Advanced Design of Intelligent transport systems

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Content

1. Introduction

Telematics is a result of convergence and following progressive synthesis of telecommunication technology and informatics. The effects of telematics are based on synergism of both disciplines.

Telematics can be found in wide spectrum user areas, from an individual multimedia communication towards intelligent use and management of large-scale networks (e.g. transport, telecommunications, public service). Advanced telematics provides intelligent environment for knowledge society establishment and allows expert knowledge description of complex systems. It also includes legal, organizational, implementation and human aspects.

Transport Telematics/ Intelligent Transport Systems (ITS) connects information and telecommunication technologies with transport engineering to achieve better management of transport, travel and forwarding processes by using the existing transport infrastructure.

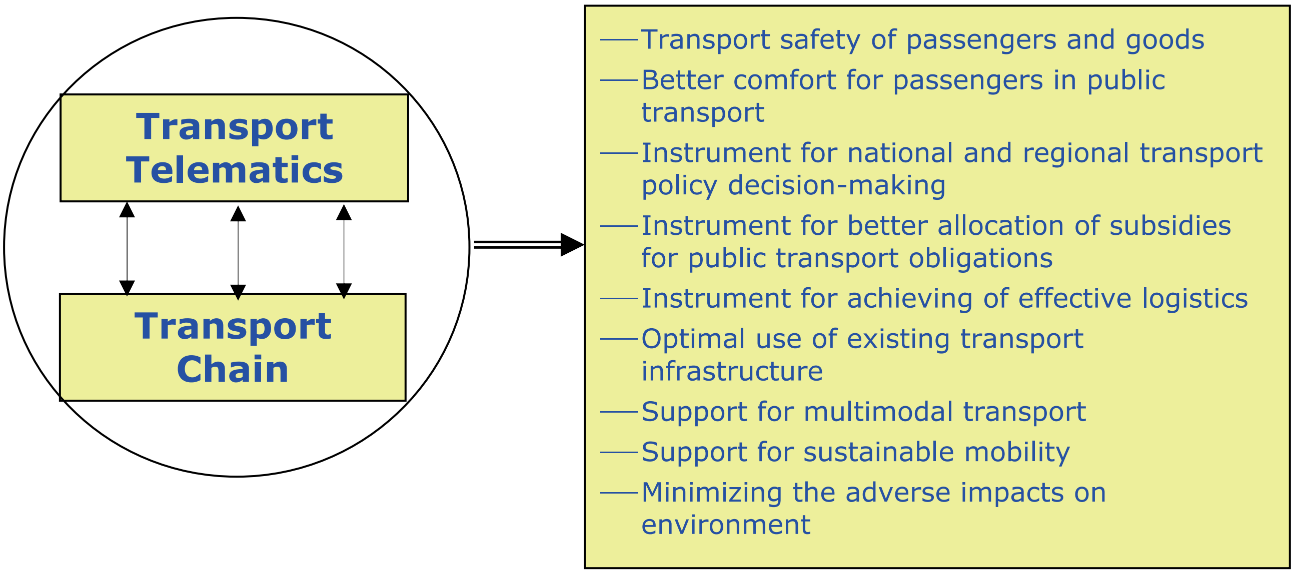


Fig.1.1 Transport telematics / Intelligent transport systems definition

Inteligent Transport Systems are concerned with the use of new information, sensor and communication technologies to support transport services and applications across all modes. The development of ITS, in accordance with ERTICO and the European Commission, provides an opportunity to apply advanced technology to systems and methods of transport for efficient, comfortable and safer highways, railways, inland waterways, airports, ports and linkages between these different types of transport.

Fig. 1.2 shows the basic organizational components of an ITS system. In rows, we can define the parts related to means of transport (passengers and goods), vehicles (cars, railway machines, aircraft, etc.), infrastructure (roads, highways, etc.) and transport terminators (logistical centers, etc.). In columns, there are technical means, means for management (SW, control strategies, etc.) and economical/passport susbsystems for management of different organizations. The model shown in Fig. 1.2 is applicable to all kinds of transport including the multimodal transport. The model in Fig. 1.3 represents the hierarchical structure of an ITS system where each level has different control and management strategy. From this point of view it is very important to say that an essential part of the ITS is formed by telecommunication environment. It is evident that the main guaranting telecommunication service must be between the first and second level of our system.

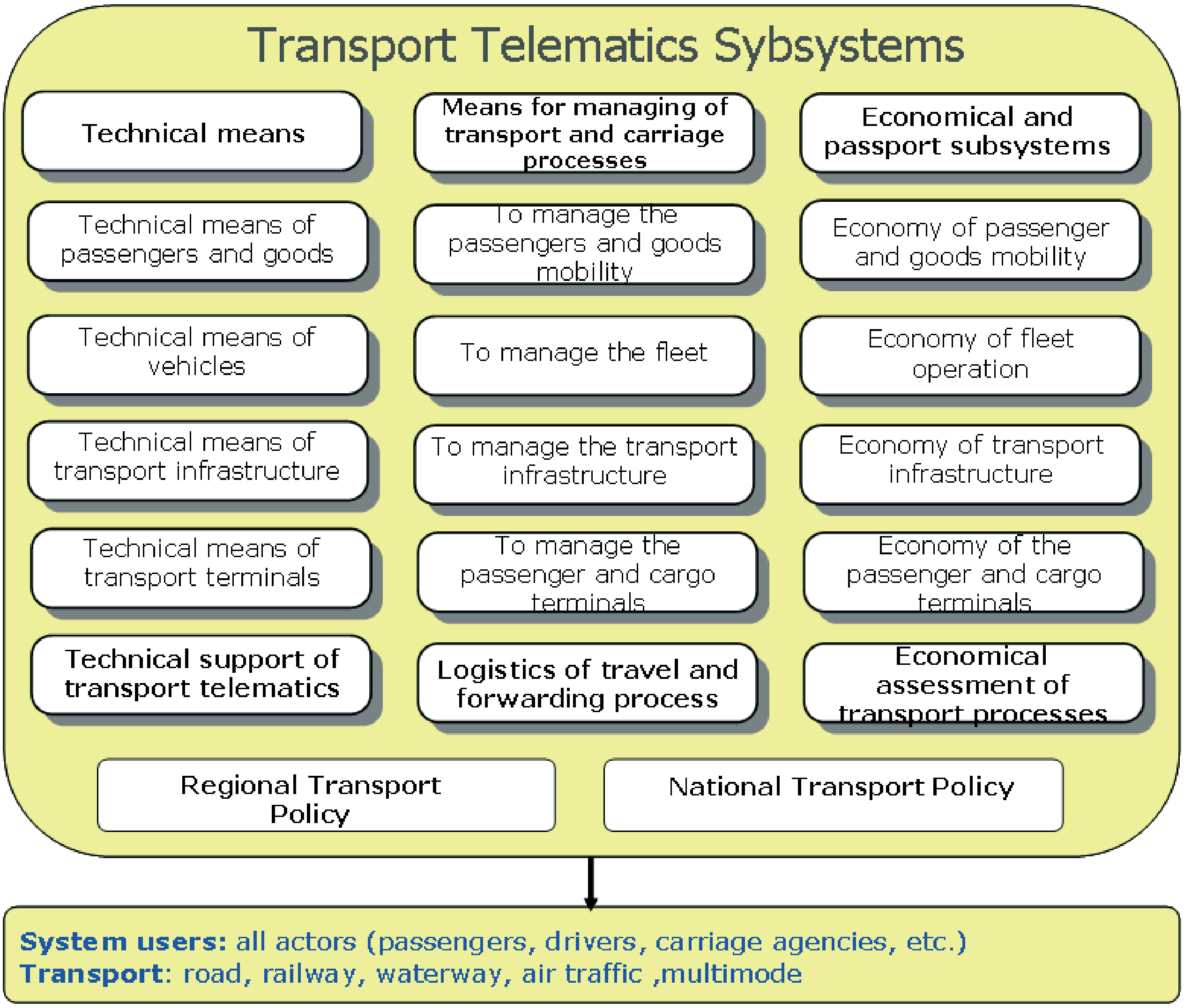


Fig. 1.2 Organizational decomposition of ITS system

As an example, a telematics application (TA) is taken into account, with its decomposition illustrated in Fig. 1.4.

Based on a wide vision of ITS deployment throughout Europe, the Trans-European Network for Transport (TEN-T) aims at establishing appropriate interconnection, interoperability and accessibility between services both on long-distance routes and in conurbation areas. The start period of ITS is characterized by strong investments for research and equipment in the road domain by private and public actors. It was in this period that the 3 biggest ITS organizations were created: ITS-America, ERTICO-ITS Europe and ITS-Japan.

Then came the experimental development period characterized by a major concern with interoperability of systems, which led public authorities to promoting of the definition of common architecture for ITS systems. In Europe it began with the EC (European Commission) programme “Advanced Road Transport Telematics” with Euro-regional cross-border projects in order to test inter-operability of road traffic management and information systems. In the railway domain, EC launched the ERTMS project (European Rail Traffic Management System) to improve effectiveness and inter-operability of signalling systems. In parallel, experimentations of e-ticketing and e-payment for public transport and Electronic Toll Collection (ETC) systems for toll motorway were conducted.

