable for general quality and natural environment management, respectively.
Ad d) Traffic/transportation systems engineering methods, suitable or developed specifically for information systems support the approach from more general to specific methods. The review of the literature and sources brought no evidence of world standards or methods on traffic/transportation of general acceptance. However, efforts have been made in the US (National Traffic Architecture), the EU, Australia, Canada, Japan and some other countries. Their ITS architectures are generic methods that allow for a development of special national traffic management architectures in every country. Indeed, some nations have developed or are developing their own national architecture (Spenze, 2004, p. 7-10).
5.3.2 Criteria for a method selection

To decide which method to use, certain criteria should be developed. These will help in comparing and distinguishing between various methods. The following criteria in order of priority are suggested:

a) general world systems engineering standards
b) EU systems engineering standards
c) world information technology standards
d) EU information technology standards
e) more detailed world traffic and/or transport standards that apply to information technology
f) more detailed EU traffic and/or transport standards that apply to information technology
g) other traffic/transportation methods of international validity with special emphasis on the EU.

5.3.3 Selection of adequate methods

After reviewing the traffic and the transport industry standards of the EU and taking into account that Slovenia is within the EU legal system, and that the most advanced general systems engineering methodologies are in the ISO, IEC, IEEE, EIA and US Military standards, the combination of the approaches b) and c) is the best. With such a combination the best results can be achieved.

The project to design, develop, build and operate a Slovene motorway ITS system is a large one and the methodology should ensure that there are no flaws, at least from the methodological viewpoint.

Before presenting the content related methods, a project management method is needed. Since the systems engineering standards define a well-known PMI project management method (PMI, 2000), this method would be used in the development and deployment in the Slovene ITS systems. This method will not be considered in depth here. Table 1 on page 26 gives an overview of the topics dealt with by the PMI project management method.
Table 1: Overview of the systems project management

<table>
<thead>
<tr>
<th>Area of Knowledge</th>
<th>Integration</th>
<th>Scope</th>
<th>Time</th>
<th>Cost</th>
<th>Quality</th>
<th>Human Resources</th>
<th>Communication</th>
<th>Risk</th>
<th>Procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initiating</strong></td>
<td>Initiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Planning</strong></td>
<td>Project plan development</td>
<td>Scope planning</td>
<td>Activity definition</td>
<td>Resource planning</td>
<td>Quality planning</td>
<td>Organisational planning</td>
<td>Communication planning</td>
<td>Risk identification</td>
<td>Procurement planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scope definition</td>
<td>Activity sequencing</td>
<td>Cost estimation</td>
<td>Staff acquisition</td>
<td></td>
<td></td>
<td>Risk quantification</td>
<td>Solicitation planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activity duration estimation</td>
<td>Cost budgeting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Risk response development</td>
<td></td>
</tr>
<tr>
<td><strong>Executing</strong></td>
<td>Project plan execution</td>
<td>Scope verification</td>
<td>Quality assurance</td>
<td>Team development</td>
<td>Information distribution</td>
<td></td>
<td>Solicitation</td>
<td>Source selection</td>
<td>Contract administration</td>
</tr>
<tr>
<td><strong>Controlling</strong></td>
<td>Overall change control</td>
<td>Scope change control</td>
<td>Schedule control</td>
<td>Cost control</td>
<td>Quality control</td>
<td>Performance reporting</td>
<td>Risk response control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Closing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Administrative closure</td>
<td></td>
<td>Contract closure</td>
<td></td>
</tr>
</tbody>
</table>

Source: PMI, 2000
5.4 Presentation of the ISO/IEC 15288 framework standard for systems engineering

After deciding that a combination of standards will be used to set up a national traffic information system, the most general standard, the ISO/IEC 15288 systems engineering - System Life Cycle Processes, was selected. This standard defines a set of life cycles needed for systems engineering.

The ISO/IEC 15288 standard says: “Every system has a life cycle. The life cycle of a system begins with a conceptualisation of a need for the system, progresses through its realisation, utilisation and evolution, and ends in its retirement.” (ISO/IEC 15288 standard, 2000, p. 10).

This standard defines life cycles as the time-based category of systems engineering. The cycle consists of the following six stages:

- Concept stage
- Development stage
- Production stage
- Utilisation stage
- Support stage
- Retirement stage.

The description of the life cycle stages and tasks is shown in Table 2 below.

Table 2: Life cycle stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td>Analyse wants, identify concepts and develop solutions</td>
</tr>
<tr>
<td>Development</td>
<td>Engineer a product that is a producible item</td>
</tr>
<tr>
<td>Production</td>
<td>Manufacture the items</td>
</tr>
<tr>
<td>Utilisation</td>
<td>Operate and use the items</td>
</tr>
<tr>
<td>Support</td>
<td>Maintain and support the items</td>
</tr>
<tr>
<td>Retirement</td>
<td>Retire, dispose and archive the items</td>
</tr>
</tbody>
</table>

Source: ISO/IEC 15288 standard, 2000
No single life cycle is sufficient for systems engineering. ISO/IEC 15288 standard defines four groups of life cycles:

- Enterprise processes
- Acquisition processes
- Project processes and
- Technical processes.

This shows that ISO/IEC 15288 is a framework standard. It also allows tailoring of the processes to the systems engineering requirements. This means that this standard defines all possible processes, though some might be omitted if the systems engineering does not require them. Figure 2, page 29, visualises an overview of the groups of processes.

At the core of these processes are technical processes. They define general steps of development. In order to control the development of systems engineering, project processes are needed. Systems are normally embedded in some ambient i.e. organisation/enterprise that has to assure resources for the systems engineering. Therefore, enterprise processes are required. Usually, enterprises do not perform all processes by themselves but secure resources from outside. That is why agreement (contract) processes are needed. However, as already said, the core processes are technical processes.

Technical processes are further divided into:

a) Stakeholder requirements definition process
b) Requirements analysis process
c) Architectural design process
d) Implementation process
e) Integration processes
f) Verification process
g) Transition process
h) Validation process
i) Operation and maintenance process
j) Disposal processes.

In the development of this motorway, ITS system engineering method the emphasis will be only on the core group i.e. group of technical processes. This does not mean that the other groups of processes are not needed. They will be developed in the scope of the motorway ITS system project. Now, the standard through the life cycle stages can be
Figure 2: Processes of ISO/IEC 15288 standard

Source: ISO/IEC 15288 standard, 2000

followed and groups of technical processes matched with them. Similar matching will have to be accomplished for the other groups of processes during the motorway ITS system project. ISO/IEC 15288 thus provides a “shell” that has to be filled in.

5.5 Methodology based on the ISO/IEC 15288 standard for systems engineering

Here are the steps that should be accomplished within the ISO/IEC framework standard.
5.5.1 Life cycle stage 1: Concept stage

In the concept stage of the systems engineering, requirements are collected from stakeholders, concepts are identified and solutions developed. One or more of the following items will be considered for elaboration in the concept stage: concept exploration, the analysis of needs, the analysis of alternatives, stakeholder requirements, concepts of operations, feasibility assessment, preliminary system requirements, concept plans and similar.

Mental and paperwork is done in this stage of the systems engineering.

5.5.1.1 Stakeholder requirements definition

The stakeholder requirements identify the parties involved with the system throughout its life cycle and express their needs, desires and expectations; together with the constraints imposed by these and the operational ambient. This involves capturing, clearly articulating and managing the requirements of every stakeholder. The Stakeholder Requirements are the reference against which operational system services are validated in order to confirm that the system fulfils needs.

Stakeholder requirements are derivative of the requirements analysis.

5.5.2 Life cycle stage 2: Development stage

5.5.2.1 Requirements analysis process

The results of the Requirements analysis process are system requirements prepared in such a way that systems design could be done. System requirement specification, because of this process shows, what the system is required to do in order to satisfy stakeholder requirements.

5.5.2.2 Architectural design process

The result of the architectural design process is a document that specifies the principal components of the system and
the interrelations i.e. interface of the components. A distinction between architecture and configuration will be clearly understood. Architecture shows typical components and typical interfaces among them. The hierarchy of the components is clearly presented. The possible system extensions are defined within the architecture.

Configuration defines how many components are needed at the specific scope of the project. The number of components may increase during the systems extension, but they are always positioned at a certain level within the architecture. Further, the human-system interfaces are defined.

Systems are divided into subsystems and partial systems. They are part of the architecture.

Architecture design specification, because of the process, will satisfy the system requirements from the previous process.

5.5.3 Life cycle stage 3: Production stage

5.5.3.1 Implementation process

The implementation process assures that the components of a system are designed, made, tested and delivered. If the standard components are available, a component design might not be needed. Hardware, software and operator's manuals for the components are provided.