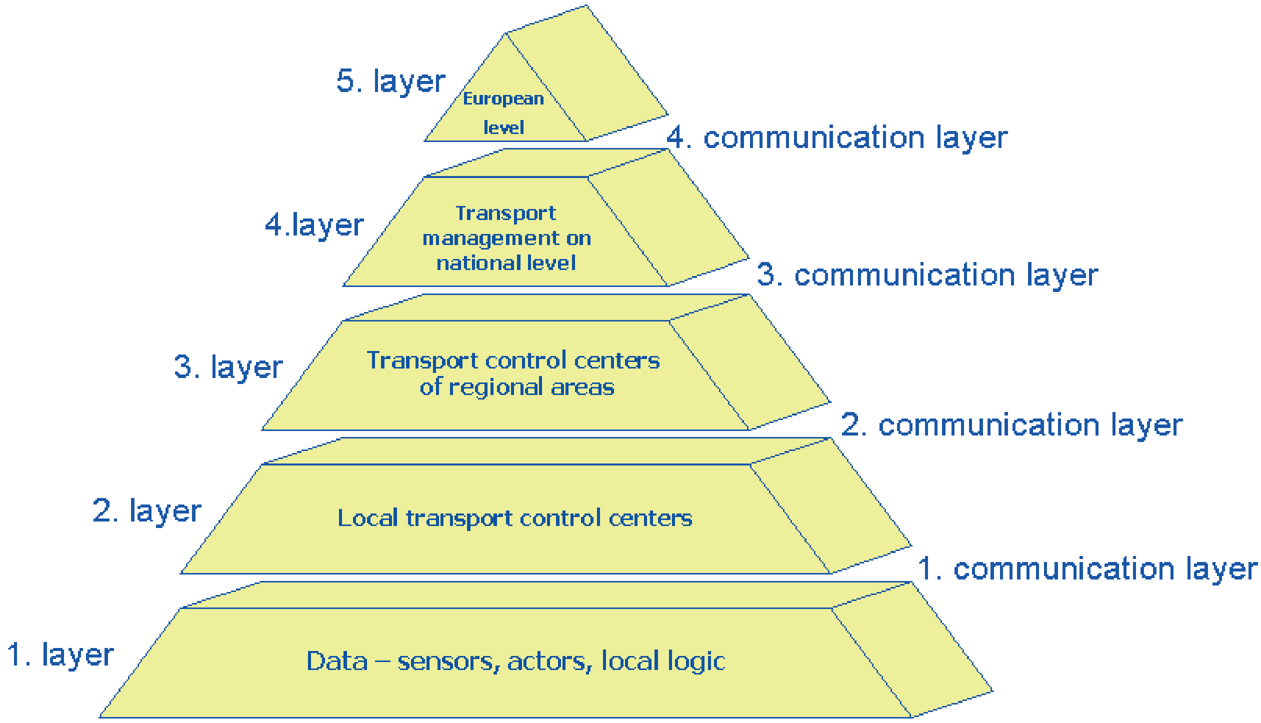


Fig 1.3 Hierarchical decomposition of ITS system

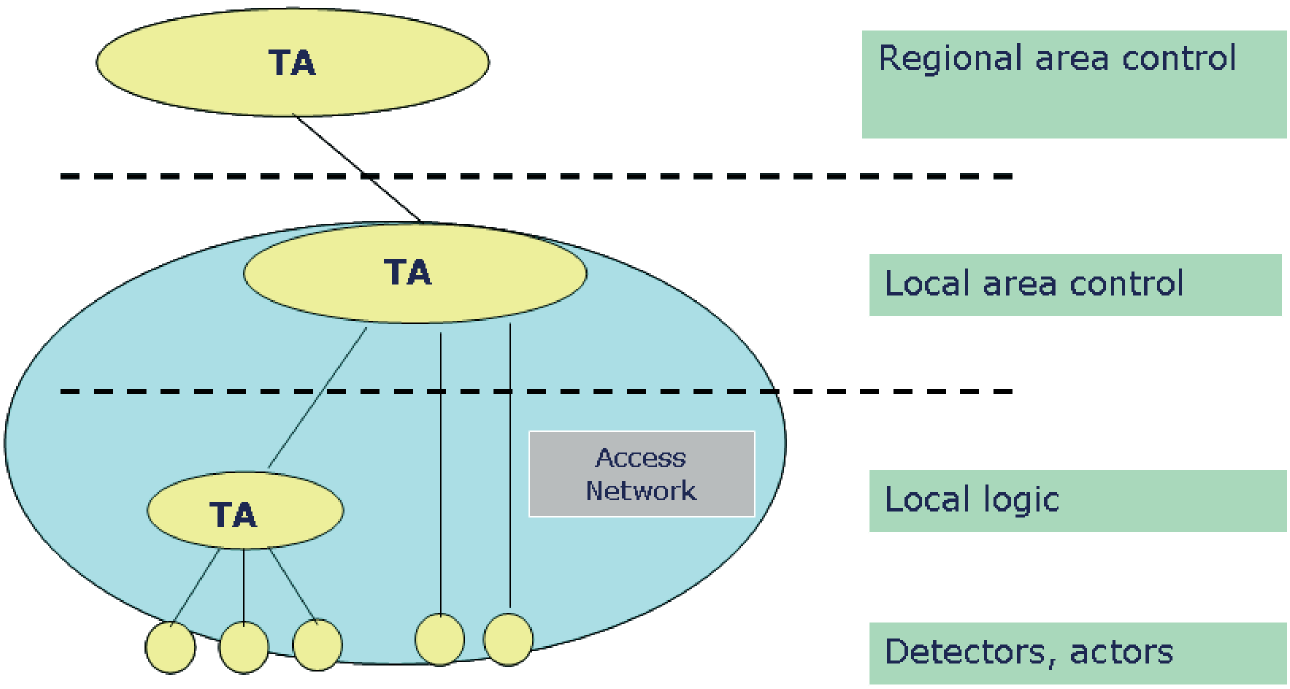


Fig 1.4 Decomposition of telematics application (TA) into three hierarchical levels

The following period of development for the market, and the extension of ITS in all transport modes has been characterized by two main preoccupations in Europe, as well as in the USA, or in Japan: it is safety and sustainability.

2. ITS Design Methodology

In this chapter the system model of ITS is firstly defined in such a way that all features like ITS architecture, ITS standards, and ITS data registry are taken into account.

The processes in the ITS architecture are defined by chaining system components through information links [17]. The chains of functions (processes) are mapped in physical subsystems or modules, and information flows between functions specifying the communication links between subsystems or modules. The functions' grouping yields into a definition of ITS market packages, taking into account the market availability of modules/applications.

If time, performance or other constrains are assigned to different functions and information links, the result of the analysis is represented by a table of different, sometimes even contradictory system requirements assigned to each physical subsystem (module) and physical communication links between the subsystems.

Referring to ITS architecture and ITS market packages, the mathematical tool of modelling ITS systems and subsystems is introduced. With help of mathematical tools the appropriate telecommunication environment can be statically/dynamically selected or switched, data can be pre-processed and reduced, e.g. in an on-board unit, and the ITS technical design can be optimized.

The ITS designer must also take into account the economical aspects. Naturally, the ITS effectiveness definition is an essential issue, therefore, it is strongly emphasised. On that account, internationally reputable methodology of cost-benefit evaluation (CBA) is chosen and connected with the effectiveness definition, so the effectiveness values are represented by, e.g., the Net present value, Internal rate of return, Pay-off period, etc.

2.1 ITS System Model

The ITS system model is defined in Fig.2.1 where the link between real and modeled system components is described. The ITS architecture defines the order of ITS applications in real world. ITS interfaces must be in line with ITS standards, and the ITS data registry represents the model of the used ITS databases.

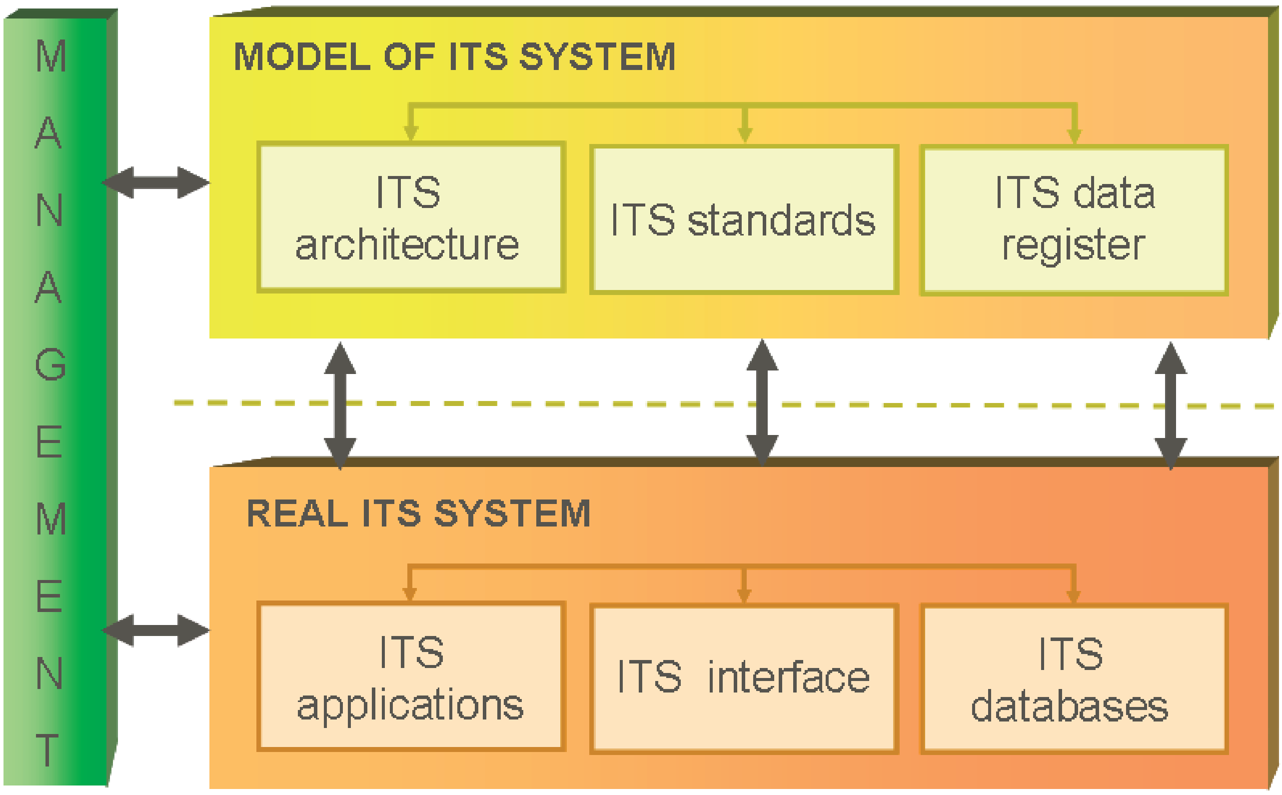


Fig.2.1 ITS System Model

In the following chapters, each part of the system model will be discussed in detail. The management issue shown in Fig. 2.1 represents the methodology of smart ITS design and maintanance with help of a well-tuned model of an ITS system.

We can summarize the basic management issues as follows:

- Optimisation of telecommunication environment between subsystems
- Maximal exploitation of the existing ITS subsystems (specific for the region)
- Optimal geographical distribution of ITS subsystems (hierarchical structure, sharing of control centers)
- Unified implementation of software and hardware components within ITS systems (charge deduction for multi-licences)
- Recommendation of favourable investment strategy
- Protocol definitions for the whole set of ITS applications
- Continual comparison between an ITS model and the reality

2.1.1 ITS Architecture

Generally, the ITS architecture is presented as a system abstract which was designed to create a uniform national or international ITS development and implementation environment. In other words, it should give us a direction to produce interoperable physical interfaces, system application parts, data connections, etc. Thus we can say that architecture is an ITS application or service development tool.

The ITS architecture reflects several aspests of the examined system, and therefore can be differetiated as:

- Reference architecture - which defines the main terminators of the ITS system (the reference architecture yields to the definition of boundary between the ITS system and the environment of the ITS system),
- Functional architecture - defines the structure and hierarchy of ITS functions (the functional architecture yields to the definition of functionality of the whole ITS system),
- Information architecture - defines information links between functions and terminators (the goal of information architecture is to provide the cohesion between different functions),
- Physical architecture - defines the physical subsystems and modules (the physical architecture could be adopted according to the user requirements, e.g. legislative rules, organisation structure, etc.),
- Communication architecture - defines the telecommunication links between physical devices (correctly selected communication architecture optimises telecommunication tools),
- Organisation architecture - specifies competencies of single management levels (correctly selected organisation architecture optimises management and competencies at all management levels).

The instrument for creating ITS architecture is the process analysis shown in Fig.2.2. The system component carries the implicit system function (F1, F2, F3, G1, G2, G3, etc.). The terminator (e.g. a driver, consignee, an emergency vehicle) is often the initiator as well as the terminator of the selected process.

The chains of functions (processes) are mapped on physical subsystems or modules (the first process is defined by functions F1, F2 and F3 in Fig.2.2, the second process is defined by chaining the functions G1, G2 and G3) and the information flows between the functions which specify the communication links between the subsystems or modules.

From the viewpoint of the construction of the selected subsystem, it is possible to consider a single universal subsystem, fulfilling the most exacting system parameters, the creation of several subsystem classes according to a set of system parameters, creation of a modular subsystem where the addition of another module entails the increase of system parameters, etc.

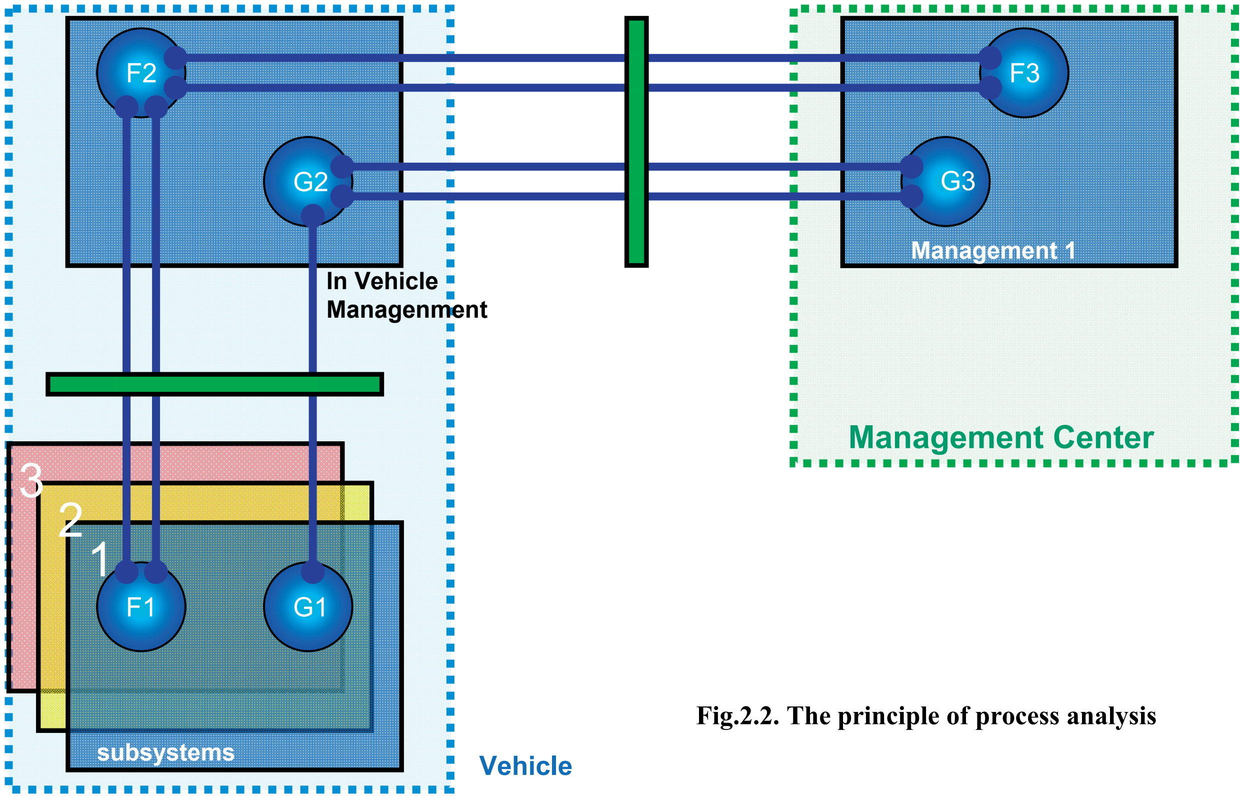


Fig.2.2. The principle of process analysis

The same principle may be applied while designing the telecommunication environment between the selected subsystems (unified radio band frequency for all transport telematic applications, combination of individual transmission systems, combination of fixed and radio networks, etc.). In analogy with the subsystem design, the design of telecommunication environment can be divided into several classes, or, as the case may be, the transmission environment can be designed in a modular way, when higher system parameters of the information transmission are likely to be achieved by using additional modules.

Similar situation applies to the other part of the ITS system, or it can occur between ITS systems of different transport modes, e.g., road and railway transport. It is necessary to consider whether each transport mode has to have a particular subsystem added , or whether it is possible to share the subsystem(s) available, etc.

ITS architecture covers the following makro-functions:

- Provide Electronic Payment Facilities (toll collection system based on GNSS/CN, DSRC, etc.)
- Provide Safety and Emergency Facilities (emergency call, navigation of rescue services, etc.)
- Manage Traffic (traffic control, maintenance management, etc.)
- Manage Public Transport Operations (active preferences of public transport, etc.)
- Provide Advanced Driver Assistance Systems (car navigation services, etc.)
- Provide Traveller Journey Assistance (personal navigation services, etc.)
- Provide Support for Law Enforcement (speed limit monitoring, etc.)
- Manage Freight and Fleet Operations (fleet management, monitoring of dangerous goods, etc.)
- Supply Archive Information (location-based information, etc.)

Fig. 2.3 describes the principle of context diagram as a part of ITS reference architecture. The functional and informational architecture is shown in Fig.2.4 and Fig.2.5 where Fig.2.4 presents the macro-functions (9 basic macro-functions) and information links between them and Fig.2.5 presents the detail view on macro-function 5 (Provide Advance Driver Assistant System).