5.5.3.2 Integration process

After the components have been provided, their integration into the working system is needed. A clear integration plan has to be developed in this process. Each component or subsystem will be tested for its functionality and specified characteristics before being integrated into the system. Reports on corrective actions will be produced if integration problems emerge.

5.5.3.3 Verification process

Verification is a demonstration of compliance of a system's behaviour and characteristics with the specified design requirements. The results of this process are the verification plan and non-conformance reports. Verification
demonstrates through assessment of the components that the system fulfils the specified design.

5.5.3.4 Transition process

The transition process assures the installation of the verified system in its operational locations according to an agreed schedule. Operating system, support system, operator-training system and user-training system are all put into the operational readiness. Training of personnel is a part of the transition process. A system ready for operation and a discrepancy report are the results of this process.

5.5.3.5 Validation process

The validation process produces evidence that the services provided by the system comply with stakeholder requirements. Validation demonstrates, through the assessment of the system services presented to the stakeholders, that the system fits the purpose. The validation plan encompasses test specifications for stakeholder requirements, non-conformance reports and, finally, the confirmation that the system services needed by the stakeholders are available to them. They are the result of this process.

5.5.4 Life cycle stage 4: Utilisation stage

5.5.4.1 Operation process

The operation process enables smooth and accurate operation activities, system operation, monitoring, operator-system performance, and the recording of the data for the operational analysis. Operation Strategy and Plans, operator's periodical licences, problem and error reports, changes and, eventually, new stakeholder requirements are the results of this process.

5.5.5 Life cycle stage 5: Support stage

5.5.5.1 Maintenance process

The maintenance process assures the smooth operation of the system with minimum disturbances. The results of this process are maintenance strategy and plans (preventive and
corrective maintenance), fault reports and component lifetime data.

5.5.6 Life cycle stage 6: Retirement stage

5.5.6.1 Disposal process

The disposal process is applied to deactivate the system. The result of this process is a destroyed, stored or recycled system and its components, the ambient returned to its original or an agreed state, the records on the system and components disposal as well as the record of the relevant operating knowledge. Normally, a new system replaces the obsolete one.

5.6 Industry specific standards
   - Standardisation of the traffic-related processes

A further problem to be addressed in the development of the methodology: “How to fill up the shell?”

At this point industry specific knowledge becomes relevant. The motorway ITS system deals with motorway passengers and commercial traffic, police, motorway operations, maintenance etc. When looking at the standards again, it is clear that the ISO deals with intelligent transport systems (TC 204) and in-vehicle transport information and control systems (TC 22) (ISO web site URL: http://www.iso.ch).

On the other hand, there are some EU efforts in intelligent transport systems. Standardisation projects run from 1993 until today and will continue to run. Although the work of ISO is more advanced in terms of produced ISO standards, European transport is different from the US transport, which was a base for the ISO standardisation (EC 2000, p. 8). This is the reason that the EU develops its own standards that will be applied throughout the EU countries. Since Slovenia is part of the EU, it has been decided to take this course, despite the fact that the CEN standards will be developed at a slower pace before becoming de facto standards.

The reason for such a decision is the future interconnection of the national traffic information and management systems with a single European system.
Therefore, the EU methodologies in the ITS (intelligent transport systems) for industry (transport) specific issues will be used, but will stay within the framework of the ISO/IEC general systems engineering standards, including the software engineering that is an essential part of modern systems.

While setting the standards framework, the life cycle refinement should be continued, combining the ISO/IEC standards framework with the EU ITS (Intelligent Transport Systems) industry systematic knowledge.

Fortunately, there are standardisation efforts within the EC for traffic management and information, but such efforts do not exist for motorway operations and maintenance standardisation processes. This standardisation happens in various EC projects that have the task of developing the European intelligent transport system. Therefore, this will have to be looked at elsewhere or a specific method for operations and maintenance be developed.

The general systems engineering method will be used to develop the methodology in detail. The general scheme presented in Paragraph 5.5. will be used and each point amended with specific traffic related topics.

5.6.1 Life cycle stage 1: Concept stage

5.6.1.1 Stakeholder requirements definition

For the stakeholder requirements definition the European ITS method described below will be used (EC, 2000 a).

Methodology defines two aspects of stakeholder requirements:

- Operational/functional requirements and
- Non-functional requirements.

5.6.1.1.1 Functional requirements – conversion tables of stakeholder requirements

The stakeholder requirements within the EU’s ITS methodology are already prepared in a structured way in order to facilitate the stakeholders.

The method provides for systematic tables (called trace tables) prepared in advance specifically for traffic industry. The stakeholder requirements are selected from a prepared group. At the other side of the table, functional requirements are found. The table below shows the structure
of standardised stakeholder requirements amended with infrastructure operation and maintenance management - assets management. Table 3 shows the grouping of stakeholders’ requirements. Complete conversion tables are found in the appendix to the European ITS Framework Architecture - List of the European ITS User Needs (EC, 2000 a).

Table 3: Grouping the stakeholder requirements

<table>
<thead>
<tr>
<th>1 General</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Management Activities</td>
</tr>
<tr>
<td>2.1 Transport Planning Support</td>
</tr>
<tr>
<td>2.2 Infrastructure Operation and Maintenance Management - Assets Management</td>
</tr>
<tr>
<td>3 Policing/Enforcing</td>
</tr>
<tr>
<td>3.1 Policing/Enforcing Traffic Regulations</td>
</tr>
<tr>
<td>4 Financial Transactions</td>
</tr>
<tr>
<td>4.1 Electronic Financial Transactions</td>
</tr>
<tr>
<td>5 Emergency Services</td>
</tr>
<tr>
<td>5.1 Emergency Notification and Personal Security</td>
</tr>
<tr>
<td>5.2 Emergency Vehicle Management</td>
</tr>
<tr>
<td>5.3 Hazardous Materials &amp; Incident Notification</td>
</tr>
<tr>
<td>6 Travel Information</td>
</tr>
<tr>
<td>6.1 Pre-trip Information</td>
</tr>
<tr>
<td>6.2 On-trip Driver Information</td>
</tr>
<tr>
<td>6.3 Personal Information Services</td>
</tr>
<tr>
<td>6.4 Route Guidance and Navigation</td>
</tr>
<tr>
<td>7 Traffic Management</td>
</tr>
<tr>
<td>7.1 Traffic Control</td>
</tr>
<tr>
<td>7.2 Incident Management</td>
</tr>
<tr>
<td>7.3 Demand Management</td>
</tr>
<tr>
<td>7.4 Safety Enhancement for Vulnerable Road Users</td>
</tr>
<tr>
<td>7.5 Intelligent Junctions and Links</td>
</tr>
<tr>
<td>8 In-Vehicle Systems</td>
</tr>
<tr>
<td>8.1 Vision Enhancement</td>
</tr>
</tbody>
</table>
8.2 Automated Vehicle Operation
8.3 Longitudinal Collision Avoidance
8.4 Lateral Collision Avoidance
8.5 Safety Readiness
8.6 Pre-crash Restraint Deployment

9 **Freight and Fleet Operations**

9.1 Commercial Vehicle Pre-clearance
9.2 Commercial Vehicle Administrative Processes
9.3 Automated Roadside Safety Inspection
9.4 Commercial Vehicle On-board Safety Monitoring
9.5 Commercial Fleet Management

10 **Public Transport**

10.1 Public Transport Management
10.2 Demand Responsive Public Transport
10.3 Shared Transport Management
10.4 On-trip Public Transport Information
10.5 Public Travel Security

Source: EC, 2000 a

Functional requirements should have the following properties (EC, 2000):

- Unambiguousness
- Testability
- Traceability
- Singularity
- Uniqueness
- Allocation.

5.6.1.1.2 **Non-functional requirements**

These specify the performance and/or quality attributes of the operational system, and can be grouped as follows:

- Data exchange compatibility
- Adaptability to changing stakeholder requirements
- Constraints to which the systems will conform
- Continuity of the service in time and space
- Cost/benefit performance to avoid unnecessary expenditure
- Expandability regarding the functions and equipment
- Maintainability that stands for maintenance, repair, modifications or enhancement with minimum disturbance
- Quality of data content that has to deliver the appropriate information in the adequate form
- Robustness to operate satisfactorily under all expected conditions
- Safety not to cause harm to persons or ambient
- Security to protect the system and data from external attack or interference
- User friendliness for simple and efficient use.