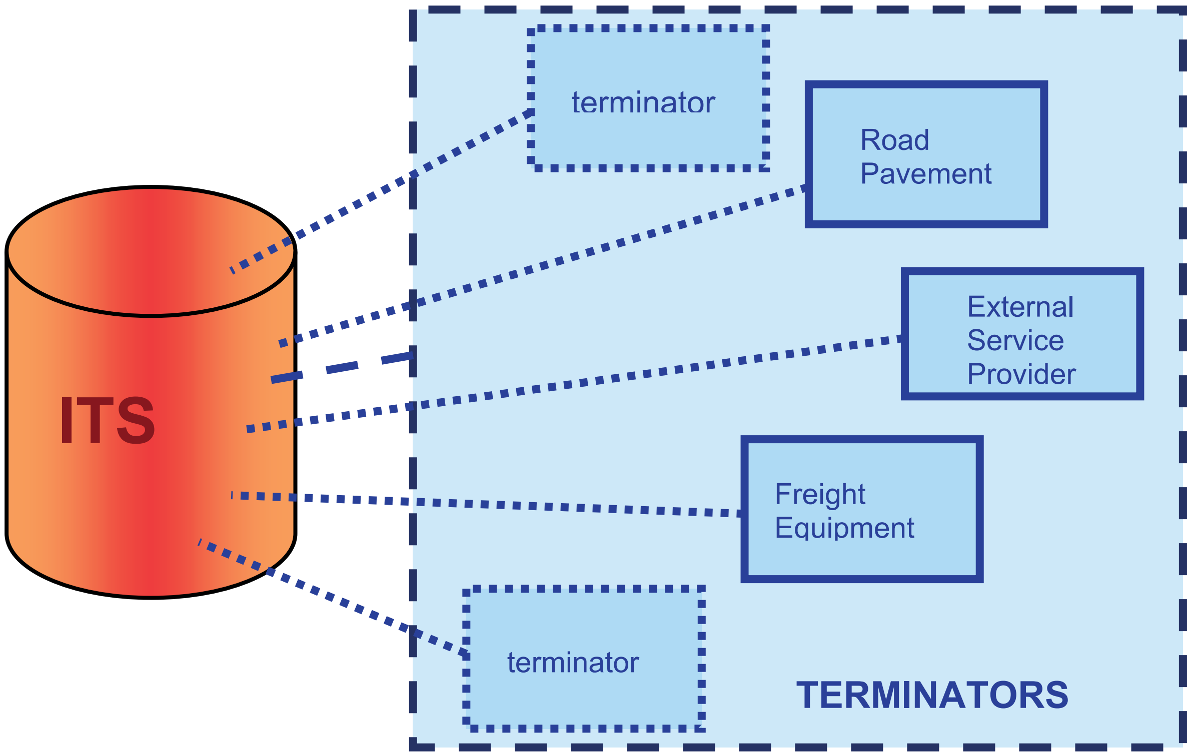
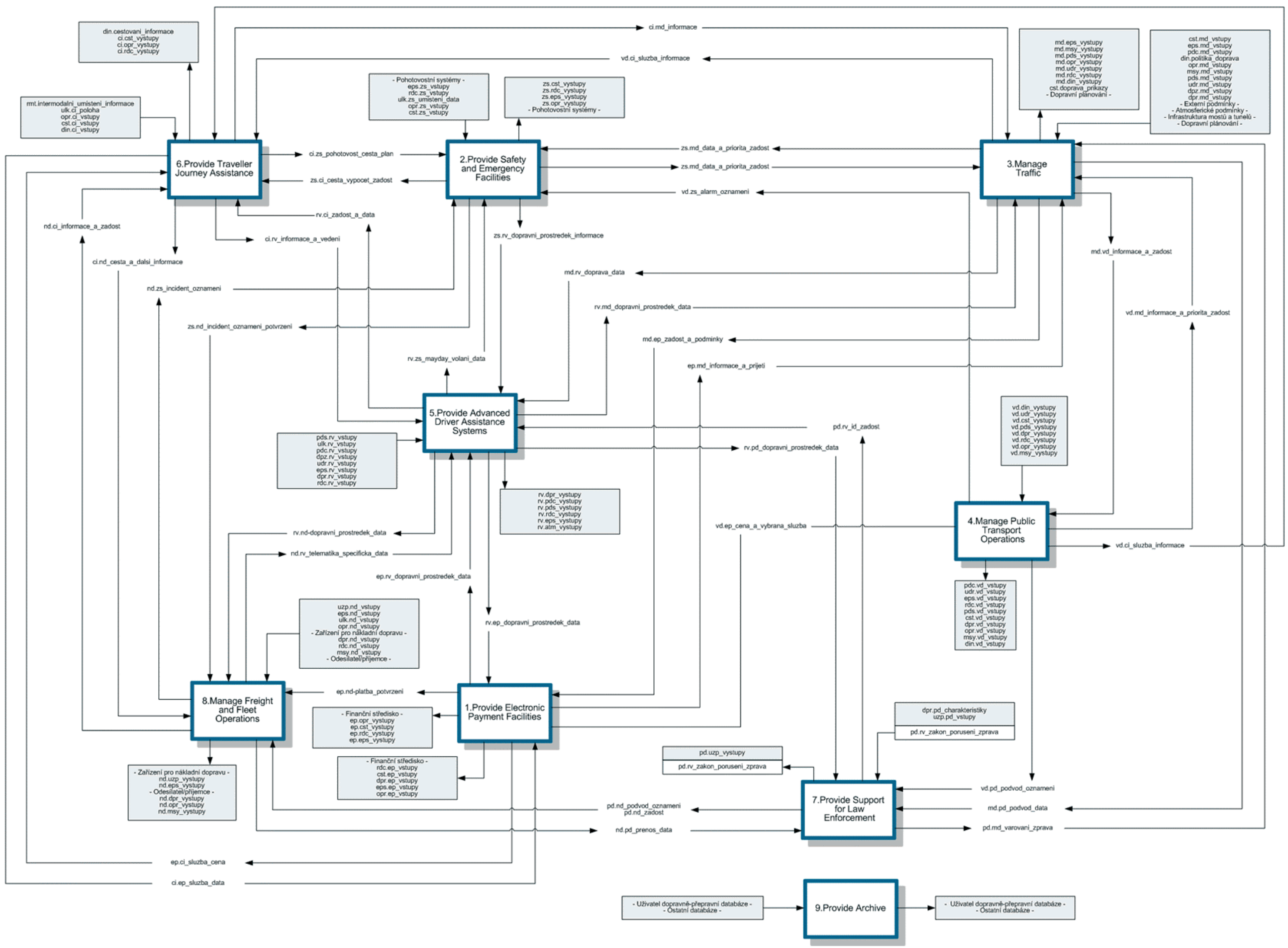


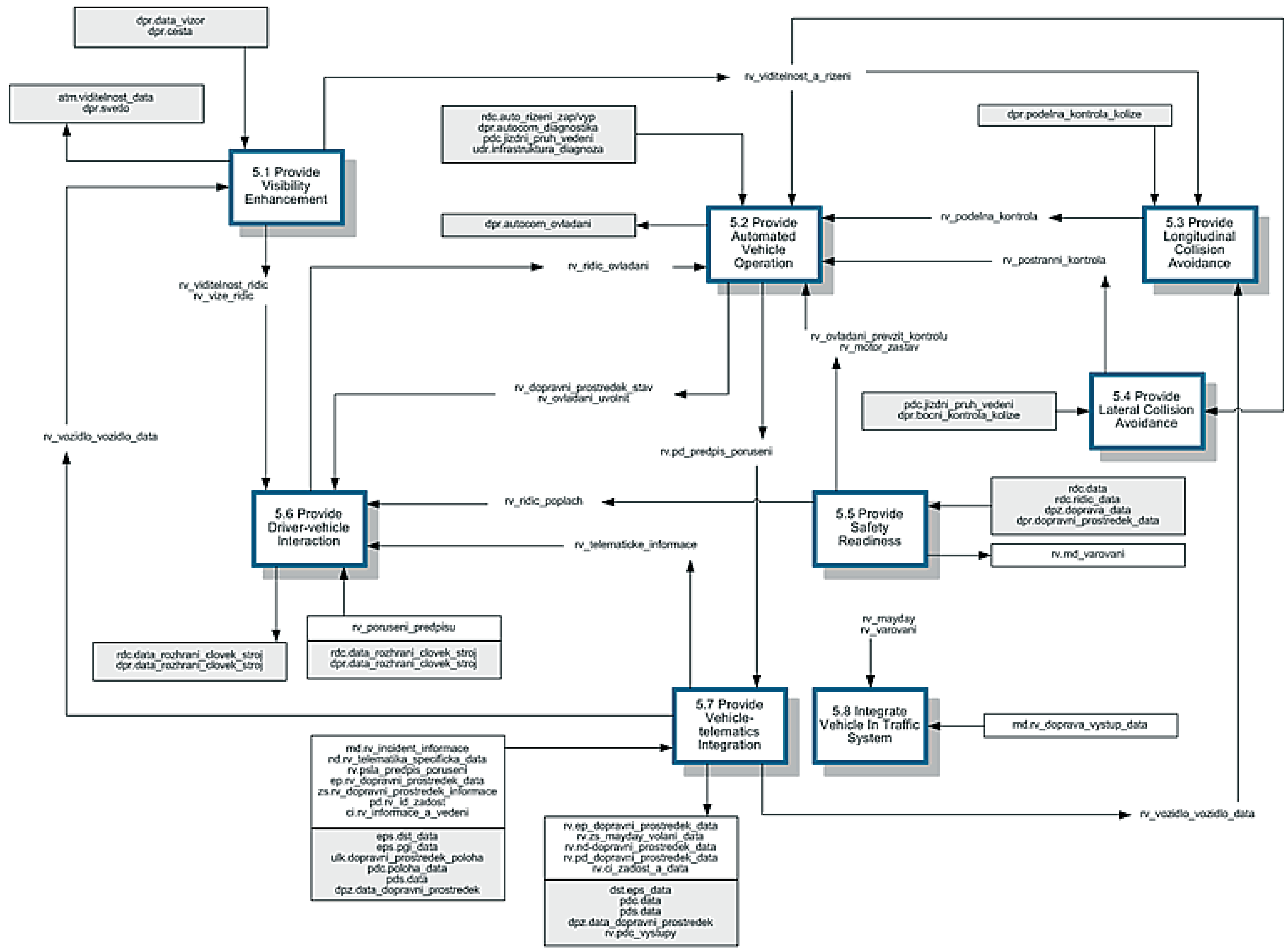
Fig.2.3 Principle of Context Diagram

The information links in the white box represent the linkage between functions, whereas the information links in the grey box represent the information linkage between the functions and terminators.

Fig. 2.6 shows the information architecture where it is given the selected function No.5 "Provide Advanced Driver Assistance Systems". We can see the data flows to/from this function and terminators or functions, respectively. This situation is realized in the first level of functional decomposition. Fig. 2.7 represents the deeper decomposition to deeper functional level and shows the function No. 5.7 "Provide Vehicle-Telematics Integration". We can see the information links on the level of such selected functional decomposition.