5.6.1.2 Groups of stakeholders

All parties involved in the motorway/road traffic need to be considered. Everyone involved may express his needs and is therefore defined as a motorway/road stakeholder. The following parties are involved in motorways/roads and could be grouped into following motorway/road stakeholder groups:

- Infrastructure Authorities - are those in charge of area planning, motorway/road planning and building as well as the natural environment protection (ex. Ministry of Area Planning, Ministry of Transport, Local communities)
- Motorway/road operation and maintenance organisations which take care that motorways/roads are fit to fulfil their role i.e. to enable mobility (movement of persons and goods)
- Traffic rule enforcement authorities that assure rules are obeyed (the police)
- Financial organisations that assure the collection of motorway/road usage tolls
- Emergency and safety organisations that provide for lives and material damage (ex. haulage, ambulance)
- Traffic management organisations that care for the flow of traffic
- Service providers to motorway/road users (ex. travel information services, guidance systems, freight and fleet management, intelligent vehicle systems etc.)
- Motorway/road users that use the infrastructure for the mobility of persons and goods. They can be divided into two groups - private and commercial users.

The European ITS methodology categorises the following stakeholders:

a) Private Consumers - Travellers
b) Commercial Consumers - Freight- and Transport Industry
c) Companies providing/using the ITS
d) Local Authorities
e) High Level Ministries
f) Exploitation Level - Operators applying the ITS
g) Industry Level - Companies developing and producing the ITS.

5.6.2 Life cycle stage 2: Development stage

5.6.2.1 Requirements analysis process

Requirements analysis process in European ITS method consists of translating the table inputs into table outputs and deleting the multiple output entries. Various standardised stakeholder inputs can have the same output system requirements, so only one instance of every different output will be used. Software for the table translation and deletion of multiple occurrences could be used. A part of stakeholder requirements list is shown in the Table 4, page 39 below.

5.6.2.2 Architectural design process

The European ITS framework architecture generically defines the components and their structural relations and flows in the road traffic sector. It covers all aspects and stockholder's interests in road traffic.

Architectural design process describes the steps that are needed to create a specific architecture that is needed to fulfil specific stakeholder requirements.

Figure 3, page 41, represents the scope of the European ITS framework architecture.

5.6.2.2.1 Characteristics of the European ITS framework architecture

In general the European ITS framework architecture is:

- **open**: the architecture does not exclude any stakeholder,
  - it enables the extension of architecture based on additional stakeholder requirements
### Table 4: Partial list of stakeholder requirements

<table>
<thead>
<tr>
<th>Related sets of Stakeholder Requirements within Fundamental Services in Functional Groups</th>
<th>Function Reference Number</th>
<th>Description of the Stakeholder Requirements</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Traffic, Incidents and Demand Management</td>
<td>7.1.0.1</td>
<td>The activities associated with traffic control, incident management and demand management, including monitoring, planning, flow control, exceptions management, speed management, lane and parking management, HOV, road pricing and zoning, and VRUs.</td>
<td>Private Consumers - Travellers, Commercial Consumers - Freight and Transport Industry, Companies providing ITS, Local Authorities, High Level Ministries, Operators applying the ITS, Industry Level - Companies developing and producing ITS, Cross reference to similar User Need</td>
</tr>
<tr>
<td>7.1 Traffic Control</td>
<td>7.1.0.2</td>
<td>The system shall support the existing and new traffic management needs of authorities by providing a flexible yet comprehensive approach to determine traffic management strategies (including bridge and tunnel control).</td>
<td>Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>7.1.0.3</td>
<td>The system shall not do anything to reduce road safety.</td>
<td>Y Y Y</td>
</tr>
<tr>
<td></td>
<td>7.1.0.4</td>
<td>The system shall manage road traffic in such a way that levels environmental (i.e. atmospheric and noise) pollution may be reduced.</td>
<td>Y Y Y</td>
</tr>
<tr>
<td></td>
<td>7.1.0.5</td>
<td>The system shall manage road traffic in such a way that congestion (travel time) may be reduced.</td>
<td>Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>7.1.0.6</td>
<td>The system shall be able to help co-ordinate the activities of TICs and TCCs.</td>
<td>Y Y Y Y</td>
</tr>
<tr>
<td></td>
<td>7.1.0.7</td>
<td>The system shall be able to exchange information between TICs and TCCs, including across national boundaries.</td>
<td>Y Y Y Y</td>
</tr>
</tbody>
</table>

**Legend:**

Write **Y** in the column if the function is required.

**Source:** EC, 2000 a
- **multi-modal:** it is designed to apply to all forms of road transport. Further, interfaces with other forms of transport are defined such as rail, air and sea transport
- **independent:** it does not require the use of a particular technology. It promotes the use of generic solutions for which several technologies are available.

The European ITS framework recognises four types of architectures that form the European ITS framework architecture:

- Functional architecture
- Physical architecture
- Communication architecture
- Organisational architecture.

Organisational architecture was not developed as a part of the European ITS architecture, because of the great difference between the countries. The development of this architecture is a clear task of each entity (nation, state, district, province or county).

### 5.6.2.2.2 Method for the creation of the architecture

The starting point for the creation of architecture is a wish or requirement to create a system. Following steps are needed to create the national traffic information, management and maintenance architecture (EC, 2000):

1. Assign a name to the proposed architecture.

2. Use the European ITS stakeholder requirements framework specification and let the stakeholders select the requirements that are to be served by the proposed architecture. These requirements should reflect the policies and goals of the proposed architecture.

3. Review of the selected stakeholder requirements to ensure that they will meet the ITS goals of the entity (nation, state, district, province or county). If there are gaps, i.e. goals that are not served by the selected stakeholder requirements, then new ones must be created and added to those selected in steps 2 and 3.
Figure 3: Outline of the European ITS Framework Architecture

Source: EC, 2000
4. Complete set of stakeholder requirements produced by Steps 2 and 3 should be reviewed by all relevant stakeholders.

5. As an aid to the process in step 4, develop one or more of the models listed below. Use them to help all the stakeholders to look at and understand the proposed architecture in the same way.

(a) Enterprise Model — shows the structure of the relationships that exist between organisations, persons, services and/or functions.

(b) Primary Process Model — shows the processes that will take place, and their relationship with the ambient outside the system, e.g. users.

(c) Layered Reference Model — shows a division of the architecture functionality into dependant layers.

(d) Conceptual Model — a high-level description of the relationship between the main functions and, possibly, their physical locations.

6. From the trace tables select the low-level functions that fulfil the stakeholder requirements identified in Steps 2 and 3 above.

7. Identify the high level functions to which each of the functions selected in Step 6 belong by looking at the hierarchy diagrams for each functional area.

8. If any new stakeholder requirements were created in steps 2 and 3, then new functionality and (possibly) new terminators will be needed to serve them.

9. The following documents and other sets of information must be created:

(a) Stakeholder requirements list: this should contain all of the European ITS stakeholder requirements identified in Step 2, plus those produced in Step 3. The draft version of this list must be used for the stakeholder review identified in Step 4. The final (definitive) version will be the result of Step 4.
(b) Functional architecture document: that is a “customised” version of the European ITS Functional Architecture Document.

(c) Physical architecture document: this should be produced in a similar way as the document in (b).

(d) Communication architecture document: this should be produced in a similar way as the document in (b).

5.6.2.2.3 Adding new terminators and new functions

The structure of the functionality in the European ITS Functional Architecture enables the adding of new Functions (both High and Low Level) and Terminators. Terminators are the links to the outside world of the system. In some cases, the scope of the new functionality that is required may lead to the creation of a new Functional Area.

5.6.2.2.4 Modifying the physical architecture database

Adding new items in the previous paragraph implies the modification of the Physical Architecture Database.
(Last three paragraphs are quoted from EC, 2002 b, p. 27-31)

5.6.2.3 Functional architecture

Functional architecture defines and describes what functions need to be included in a system that can fulfil the stakeholder requirements within the European ITS architecture. The functional architecture therefore represents the system in functional terms. It also shows how its functionality links to the ambient.

Functional architecture in the European ITS framework architecture uses a process-oriented approach. This means that functional architecture is described as a series of functions gathered into various functional areas (EC, 2002). Functional architecture contains:

- functions grouped in functional areas
- linked data stores (sometimes)
- terminators (links to the outside of the system) and
- data flows represented by data flow diagrams.
In order to be able to control the functional requirements against the stakeholder requirements, table of relations, showed in Table 5, page 45, was developed.

5.6.2.4 Physical architecture

A physical architecture defines and describes the way in which the components of the functional architecture can be grouped to form physical entities. Physical entities are created to provide one or more services specified by the stakeholder requirements. Resources such as roadside structures, equipment software and similar are needed to create them.

A set of physical entities forms a system. Systems can be created in many different ways, yet they can provide the same services. Because of that, a unique physical architecture cannot be built.

Physical architecture contains:

- systems
- physical data flows
- physical terminators.

Systems that correspond to stakeholders’ requirements and functional architectures are decomposed into hierarchically connected sub-systems that communicate between each other and with terminators.

Sub-systems may be put into different locations. Some generic locations are defined within the scope of the physical architecture (EC, 2000 b, p. 7):

- Centre - the place to collect and manage the storage of data
- Roadside - the place for the detection of data and issuance of commands
- Vehicle - a device for moving through the road network and carrying people and/or goods
- Personal device - a device carried by persons as one of their personal possessions
- Freight device - a device in a freight carrying unit
- Kiosk - a device located in a public place that enables a person limited access to some system facilities.
<table>
<thead>
<tr>
<th>Functional Area</th>
<th>Stakeholder requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
</tr>
<tr>
<td>1. Provide Electronic Payment</td>
<td>4.1</td>
</tr>
<tr>
<td>Facilities</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>2. Provide safety and Emergency Facilities</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td>3. Manage Traffic</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
</tr>
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<td>6.1</td>
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<td></td>
<td>7.1</td>
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<td></td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>8.2</td>
</tr>
<tr>
<td>4. Manage Public Transport</td>
<td>10.1</td>
</tr>
<tr>
<td>Operations</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>10.3</td>
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<tr>
<td></td>
<td>10.4</td>
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<td>10.5</td>
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<td>4.1</td>
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<td>5.1</td>
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<td>5.3</td>
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<td></td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>5. Provide Advanced Driver</td>
<td>4.1</td>
</tr>
<tr>
<td>Assistance Systems</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>8.1</td>
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<tr>
<td></td>
<td>8.2</td>
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<td>8.3</td>
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<td>8.4</td>
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<td></td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>8.6</td>
</tr>
<tr>
<td>6. Provide Traveller Journey</td>
<td>10.1</td>
</tr>
<tr>
<td>Assistance</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>6.1</td>
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<td>6.2</td>
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<td></td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>7. Provide Support Law</td>
<td>3.1</td>
</tr>
<tr>
<td>Enforcement</td>
<td></td>
</tr>
<tr>
<td>8. Manage Freight Fleet</td>
<td>5.3</td>
</tr>
<tr>
<td>Operations</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
</tr>
</tbody>
</table>

Source: EC, 2002
Sub-systems are further divided into modules.

Physical terminators are physical units that are connecting the outer world with the system. Terminators for the functional and the physical architectures are the same.

Examples of the physical systems supported by the European ITS architecture (EC, 2000 b, Annex 1) are shown in Table 6 below.

5.6.2.5 Communication architecture

Communication architecture defines and describes the means for the exchange of information between different parts of the system (EC, 2000 c). This information exchange is carried out using physical data flows.

Two issues are important for the communication architecture. First, the means for information transport are needed in the system, and second the information should be properly understood at the other side of the link.

Table 6: Examples of physical architecture systems

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Example of the physical systems architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Road asset management systems</td>
</tr>
<tr>
<td>2</td>
<td>Integrated traffic management systems</td>
</tr>
<tr>
<td>3</td>
<td>Electronic fee collection systems</td>
</tr>
<tr>
<td>4</td>
<td>Safety and emergency systems</td>
</tr>
<tr>
<td>5</td>
<td>Traffic management systems</td>
</tr>
<tr>
<td>6</td>
<td>Vehicle systems</td>
</tr>
<tr>
<td>7</td>
<td>Traveller assistance and route guidance systems</td>
</tr>
<tr>
<td>8</td>
<td>Law enforcement systems</td>
</tr>
<tr>
<td>9</td>
<td>Freight and fleet management systems</td>
</tr>
</tbody>
</table>

Source: EC, 2000 b

The first issue leads to the definition of the communication links at the interfaces of the system. The second issue calls for a definition of private traffic communication protocols.

Communication architecture consists of:

- communication links and
- communication protocols.
Describing the typical telecommunication requirements is the first task of the communications architecture. Telecommunication technologies are changing so fast that it is not possible to provide a long-term architecture based on today's technologies. The generic description of physical data flows remains valid as long as the systems do not change too much.

The European ITS framework communication architecture provides a help in the form of tables that show the communication requirements for each function in the architecture. On the other side it provides an overview of the general telecommunication systems such as PTN, GSM, GPS, fixed lines and similar. The industry specific communication protocol standards (DATEX, RDS-TMC) have been developed and the selection table is available for the selection support. (EC, 2000 b, Annex 1 and 2)

5.6.2.6 Organisational architecture

Organisational architecture is necessary for a smooth and proper operation of the system that might be spread out in different organisations at international, national, state, district, province or county level. The development of this kind of architecture is a domain of the entities that are involved with a specific system. In the development of the organisational architecture, the responsibilities, authorities and provided services should be defined. It should be emphasised that this is a very important aspect in the creation and operation of the system. New regulations or change of the existing one might be needed in order to assure clear division and cooperation among the stakeholders.

5.6.3 Remaining life cycle stages

The remaining life cycle stages are not industry specific, so general systems engineering methods described in the ISO/IEC 15288 and IEEE 1220 standards will be used. The goal of these life cycles is to produce components, subsystems and systems, test their functionality and performance, integrate them gradually in the system and verify that the system performs its functions as described in the system requirement specification. Then, smooth introduction of the operations by the new system or change from the old to the new system should be accomplished. The verification that the

47
system provides services that fulfil stakeholder requirements follows.

Operation and necessary maintenance along with possible system extensions constitute the life of the system.

Finally, after the operation time the system is disposed of.

6 EXAMPLES OF MOTORWAY ITS SYSTEM ARCHITECTURE

6.1 Example of Functional Architecture

Elements of the Functional Architecture are defined in the European ITS architecture (EC, 2002). The elements are grouped as shown below.

6.1.1 Provide Electronic Payment Facilities

This area will provide functionality that enables the acceptance of payment for services provided by other functional areas within the architecture. It will have an interface with the Financial Clearinghouse Terminator to enable actual payment transactions to be made. If fraudulent payment is detected, any details available will be passed to functionality in the Law Enforcement Area.

This area is divided into the following high-level functions:

F 1.1 Set up Contract
F 1.2 Manage User's Account
F 1.3 Perform Electronic Payment Transaction
F 1.4 Manage Operators' Revenue
F 1.5 Control Fraud
F 1.6 Manage Tariffs and Access Rights.

6.1.2 Provide Safety and Emergency Facilities

This area will provide functionality that enables the emergency services to respond to incidents. The functions in this area will have links with the Manage Traffic Area to enable the reporting and detection of incidents, the management of their impacts and the granting of priority to emergency vehicles. It will be possible for priority to be
provided either locally at each controlled point on the road network, or as a "route" through the network. There will be links to the Provide Traveller Journey Assistance Area to enable priority routes for emergency vehicles to be produced.

This area is divided into the following high-level functions:

F 2.1 Manage Emergencies
F 2.2 Manage stolen vehicle notification.

6.1.3 Manage Traffic

This area will provide functionality enabling the management of traffic in urban and inter-urban environments. Functionality will be included to detect and manage the impact of incidents, produce and implement demand management strategies, monitor car park occupancies and provide road transport planning. Links will be provided to the Provide Safety and Emergency Facilities and Manage Public Transport Areas so that their vehicles get priority on the road network and to enable assistance provision in the implementation of incident and demand management strategies. The External Service Provider terminator will be sent data on traffic conditions and strategies.

This area is divided into the following high-level functions:

F 3.1 Provide Traffic Control
F 3.2 Manage Incidents
F 3.3 Manage Demand
F 3.4 Provide Environmental Information
F 3.5 Manage Road Maintenance.

6.1.4 Manage Public Transport Operations

This area will provide functionality to enable the management of public transport. It will include the scheduling of services and the generation of information, that can be made available to travellers. The area will have links with the Manage Traffic Area to provide priority for its vehicles, and to provide data on the use of services so that an assessment can be made of demand for different modes of transport. The Manage Traffic Area will also provide requests for service changes to enable a move towards a
better balance in the use of transport modes. There will also be links to other areas to provide information about fraud and incidents that have been detected in the Public Transport network.

This area is divided into the following high-level functions:

F 4.1 Monitor Public Transport Fleet
F 4.2 Plan Public Transport Service
F 4.3 Provide Public Transport Management
F 4.4 Control Public Transport Fleet.