1.Provide Electronic Payment Facilities
2.Provide Safety and Emergency Facilities
3.Manage Traffic
4.Manage Public Transport Operations
5.Provide Advanced Driver Assistance Systems
6.Provide Traveller Journey Assistance
7.Provide Support for Law Enforcement
8.Manage Freight and Fleet Operations
9.Provide Archive
ci.md_informace
vd.ci_sluzba_informace
ci.zs_pohotovost_cesta_plan
zs.ci_cesta_vypocet_zadost
zs.md_data_a_priorita_zadost
vd.zs_alarm_oznameni
rv.ci_zadost_a_data
ci.rv_informace_a_vedeni
nd.ci_informace_a_zadost
ci.nd_cesta_a_dalsi_informace
zs.rv_dopravni_prostredek_informace
md.vd_informace_a_zadost
md.rv_doprava_data
rv.md_dopravni_prostredek_data
vd.md_informace_a_priorita_zadost
md.ep_zadost_a_podminky
ep.md_informace_a_prijeti
nd.zs_incident_oznameni
zs.nd_incident_oznameni_potvrzeni
rv.zs_mayday_volani_data
pd.rv_id_zadost
rv.pd_dopravni_prostredek_data
vd.ep_cena_a_vybrana_sluzba
vd.ci_sluzba_informace
rv.nd-dopravni_prostredek_data
nd.rv_telematika_specificka_data
ep.rv_dopravni_prostredek_data
rv.ep_dopravni_prostredek_data
ep.nd-platba_potvrzeni
vd.pd_podvod_oznameni
md.pd_podvod_data
pd.md_varovani_zprava
pd.nd_podvod_oznameni
pd.nd_zadost
nd.pd_prenos_data
ep.ci_sluzba_cena
ci.ep_sluzba_data
din.cestovani_informace
ci.cst_vystupy
ci.opr_vystupy
ci.rdc_vystupy
rml.intermodalni_umisteni_informace
ulk.ci_poloha
opr.ci_vstupy
cst.ci_vstupy
din.ci_vstupy
- Pohotovostní systémy -
eps.zs_vstupy
rdc.zs_vstupy
ulk.zs_umisteni_data
opr.zs_vstupy
cst.zs_vstupy
zs.cst_vystupy
zs.rdc_vystupy
zs.eps_vystupy
zs.opr_vystupy
- Pohotovostní systémy -
md.eps_vystupy
md.msy_vystupy
md.pds_vystupy
md.opr_vystupy
md.udr_vystupy
md.rdc_vystupy
md.din_vystupy
cst.doprava_prikazy
- Dopravní plánování -
cst.md_vstupy
eps.md_vstupy
pdc.md_vstupy
din.politika_doprava
opr.md_vstupy
msy.md_vstupy
pds.md_vstupy
udr.md_vstupy
dpz.md_vstupy
dpr.md_vstupy
- Externí podmínky -
- Atmosférické podmínky -
- Infrastruktura mostů a tunelů -
- Dopravní plánování -
pds.rv_vstupy
ulk.rv_vstupy
pdc.rv_vstupy
dpz.rv_vstupy
udr.rv_vstupy
eps.rv_vstupy
dpr.rv_vstupy
rdc.rv_vstupy
rv.dpr_vystupy
rv.pdc_vystupy
rv.pds_vystupy
rv.rdc_vystupy
rv.eps_vystupy
rv.atm_vystupy
vd.din_vystupy
vd.udr_vystupy
vd.cst_vystupy
vd.pds_vystupy
vd.dpr_vystupy
vd.rdc_vystupy
vd.opr_vystupy
vd.msy_vystupy
pdc.vd_vstupy
udr.vd_vstupy
eps.vd_vstupy
rdc.vd_vstupy
pds.vd_vstupy
cst.vd_vstupy
dpr.vd_vstupy
opr.vd_vstupy
msy.vd_vstupy
din.vd_vstupy
uzp.nd_vstupy
eps.nd_vstupy
ulk.nd_vstupy
opr.nd_vstupy
- Zařízení pro nákladní dopravu -
dpr.nd_vstupy
rdc.nd_vstupy
msy.nd_vstupy
- Odesílatel/příjemce -
- Finanční středisko -
ep.opr_vystupy
ep.cst_vystupy
ep.rdc_vystupy
ep.eps_vystupy
- Finanční středisko -
rdc.ep_vstupy
cst.ep_vstupy
dpr.ep_vstupy
eps.ep_vstupy
opr.ep_vstupy
- Zařízení pro nákladní dopravu -
nd.uzp_vystupy
nd.eps_vystupy
- Odesílatel/příjemce -
nd.dpr_vystupy
nd.opr_vystupy
nd.msy_vystupy
dpr.pd_charakteristiky
uzp.pd_vstupy
pd.rv_zakon_poruseni_zprava
pd.uzp_vystupy
pd.rv_zakon_poruseni_zprava
- Uživatel dopravně-přepravní databáze -
- Ostatní databáze -
- Uživatel dopravně-přepravní databáze -
- Ostatní databáze -



5.1 Provide Visibility Enhancement
5.2 Provide Automated Vehicle Operation
5.3 Provide Longitudinal Collision Avoidance
5.4 Provide Lateral Collision Avoidance
5.5 Provide Safety Readiness
5.6 Provide Driver-vehicle Interaction
5.7 Provide Vehicle-telematics Integration
5.8 Integrate Vehicle In Traffic System
dpr.data_vizor
dpr.cesta
atm.viditelnost_data
dpr.svetlo
rv_viditelnost_a_rizeni
rdc.auto_rizeni_zap/vyp
dpr.autocom_diagnostika
pdc.jizdni_pruh_vedeni
udr.infrastruktura_diagnoza
dpr.podelna_kontrola_kolize
dpr.autocom_ovladani
rv_podelna_kontrola
rv_postranni_kontrola
rv_viditelnost_ridic
rv_vize_ridic
rv_ridic_ovladani
rv_ovladani_prevzit_kontrolu
rv_motor_zastav
rv_dopravni_prostredek_stav
rv_ovladani_uvolnit
pdc.jizdni_pruh_vedeni
dpr.bocni_kontrola_kolize
rv_vozidlo_vozidlo_data
rv.pd_predpis_poruseni
rv_ridic_poplach
rdc.data
rdc.ridic_data
dpz.doprava_data
dpr.dopravni_prostredek_data
rv.md_varovani
rv_telematicke_informace
rv_poruseni_predpisu
rdc.data_rozhrani_clovek_stroj
dpr.data_rozhrani_clovek_stroj
rdc.data_rozhrani_clovek_stroj
dpr.data_rozhrani_clovek_stroj
rv_mayday
rv_varovani
md.rv_doprava_vystup_data
md.rv_incident_informace
nd.rv_telematika_specificka_data
rv.psla_predpis_poruseni
ep.rv_dopravni_prostredek_data
zs.rv_dopravni_prostredek_informace
pd.rv_id_zadost
ci.rv_informace_a_vedeni
eps.dst_data
eps.pgi_data
ulk.dopravni_prostredek_poloha
pdc.poloha_data
pds.data
dpz.data_dopravni_prostredek
rv.ep_dopravni_prostredek_data
rv.zs_mayday_volani_data
rv.nd-dopravni_prostredek_data
rv.pd_dopravni_prostredek_data
rv.ci_zadost_a_data
dst.eps_data
pdc.data
pds.data
dpz.data_dopravni_prostredek
rv.pdc_vystupy
rv_vozidlo_vozidlo_data

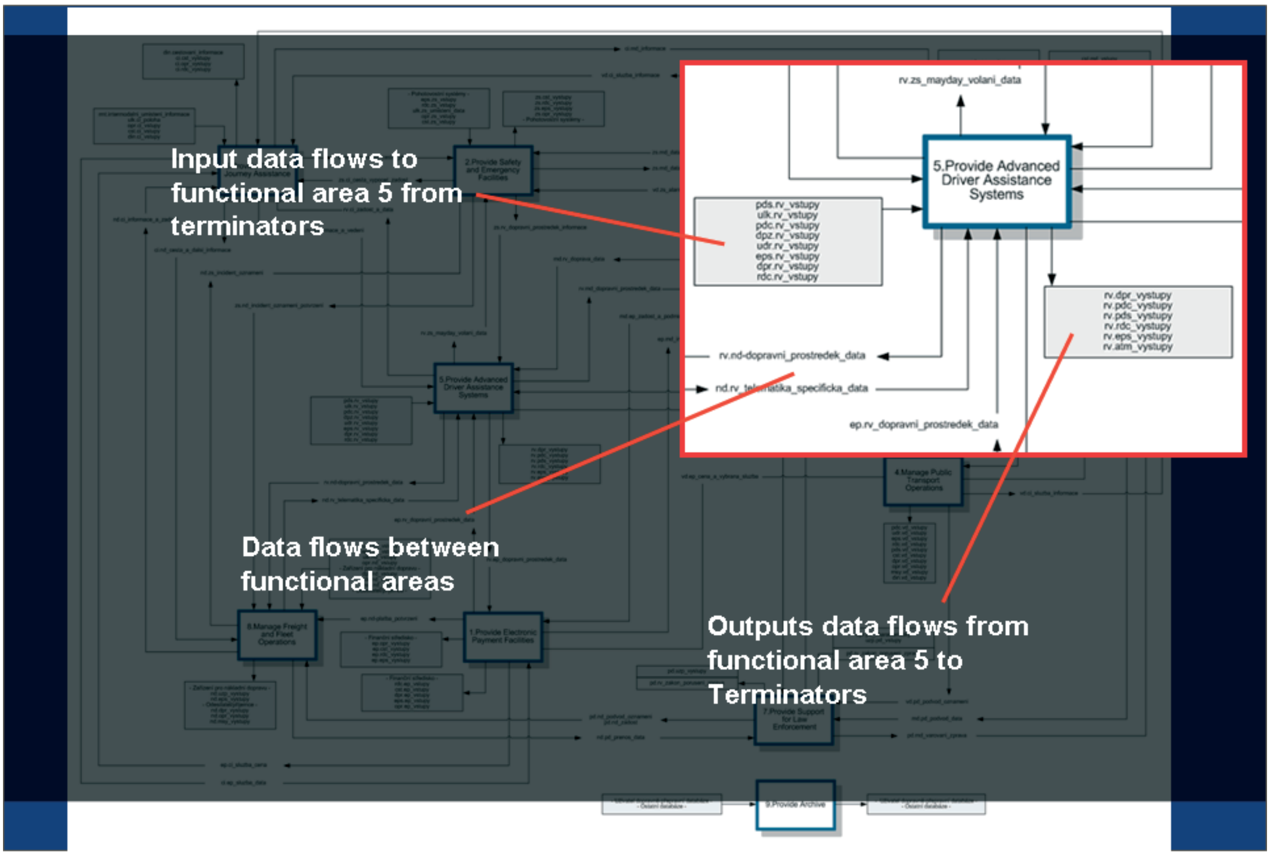


Fig.2.6 Data flow to/from ITS function No.5

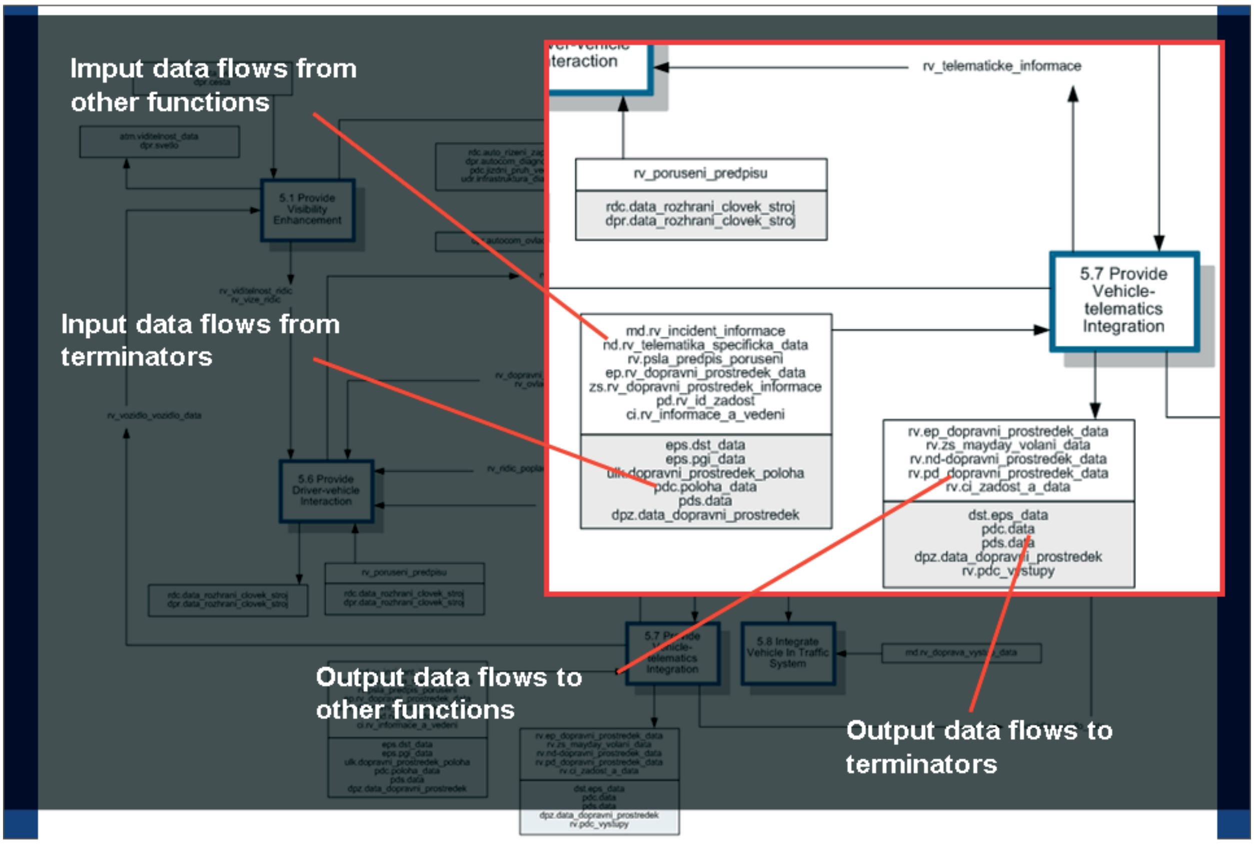


Fig.2.7 Data flow to/from ITS function No.5.7

The physical ITS architecture is shown in Fig.2.8. On the interactive web it is available on the web page www.its-portal.cz.

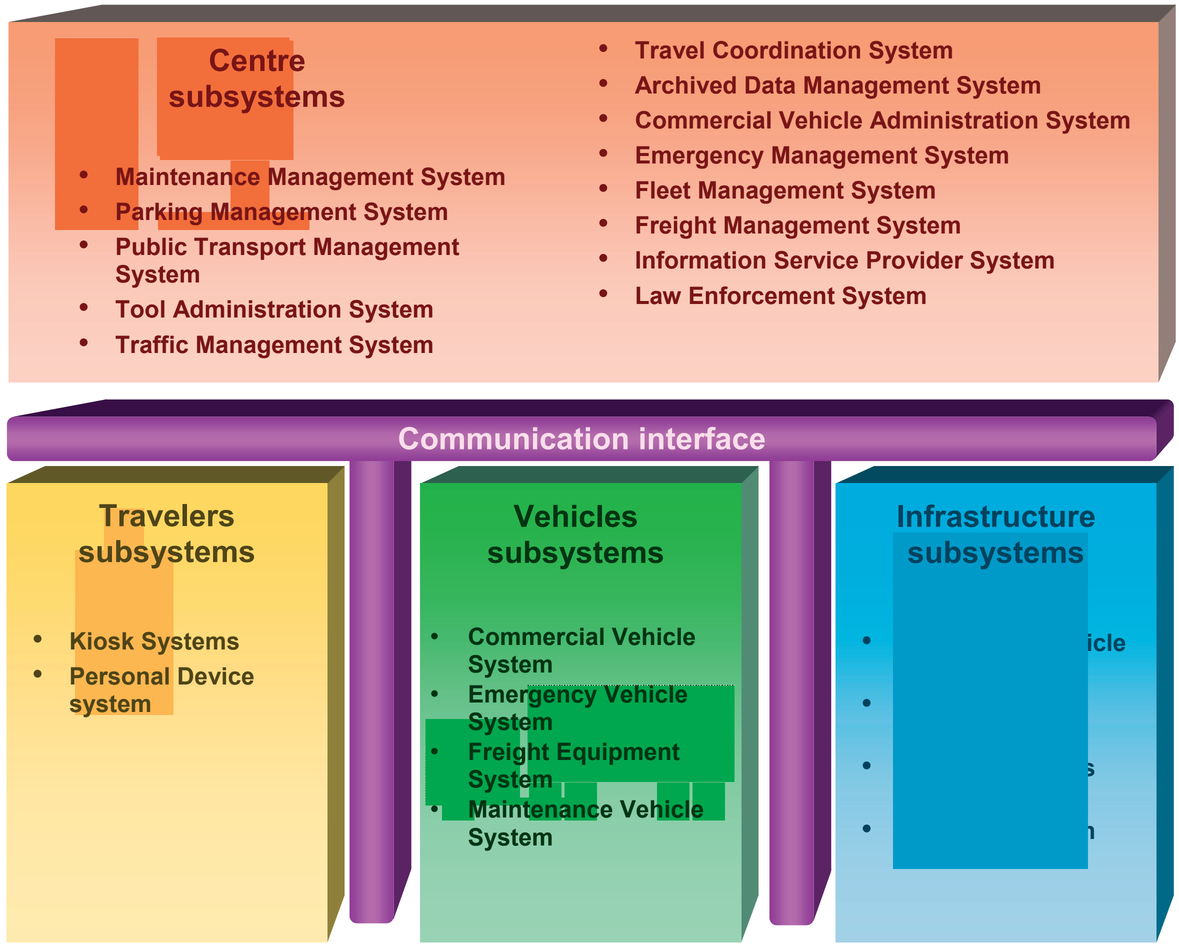


Fig. 2.8 ITS physical architecture

2.1.2 ITS Market Packages

Each market package defines a group of subsystems, terminators, and data links (logical and physical) dedicated to cover functions coming directly from these elements. Basic market package sets are as follows:

- Transport management
- Management of integrated and safety systems
- Traffic information
- Public transport
- Commercial vehicles management
- Data management and archiving
- Advanced vehicle safety systems

The relation between ITS architecture, ITS market packages and real applications is shown in Fig.2.9.

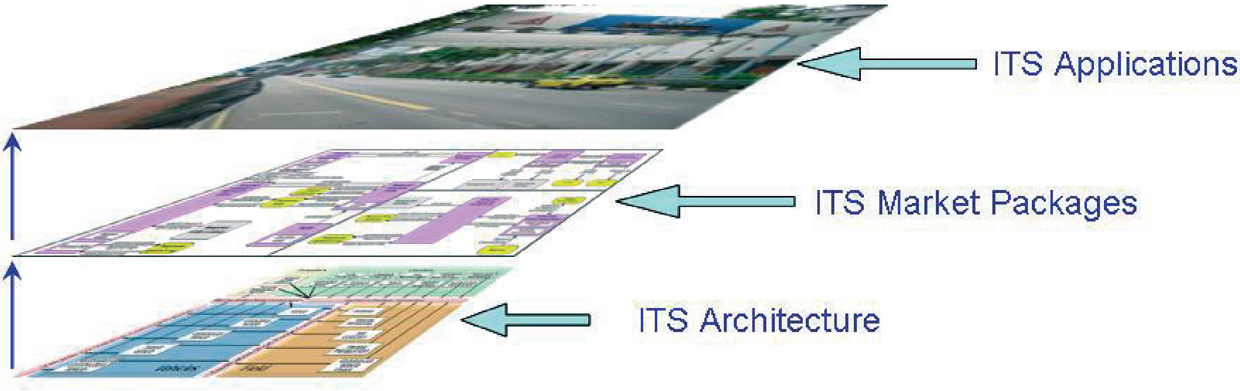


Fig.2.9 ITS architecture, ITS market packages and real ITS applications

A Market Package ATIS04-Dynamic Route Guidenance example is presented in Fig. 2.10. More information about the USA ITS architecture and 91 Market Packages is available on http://www.iteris.com.