6.1.5 Provide Advanced Driver Assistance Systems

This area will provide functionality that enables the control of vehicles whilst they are using the road network. Interfaces will be provided to the Provide Safety and Emergency Facilities Area to provide a speedy response to calls from vehicles. Vehicle identities will be provided to other areas for payment collection and the identification of fraud. Functionality will also be provided to enable the output of traffic and travel information provided by the Manage Traffic Area.

This area is divided into the following high-level functions:

F 5.1 Provide Visibility Enhancement
F 5.2 Provide Automated Vehicle Operation
F 5.3 Provide Longitudinal Collision Avoidance
F 5.4 Provide Lateral Collision Avoidance
F 5.5 Provide Safety Readiness
F 5.6 Provide Driver-Vehicle Interaction
F 5.7 Provide Vehicle-Telematics Integration
F 5.8 Integrate Vehicle in Traffic System.

6.1.6 Provide Traveller Journey Assistance

This area provides functionality that enables the provision of information to all types of travellers about traffic conditions and about other modes of transport. Functions also provide route determination and guidance, and travel planning. This includes access to other services such as accommodation.
This area is divided into the following high-level functions:

F 6.1 Define Traveller's GTP
F 6.2 Plan Trip
F 6.3 Support Trip
F 6.4 Evaluate Trip.

6.1.7 Provide Support for Law Enforcement

This area will provide functionality to enable the provision of an interface to Law Enforcement agencies. This interface will be used to provide information about frauds and violations that have been detected by functionality within other areas. Examples of frauds and violations will include but not be limited to invalid or missing payment, speeding, incorrect use of lanes in the road, incorrect observance of other commands sent to drivers. Over-weight vehicles will be detected by the functionality within the area itself and the details passed to the Law Enforcement Agency.

This area is divided into the following high-level functions:

F 7.1 Detect Fraud
F 7.2 Identify Violator
F 7.3 Process Fraud Notifications
F 7.4 Store Fraud
F 7.5 Manage Rules and Users' Registrations.

6.1.8 Manage Freight and Fleet Operations

This area will provide functionality that enables the management of Freight and Fleet Operations. This will control the use of freight vehicles and their transportation of goods. The use of other modes of freight transport will also be supported. An interface to the Provide Safety and Emergency Facilities Area will also be included to enable the provision of information about hazardous goods. Route planning for this and other types of goods will be provided through the interface to the Provide Traveller Journey Assistance Area.

This area is divided into the following high-level functions:

F 8.1 Manage Logistics and Freight
F 8.2 Manage Commercial Fleet
F 8.3 Manage Vehicle/driver/cargo/equipment during trip

6.1.9 Maintenance and Construction Operations

The European ITS architecture does not cover one domain that covers the functions of road maintenance and construction. Therefore, this functional group from the US National ITS Architecture that recognises this functional group (FHWA, 2003, p. 7) will be included.

This area will provide functionality that enables the management of Maintenance and Construction Operations. This will monitor and manage roadway infrastructure construction and maintenance activities. Representing both public agencies and private contractors that provide these functions, this subsystem manages fleets of maintenance, construction, or special service vehicles (e.g. snow and ice control equipment) and performs vehicle dispatch, routing, and resource management for the vehicle fleets and associated equipment.

This area is divided into the following high-level functions:

F 9.1 Maintenance and Construction Vehicle and Equipment Tracking
F 9.2 Maintenance and Construction Vehicle Maintenance
F 9.3 Road Weather Data Collection
F 9.4 Weather Information Processing and Distribution
F 9.5 Roadway Automated Treatment
F 9.6 Winter Maintenance
F 9.7 Roadway Maintenance and Construction
F 9.8 Work Zone Management
F 9.9 Work Zone Safety Monitoring
F 9.10 Maintenance and Construction Activity Coordination.

6.2 Functional analysis for Slovene motorways

For the purposes of the Slovene motorways operations the full functionality of the ITS system will not be required. An in-depth stakeholder requirements analysis will give the function areas and functions within these areas. This work is beyond the scope of this thesis, given that it deals with
the construction of a methodology that should facilitate the development of an operational motorway ITS system for Slovenia.

The result of functional analysis is a functional architecture. An example of one the functional architectures is shown in Figure 4, page 54, below.

6.3 Example of physical architecture

A physical architecture is a consequence of grouping the items of the Functional Architecture into physical entities. Items in the physical architecture are systems (on the first level). Systems are means for implementation of the Functional Architecture. They fulfil a few particular stakeholder requirements.

6.3.1 Systems

It is possible to create Systems for a Physical Architecture in many different ways by using the items of the Functional Architecture. Therefore, the unique Physical Architecture for a specific Functional Architecture does not exist. Physical Architecture can be depicted in diagrams. One such diagram is shown in Figure 5, page 56, below.

6.3.2 Sub-systems

Systems consist of two or more Sub-systems. A Sub-system performs one or more tasks and may be defined as a commercial unit. Each Sub-system will consist of one or more parts of the Functional Architecture (Functions and Data Stores), and may be required to communicate with other Sub-systems and terminators in order to work.

Each Sub-system will encompass the parts of the Functional Architecture in the same physical location. This is the point where architecture changes to configuration. Every location has its own sub-system denominated uniquely in the system. Following possible locations for Sub-systems exist:

Central - the place that is used by parts of a System to collect, manage the storage of traffic data, toll payments, freight shipping orders, and/or the generation of traffic management measures, fleet management instructions. (Traffic
Figure 4: Example of functional architecture of an Inter-urban traffic management system

Source: EC, 2002
Management Centre, Traffic Control Centre, Fleet Management Centre, Toll Collection Centre etc.)

Roadside - the place that is used by parts of a System for the detection of traffic, vehicles and pedestrians, or the collection of tolls, provision of information and execution of commands to drivers or pedestrians.

Vehicle - a device that is capable of moving through the road network and transporting people and/or goods.

Personal Device - a device that is part of the System but is used by Travellers as one of their personal belongings.

Freight Device - a device in which part of the System can be installed to a freight-carrying unit.

Kiosk - a device usually located in a public place, containing a part of the System that enables Travellers to access some facilities.

There can be more than one Sub-system in the same location. For example, there may be more than one Sub-system in a "Central" location because they can be in different micro locations.

On the contrary, a Sub-system may not cover two or more different generic locations. Sub-systems that provide the same or similar services, but in different locations, will be treated as two separate Sub-systems.

6.3.3 Modules

Sub-systems are split into Modules. The main difference between Modules and Sub-systems is that each Module contains functionality from a single Area of the Functional Architecture. Modules are physical components containing a grouping of functionality that is more logical from a manufacturing or physical design viewpoint. Modules communicate with each other.

6.3.4 Physical Data Flows

Physical Data Flows provide communication links within a System. They enable data to be sent between Sub-systems, between Modules, between Sub-systems and Modules, as well as
to and from Terminators. They may consist of one or more Functional Data Flows.

Figure 5: Example of a Physical Architecture of an Inter-urban traffic management system

Source: EC, 2000 b
6.3.5 Terminator Data Flows

Terminator Data Flows provide the links between the Sub-systems and Modules and the outside World that is represented by the Terminators.

6.3.6 Terminators

Terminators for the Physical Architecture are the same as those for the Functional Architecture. A complete list of terminators within European ITS Architecture is:

- Ambient
- Bridge/Tunnel Infrastructure
- Consignor/Consignee
- Driver
- Emergency Systems
- External Service Provider
- Financial Clearinghouse
- Freight Equipment
- Law Enforcement Agency
- Location Data Source
- Maintenance Organisation
- Multi-Modal System mms
- Operator
- Related Road System
- Road Pavement
- Traffic
- Transport Planner
- Traveller
- Vehicle
- Weather Systems.

In the real systems, not all terminators may be used.

6.4 Example of communication architecture

Within the systems and between the systems and the ambient, there are clearly some interactions. These interactions call for the exchange of information, material, and energy. The source and the sink of the flows are terminators. In the Communication architecture, only the physical terminator links to non-human entities are analysed. This is because the links to human entities are non-electronic. An example
of Communications Architecture is shown on Figure 6, page 59.

Communications are performed by technical communication systems. Appropriateness of various technical means should be determined. One example of the appropriateness of the communication transmission technology is shown in Table 7, page 60.

The next very important issue in the Communication Architecture are the communication protocols. Special transport-related communication protocols are proposed by the European Commission funded traffic management projects.

Transport-related standardisation efforts for communication protocol run under the CEN and ISO standardisation bodies.

6.5 Example of organisational architecture

Organisational Architecture identifies organisations as stakeholders in the development of the architecture. Table 8, page 61 shows an example of organisational architecture.