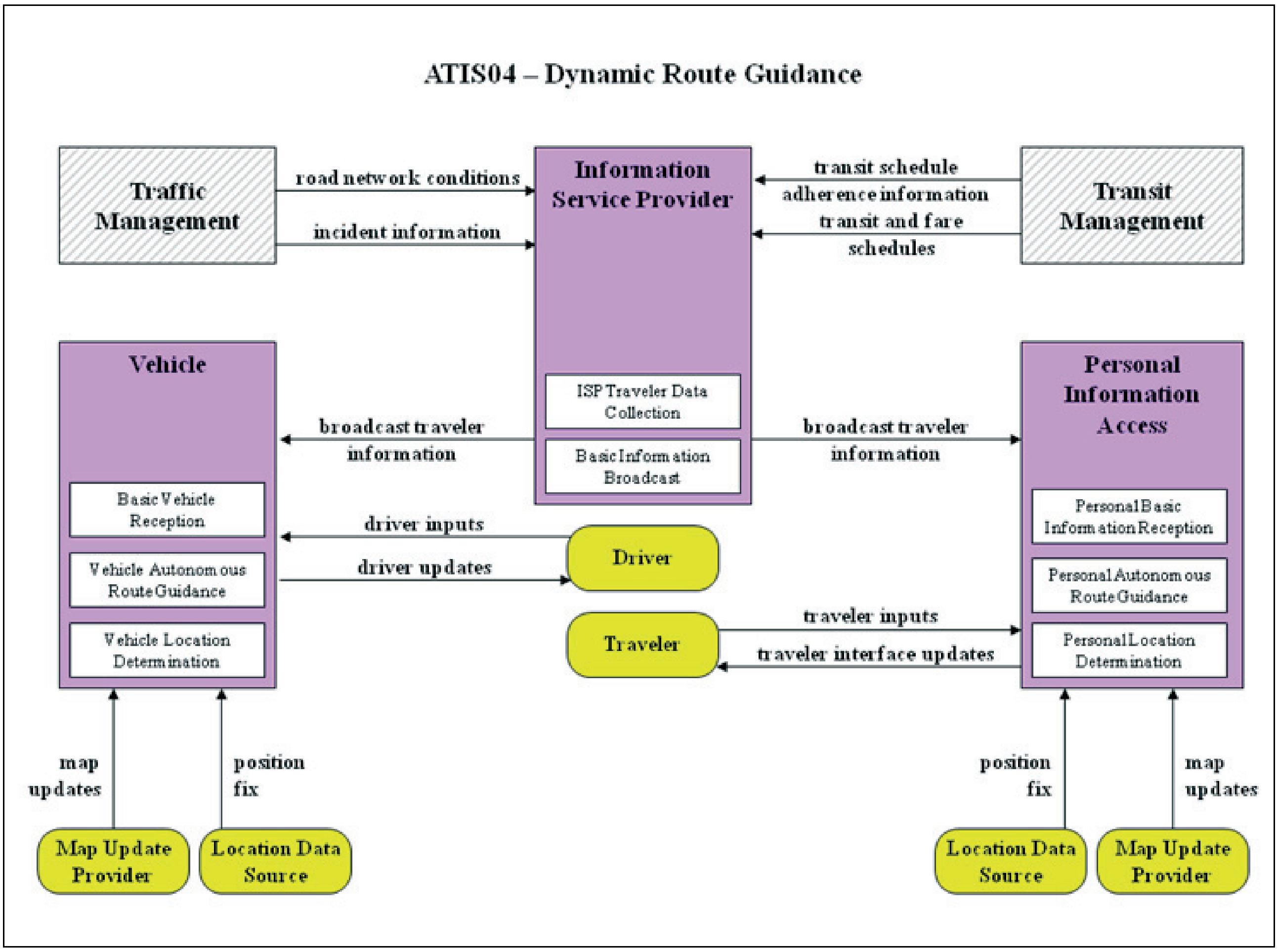


Fig. 2.10 Example of the "Dynamic Route Guidenance" market package

2.1.3 ITS Standards

ITS standards are created within the well-known standardisation bodies CEN 278 and ISO 204. These two groups are specialize in standards of the ITS or transport telematics area. Just for information, we can summarize the CEN working groups as follows:

WG1 - Automatic Fee Collection and Access Control
WG2 - Freight and Fleet Management System
WG3 - Public Transport
WG4 - Traffic and Traveler Information
WG5 - Traffic Control
WG6 - Parking Management
WG7 - Geographic Road Database
WG8 - Road Traffic Data
WG9 - Dedicated Short Range Communication
WG10 - Human-Machine Interface
WG11 - Systems Interface
WG12 - Automatic Vehicle and Equipment Identification
WG13 - Architecture and Terminology
WG14 - After-theft Systems for Vehicle Recovery

The main role of the ITS standards is to define the parameter, time, and protocol synchronization. Fig. 2.11 defines requirements for a localization parameter in such a way that the vehicle position can be used for both systems (electronic fee and freight fleet management). The ITS data registry, which will be described in next chapter, identifies the proper system for localization of the vehicle. If the position information is defined correctly, it can be shared within the ITS system as a whole. Then, the ITS standards can fix such requirements for cross-boarder applications.

If we continue analysing, we can easily find out that for both systems time synchronization has to be defined, as it is shown in Fig.2.12. Each application, however, has different requirements for the sample frequency of data transmission. The solution is given in Fig. 2.13 where the data protocol is introduced as an interface between both systems. The Abstract Syntax Notation Numbre One (ASN.1) is used in the standards to define all the above meantioned features. We can also specify other requirements, such as personal data, etc. as it is shown on Fig. 2.13.