7 RISK MANAGEMENT FOR THE DEPLOYMENT OF A SLOVENE MOTORWAY ITS SYSTEM

Within the methodology development for a Slovene motorway information system, risk assessment should be accomplished. This project is a national project and before any implementation a success possibility should be estimated. In other word, the risk management method should be a part of the methodological framework.

Planning is an organised consideration of the whole risk management process in order to recognise, optimise and not to omit the aspects of risks. Then risks have to be identified. The best way is the top-down approach so that the categories of risks are first identified and then categorised. Threat analysis is the following step where the probabilities of occurrence and the impact of severity is assessed. Risk handling comes next. Reviews, re-analysis, meetings and reports are conducted and written in order to monitor the success of risk measures.
Figure 6: Example of Communication Architecture of an Inter-urban traffic management system

Source: EC, 2000 c
Table 7: An example of appropriateness of communication transmission technologies for the communication between Inter-urban traffic management centre and emergency services.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Main Advantages</th>
<th>Main Drawbacks</th>
<th>Conclusion and Other remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless, mobile and broadcasting technologies (DECT, TETRA, GSM, Satellite, DAB)</td>
<td>None</td>
<td>Not designed for that kind of application.</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Broadcasting technologies (DAB, Satellite)</td>
<td>None</td>
<td>Not designed for symmetric bi-directional application</td>
<td>Not Recommended</td>
</tr>
<tr>
<td>Bi-directional satellite (VSAT)</td>
<td>None</td>
<td>Antennas and amplifier (in particular at the Centre)</td>
<td>Not Recommended. Except if already used with other Terminators</td>
</tr>
<tr>
<td>Internet</td>
<td>Inexpensive No quality of service</td>
<td>Uses public network</td>
<td>Not Recommended. Not compatible with security requirements.</td>
</tr>
<tr>
<td>Wireless Terrestrial (LMDS, MMDS,...)</td>
<td>No infrastructure required</td>
<td>Specific terminal Equipment. Short distance. High bandwidth solution.</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Dial-up connections (PSTN, ISDN)</td>
<td>Easy installation. Connections can be released between two connections. Inexpensive in some countries. Private</td>
<td>Delay needed for connections.</td>
<td>Not really adapted except if connection can be anticipated.</td>
</tr>
<tr>
<td>Leased line</td>
<td>Private</td>
<td>Cannot be shared with other terminators</td>
<td>Recommended (depends on bandwidth needed).</td>
</tr>
<tr>
<td>Wired Private Networks low bandwidth (X.25)</td>
<td>Adapted bandwidth. Managed by a Telecom provider Secured</td>
<td>None</td>
<td>May be recommended. Should be shared with other terminators (e.g. ESP)</td>
</tr>
<tr>
<td>Wired Private Networks, high bandwidth (Frame relay, ATM)</td>
<td>Managed by a Telecom provider. Secured.</td>
<td>Excessive cost for the low bandwidth that is needed.</td>
<td>Not recommended except if the System needs more bandwidth for extra functions.</td>
</tr>
</tbody>
</table>

Source: EC, 2000 c
Table 8: An example of organisational architecture for Inter-urban traffic management

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Role of the organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>National traffic management centre</td>
<td>Central coordination of traffic on the national level</td>
</tr>
<tr>
<td>Road operation and maintenance organisation</td>
<td>Road maintenance and operation, Setting of road barriers</td>
</tr>
<tr>
<td>Police</td>
<td>Traffic security, Emergency service</td>
</tr>
<tr>
<td>Haulage company</td>
<td>Haulage of crashed vehicles</td>
</tr>
<tr>
<td>Association of radio stations</td>
<td>Traffic reports</td>
</tr>
<tr>
<td>Association of city administrations</td>
<td>Traffic coordination between national and urban traffic management</td>
</tr>
<tr>
<td>Association of assurance companies</td>
<td>Providing data on insurance indemnifications in transport</td>
</tr>
</tbody>
</table>

Experience through history has shown that risks can be managed to some extent. An approach has been developed for risk management. Risk management consists of four separate but related activities.

Figure 7, page 62 represents risk management activities.

7.1 Risk management planning

Based on the above presented general risk management method, European transportation and risk experts developed a structure that helped them through the process.

7.2 Threat identification groups

A list of identified threats was developed on the European level (Berghout et al., 1999). This generic list could be used for a national risk management scheme. This list consists of the following groups of threats, each described in detail:

- framework architecture
- communication
- cost & benefits
- deployment & operation
- fund provision
- ITS Infrastructure
- legacy systems
Figure 7: Risk management structure and activities

Source: Berghout et al., 1999

- politics
- privacy
- safety
- stakeholder
- acceptance
- standardisation
- technology maturity
- traveller acceptance
- organisation
- institutional issues.

Only a critical selection of the national risk management issues from the list is needed for the development of the national risk scheme.
7.3 Threat analysis

Every identified threat was assessed from two points of view: probability of occurrence and impact level. Both of them were assessed at three levels: low, medium and high. Out of all 27 theoretical combinations of these two points 5 categories have been developed. All possible threat impacts for every threat from a threat group belong to one of the 5 threat impact groups. Because it is impossible to have, all its combinations analysed for a specific ITS architecture, scenarios should be developed and their threats assessed. Scenarios should be build based on the following criteria:

- geographical scope (rural, urban, inter-urban)
- main ITS trends (information dissemination, traffic control and demand management)
- public-private management (public, private, mixed)
- time horizon (targeted year of implementation)

7.4 Risk handling

After the threat analysis, threat reports are written, meetings held and decisions need to be taken. The decisions are based on the distinctive strategies that are adopted. Each strategy has following 4 components:

- mitigation action (support, standardisation, data exchange, ITS promotion, public-private partnership, driver assistance etc.)
- strategy actor (EC, government, ministry, road operator, ITS provider)
- action category (address, define, promote, adopt, enforce the European ITS) and
- action type (risk avoidance, risk control).

This risk management method could be deployed for the Slovene motorway ITS system. The method was specifically developed for and is targeted at the ITS deployment in general. A critical consideration of the Slovene risk factors and actors is needed under the perspective of this method.
8 STRATEGIC IMPACTS OF IMPLEMENTATION OF A SLOVENE ITS ARCHITECTURE

8.1 Benefits of the ITS architecture

A survey regarding the impact of the European ITS architecture has been conducted in some European countries where national ITS Architectures have been developed and/or parts of the ITS systems implemented, based on European ITS Architecture (EC, 2003). This experience might be valuable also for a Slovene motorway ITS, that will be built in the near future.

Four benefits may be expected from development of the Slovene national ITS architecture:

- integration of operation of many organisations involved
- interoperability of traffic systems in Slovenia and abroad
- open market for transportation and traffic services
- national cost savings in traffic, energy and ecology.

An analysis of the benefits of the implemented ITS shows the improved mobility. This reflects in:

- reduced travel time
- reduced variability of travel time
- improved congestion resolving
- less congestion building if ITS systems are interconnected.

The impact of the Slovene national ITS architecture on the transport situation in Slovenia and the European region to which it belongs may be assessed on the basis of the existing experience and analysis as follows:

a) The European ITS framework architecture provides a good starting point for the development of a national ITS architecture. The Slovene Ministry of Transport and other pertinent Slovene institutions do not need to start its work from scratch. A common language and understanding of country stakeholders already exists within the framework of the European ITS architecture.
b) With the architecture (especially the inter-modal one) an overview of all functions, stakeholders, information flows, physical systems and communication equipment is given. The assurance of communications and interoperability within the country and with neighbouring countries is also of great importance.

c) Cost and timesaving benefits during the development process of the ITS applications, using the available national ITS architectures is assured. Standardised equipment packages with clearly defined interfaces lead to more competition between the producers.

d) The development of domestic knowledge for the building of a Slovene transports ITS system and the development of specific traffic solutions that could provide a good basis for the sale of the systems abroad.

8.2 Cost structure of a Slovene ITS architecture

In the development of a Slovene ITS architecture costs will be incurred by various organisations. It is therefore good to have at least a rough cost scheme in order to assess the possible problems individual stakeholders could have and their impact on the complete project. Table 9, page 67, was developed in order to give a rough overview of cost bearers.

8.3 Cost savings in a Slovene ITS architecture

Costs are another important factor that has to be considered when introducing a Slovene motorway ITS system. Some cost structures based on the methodology for the development of the European ITS architecture (EC, 2000 d) will be introduced. If a Slovene ITS architecture is based on the European ITS methodology, significant cost and timesavings are assured. Costs reflect the life cycle method and are summarised in the following categories:

a) Architecture concept definition cost savings

Cost savings are assured because European ITS architecture already has clear list of all possible stakeholder requirements that might be used straight away. Therefore, no method for stakeholder requirements capturing needs to be developed. Costs savings occur at:
- general management
- stakeholders' identification and involvement
- stakeholders' requirements definition.

b) Architecture development cost savings

A formal method lowers the costs associated with stakeholders' analysis at:

- general management
- planning phase, including identifying the vision
- reviewing the current situation and identifying how to
  perform and finance the process of technical development
- technical development of the architecture (reference, functional and physical architecture and defining a deployment plan)
- review of results and final document acceptance.

c) Architecture production cost savings

Costs savings in the architecture production are envisaged at:

- general management
- modularly build open architecture
- standardised interfaces of the all over national ITS system
- more competition among ITS industry
- standardised delivery and acceptance of systems
- standardised training on use of new systems.

d) Architecture utilisation cost savings

Cost savings anticipated in this stage are through:

- interoperability of the subsystems in the country and abroad
- cross-boarder clearing operations
- smooth traffic with no necessary stops or slowdowns
- international financial checking and financial enforcement of provided services
- accurate traveller information services.
Table 9: Cost bearers of a Slovene ITS architecture

<table>
<thead>
<tr>
<th>Development stage</th>
<th>Private users</th>
<th>Commercial users</th>
<th>Companies providing / using ITS services</th>
<th>Value-added ITS service providers</th>
<th>The ITS industry</th>
<th>Public authorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of Stakeholders</td>
<td>Individuals</td>
<td>Commercial transport organisations</td>
<td>Public or private road operators</td>
<td>Broadcasters Internet service providers GSM service providers</td>
<td>System manufacturer s and suppliers</td>
<td>National authorities City authorities</td>
</tr>
<tr>
<td>Architecture concept definition costs</td>
<td>No direct costs, but their organisation is involved</td>
<td>No direct costs, but their organisation is involved</td>
<td>Direct costs through participatio n of own employees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Architecture development costs</td>
<td>No direct costs, but their organisation is involved</td>
<td>No direct costs, but their organisation is involved</td>
<td>Direct costs through participatio n of own employees</td>
<td>Direct costs through participatio n of own employees</td>
<td>Not involved, therefore no costs</td>
<td>This would normally be a public authority role: costs would be incurred at a national level</td>
</tr>
<tr>
<td>Architecture production costs</td>
<td>Possible costs for purchasing or change of in vehicle equipment</td>
<td>Possible costs for upgrading or change of in vehicle equipment</td>
<td>Possible costs for upgrade of the old or procurement of new equipment/services/procedures Costs shared with Public authorities</td>
<td>Start-up costs for new services and connection costs of the existing services Possible contribution to public infrastructure funding through a public - private partnership</td>
<td>Extensive funding required for new/revised systems which are compatible with the framework</td>
<td></td>
</tr>
<tr>
<td>Architecture utilisation costs</td>
<td>Fees for some services</td>
<td>Fees for some services</td>
<td>Costs of maintaining state-of-the-art by following relevant trends in the field</td>
<td>Costs of maintaining state-of-the-art by following relevant trends in the field</td>
<td>Costs of maintaining state-of-the-art by following relevant trends in the field</td>
<td></td>
</tr>
<tr>
<td>Architecture support costs</td>
<td>Possible costs for maintenance of in vehicle equipment</td>
<td>Possible costs for maintenance of in vehicle equipment</td>
<td>Costs are unlikely to be higher than for systems without a common architecture</td>
<td></td>
<td>Responsible for maintenance, but not cost holder</td>
<td></td>
</tr>
<tr>
<td>Architecture retirements costs</td>
<td>Possible costs for retirement of in vehicle equipment</td>
<td>Possible costs for retirement of in vehicle equipment</td>
<td>Possible retirement costs of systems</td>
<td>Retirement costs of their own service systems</td>
<td>Retirement costs of systems</td>
<td></td>
</tr>
</tbody>
</table>

Source: EC, 2000 d
e) Architecture support cost savings

Support costs are lowered because of:
- standardised equipment built-in in the most effective way
- standardised and unified error detection procedures
- redundancy of critical systems components.

f) Architecture retirement cost savings

Savings in this stage are achieved by:
- gradual exchange of systems components
- known chemical composition of systems' building blocks
- known environment impact.

It is obvious that the approach of using worldwide knowledge that is available at minimal cost is the best cost/benefit approach for the development and building of a Slovene motorway ITS system. Cost savings are mainly in the system development. The costs of provision for the development technology are minimal. They encompass purchasing of the available documentation and the study of it. The purchasing costs of the physical equipment are lowered because of good equipment and services requirements that are produced through system development process. The consequence of good requirements specification is a better competition that lowers the purchasing prices for the equipment and services.

9 PRESENT SITUATION AND DEVELOPMENT OF A NEW SLOVENE MOTORWAY ITS SYSTEM

9.1 Operating information systems

A couple of information systems serving various interest groups of the Slovene motorways are available today. They partially cover the anticipated needs of some interest groups. A comprehensive coverage of the needs at national level that would take into account transport inter-modality in Slovenia, neighbouring countries and the EU does not exist at present.
Nevertheless, the existing situation in this respect in Slovenia should be considered. Information about the Slovene motorways and related information could be found in the following information systems shortly presented below.

9.1.1 Information systems at the Motorway Company in the Republic of Slovenia (DARS)

DARS d.d. is a company responsible for the building and maintenance of the Slovene motorways. It has its own management information system that provides information to the company management and public accountancy. Alongside this, transport and client oriented information systems exist such as:

- KAŽIPOD an information system providing information on the actual motorway status (barriers, diversions, congestion etc.)
- ATC an automatic electronic toll collection system for 4 categories of vehicles
- various tunnel control systems, providing for traffic control and safety of the tunnels
- a system of emergency calls along the motorways
- a motorway weather monitoring system that provides for weather data, including motorway ice warning
- motorway incidents reporting and statistics
- a web site (URL: http://www.dars.si) providing information in Slovene and English on the motorway traffic conditions along with traffic monitoring video cameras installed at some motorway points.

9.1.2 Information system at Automobile Association of Slovenia (AMZS)

AMZS is the Automobile Association of Slovenia, having around 100,000 members - private car drivers. It offers services to its membership and to the members of associated foreign partner automobile clubs. One of the services is the web site that provides information on the road status in Slovenia. An actual status of the Slovene motorways is presented on their web site (http://www.amzs.si).
9.1.3 Information system used by the Police (Policija)

The Police are responsible for traffic safety and law enforcement. They have information systems providing information on:

- traffic accident reporting to the Operation and Communication Centre
- road traffic control measures
- road accident statistics
- transport of hazardous goods and violations of respective regulations.

Pertinent information is published on the website (http://www.policija.si/si/).

9.1.4 Radio Slovenia Road Traffic Information Service

Radio Slovenia uses the electronic information systems of DARS, the Police, the DRSC and others to broadcast reports on road traffic situation in Slovenia.

9.1.5 Information systems at the Directorate of the Republic of Slovenia for Roads (DRSC)

DRSC is a body within the Ministry of Transport that undertakes professional-technical, developmental, organisational and administrative tasks relating to the construction, maintenance and protection of main and regional roads; tasks relating to transport in road freight and passenger traffic; and vehicle type approval. The following information is available from them:

- records on national roads
- traffic counting on national roads and partly for motorways (Traffic Agent System)
- public information on the condition of and traffic on national roads.

Traffic information of DRSC is published on DRSC web site (URL: http://www.drsc.si/default1.asp?l=2&n=42&p=content).
9.1.6 Information system at Fire Officers Association (Gasilska zveza Slovenije)

Fire Officers Association help at the fires and other accidents that happen on the roads and motorways. They keep records and statistics of their intervention on:

- fire on the roads
- accidents with danger goods on roads

They also maintain the web site (URL: http://www.gasilec.net/
podrobnostatistika požarov)

9.1.7 Chamber of Commerce and Industry of Slovenia (GZS)

GZS is an independent, non-profit making organisation, associating business enterprises and activities. They have the Transport and Communications Section, which represents the professional transport sector in Slovenia. It maintains the database of transport enterprises.

9.1.8 Insurance companies

Insurance companies have their own information systems, dealing with indemnities of injuries and material damages. Statistical data such as the volume of indemnities per damage or injuries could be available from these sources.

9.2 Strategic planning of Slovene motorway operations

9.2.1 A generic strategy of Slovene motorways operations is required

Once the motorways are built the question might arise of whether a motorways operations and maintenance strategy is needed. This question might be addressed differently in Slovenia, which as a small EU country, than in a large one.

For Slovene motorways operations and maintenance, the strategy is needed for the following reasons:
a) Motorways operations shall return the investment in the motorways from the toll collection.
b) Motorways throughput (and with it, connected motorways performance measures) may assure smooth traffic operations and minimise traffic congestion.
c) Frequent and heavy traffic congestion may oblige motorway users to divert to other roads and therefore diminish the toll revenues.
d) A too high motorway toll might cause the motorways users to take other roads and diminish the toll revenues.
e) Optimal motorways operations and maintenance might increase the earned revenue.
f) Future competition between the motorways in Slovenia, Austria, Italy and Croatia might affect the long term traffic behaviour patterns, and reduce the revenue from international traffic.

In the light of these points, it can be seen that in the near future Slovene motorways will be part of a competitive environment and a competitive economic strategy should therefore be developed before such a situation emerges.

9.2.2 The EU and Slovene platforms for strategy

In the establishing of information systems, contemporary approaches claim that a business strategy is one of the main drivers for defining the scope, technology, costs and other related issues of the information system. This is important since the information system should support the corporation in its strategic orientation. Strategic alignment between a corporate business strategy and information system should be established so that the information system facilitates the business (Ward and Peppard, 2002, p.44-45). Strategic information system planning is therefore needed.

Regarding the information system technology for the roads the following circumstances will have to be taken into account:

- The European Union has already elaborated the political platform and is financing the development of new organisational (legal framework for country cross-border interoperability of) and information technologies (“on the vehicle” units, toll collection systems etc.) as well as standardisation. The EU is aware that only integrated transport without national borders and without traffic stops for the performance of services or their payment is
an imperative for the smooth and advantageous internal transport services. The EU issued the White Paper on Transport Policy (2001) that gives a general direction of the concerns and development. Strategy regarding ITS in the EU is described there together with measures for its implementation.

- Slovenia has no elaborated political, organisational or technological ITS platforms. Some are in the process of elaboration. The methodology developed in this thesis could be a systematic step towards this goal. It is also clear that the Slovene platform will have to comply with the one from the EU.

This situation in the EU and Slovenia, and, taking into account that there are many stakeholders and pressure groups with an interest in the establishment of the motorway ITS system, does not allow for more elaborated results in this thesis. It would therefore be premature, and it is not the task of this thesis, to align the Slovene motorways operations and Slovene motorway ITS system with a motorway business strategy.

The situation of the strategic information system planning for Slovene motorways confirms the findings of a research paper (Groznik et al., 2000) that the majority of Slovene organisations, and government institutions, do not have a strategy of information systems.

9.2.3 Towards a generic business strategy of Slovene motorways

Porter in his research of competition shows four generic business strategies within which Slovene motorways will have to find its own strategic path:

- cost leadership strategy (low cost on broad scope)
- differentiation strategy (uniqueness of service on broad scope for higher price)
- cost focus strategy (low cost on narrow scope) or
- differentiation focus strategy on service (uniqueness of service on narrow scope)

It is beyond the scope of this thesis to determine the competitive strategy of Slovene motorways operations. Some limitations that emerge from the geopolitical position of Slovenia, some economic rules of the EU regarding the compulsory methodology of toll calculations, ecological
costs of transportation etc., will have to be seriously considered, when defining the appropriate generic operational strategy. The pertinent organisations will have to do it in the near future.

9.3 Towards a Slovene ITS system strategy - strategic alignment with business strategy

As developed by Porter in his work for business strategies, five competitive forces are important for strategic considerations of a business i.e.: power of suppliers, power of users, threat of substitutes, threat of new entrances in the business and the existing competition. Information systems strategy researchers see the essence of the information systems strategy development in the role these systems have in five competitive forces. Applegate et. al., (1999, p. 64-71) see the role of information technology in the relationship to business strategy as follows:

- Information technology can in the existing competition radically change the cost structure of products/services, cost of distribution channels and cost of service, if the technological impact causes the change in the costs or improves or differentiates the services. Slovene stakeholders with the Ministry of Transport in the first place, will have to analyse the future role of the information technology.

- Information technology can prevent or enlarge the entry barriers of new entrants of services, or enable them to entry the business, if the technology is used/produced in Slovenia. If the Slovene motorways will not be equipped with the information technology, new entrants having adequate technology might enter Slovenia with special services. This situation has to be envisaged and analysed carefully and an action plan drawn. Information technology has an impact on the economies of scale, switching costs from the existing service providers to new entrants and access to service provider channels. Evaluation should be done from the point of view of the existing service providers and new entrants.

- Information technology can have an impact on the usage of substitute services, if these services are offered at a lower price. A lower price may be achieved by the usage of information technology. A special bundling of services
might prevent or make difficult the usage of substitute services. A careful analysis of Slovene circumstances that ease or hamper the usage of substitute services is needed.

- Information technology can increase or decrease users' bargaining power. If better or more integrated services are provided from competitors and the costs of existing service providers are high, the users may acquire higher bargaining power. If there is a majority of large users, they have larger bargaining power. The situation of Slovene users has to be carefully analysed.

- Information technology has an impact on the power of the suppliers to Slovene motorways. This is important regarding the number of suppliers of components of information technology. Slovene motorways need to have a choice of components and develop their own resources for information system integration, support and maintenance. Modular approach in procurement of information technology is therefore recommended.

The role of information technology in the provision of services should be carefully analysed in each of the above-mentioned categories and as a whole. The result should be an ITS system and information technology strategy, consistent and supportive to a general business strategy of Slovene motorway operations and maintenance.

9.4 Deployment of the methodology for establishing a Slovene ITS system

After the definition of the strategy of the Slovene motorway operations and the aligned Slovene ITS strategy, a methodology developed in this thesis should be used for establishing a Slovene ITS system. These activities are somewhat complicated, given the many stakeholders and, possibly, pressure group interests involved. Defining the strategy, strategic ITS alignment and ITS development is easier, if conducted within one organisation, where the chief executive officer and management can resolve problems easier. Situation is a bit more complicated if there are few independent partners who have to reach an acceptable compromise of their interests. The latter is the case in Slovenia where the Ministry of Transport should have the prime responsibility among the partners for conducting the
processes defined and described in this thesis, or appoint an agent to conduct this work.

10 CONCLUSION

This thesis sought to develop a viable methodology, based on some theoretical background in general systems theory.

It is composed of three parts: theory, methodology and preparation for the implementation.

The theoretical part deals with the general systems theory as it was originally presented by Bertalanffy and further developed by Luhmann. Its original theoretical contribution is in an attempt to make the initial mathematical formulations based on Luhmann’s general systems theory, the new concepts of which are self-referencing and autopoiesis. Formal method for information system definition was presented as well.

The approach taken in the methodical elaboration was not to develop everything from the beginning but, rather, to consider international efforts and results in systems engineering. It appears that the consequence of this approach is a substantial reduction in the time needed for the preparation of a methodological framework for a future Slovene motorway ITS system.

A combination of the ISO/IEC 15288 System Life Cycle Processes standard, the IEEE P1220 Standard for the Application and Management of the Systems Engineering Process and the European ITS Framework Architecture, developed through the EC granted projects and the PMI Project Management Method forms a solid basis for a successful gradual development and implementation of a Slovene motorway ITS system.

Given that, stakeholders (i.e. institutions that will monitor the development of the Slovene motorway ITS system and change their requirements through time) form part of the system, the theoretical concept of autopoiesis might be used. Self-referencing i.e. considering the entire Slovene motorway ITS system as a system of subsystems is assured.

It can therefore be stated that the framework of the developed methodology fits with the modern general systems theoretical background.
The original contribution of this thesis is twofold. As far as the review of the available literature showed, this is the first attempt at the initial mathematical formulation of Luhmann’s general systems theory. Furthermore, the practical methodology as a combination of existing internationally recognised methods was developed, which is tailored to the general and specific requirements for the development of a Slovene motorway ITS system.

Further work in the following three directions is suggested. First, the theoretical one should be directed towards an improved and consistent general systems theory. Luhmann himself claims that the general systems theory lacks consistency in its presentation, but it was found that some theoretical concepts in the area of discernment and differentiation are not sufficiently elaborated. Second, the practical work in the methodological framework needs to be refined in more detail. The project management method that is a framework itself needs to be adapted to the actual project. The appropriate project management tools should be selected from the project management toolbox in the near future. Third, the conversion from the improved general systems theory into the practical methodology might be an interesting topic of further research.

11 LITERATURE


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