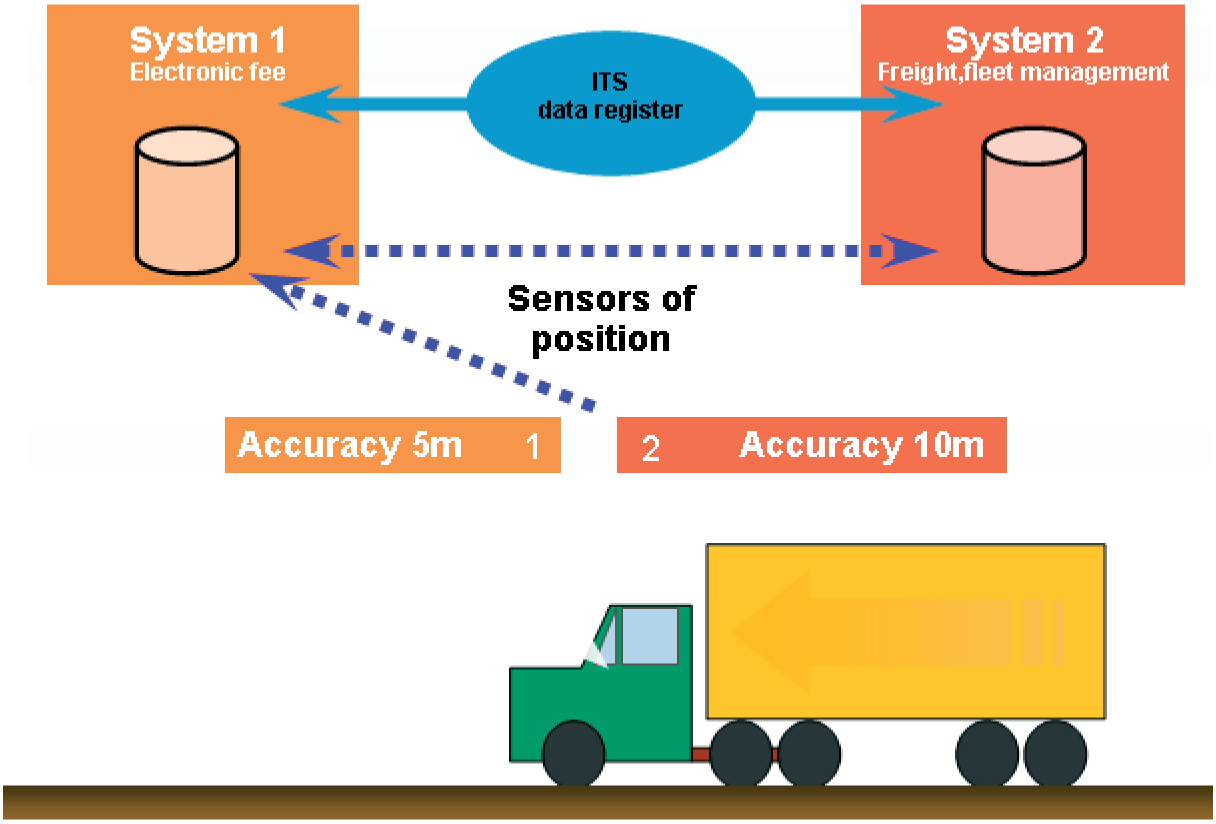


Fig 2.11 Parameter synchronization

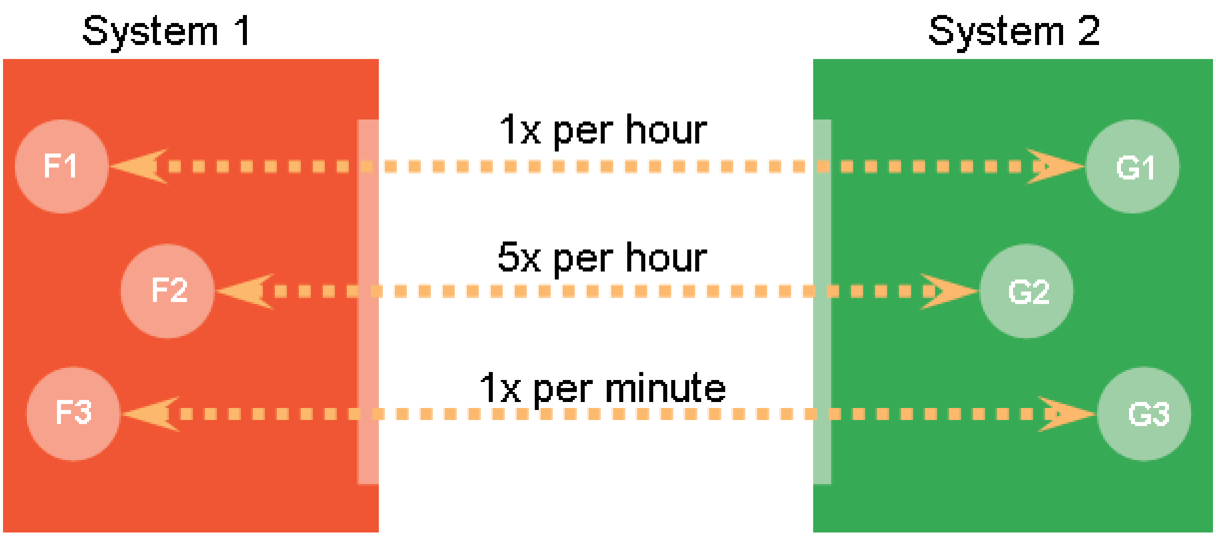


Fig 2.12 Time synchronization

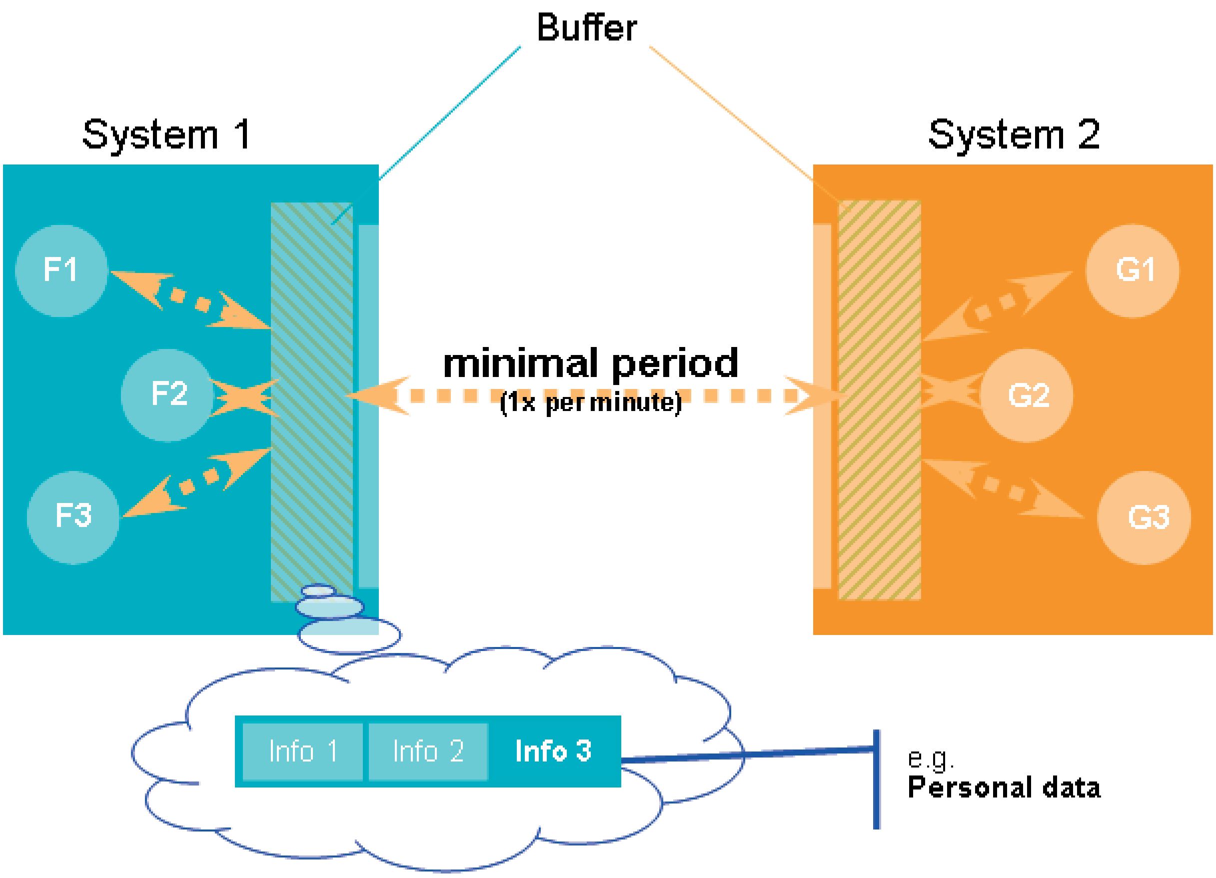


Fig 2.13 Protocol synchronization

The example of ASN.1 syntax for personal data of ITS application is given:

```
Personalia DEFINITIONS ::=
BEGIN
-- ASN.1 Type Definition:
Personal Data ::=SEQUENCE {
Title          IA5String (SIZE(1..50))OPTIONAL,
PostCode       INTEGER(0..10000),
FullName       SET OF IA5String
…
}
-- ASN.1 Value Definition:
personalData PersonalData::={
Title          „Project Manager“,
PosrCode       7002,
```

FullName {“Karel”, “Vonasek”}

}

END

where predefined data types are:

- integers (INTEGER)
- booleans (BOOLEAN)
- character strings (IA5String, UniversalString, ...)
- bit string (BIT STRING)

or composed data types

- structures (SEQUENCE)
- list (SEQUENCE OF)
- choice between types (CHOICE)

There are available three "parcers" BER (**B**asic **E**ncoding **R**ules), DER (**D**istinguished **E**ncoding **R**ules) and PER (**P**acked **E**ncoding **R**ules) that can transform the standardized data structure written in ASN.1 into more than 150 programming languagues.

2.1.4 ITS Data Registry

The ITS data registry is defined in standard ISO/IEC 11179. It is an information resource kept by a registration authority that describes the meaning form of data elements, including registration identifiers, definitions, names, value domains, metadata and administrative atributes.

The data registry should manage two types of information:

- Data and information standards at micro and macro information levels to be used in data management
- Information about current (legacy) data elements

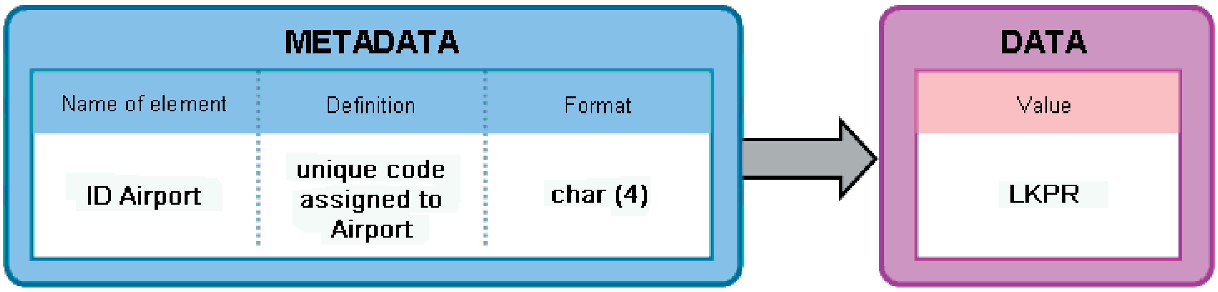
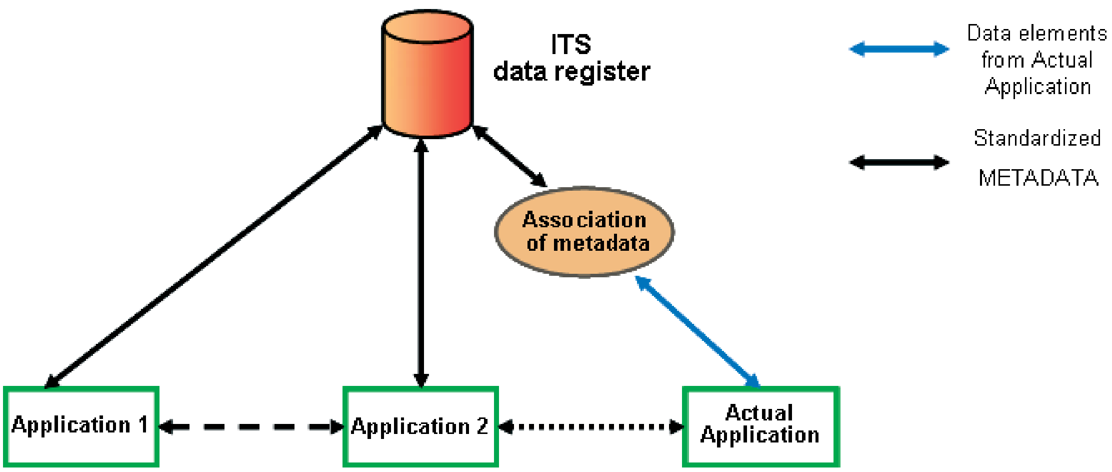


Fig 2.14 ITS data registry

In Fig 2.14, a basic example of the data registry is presented. In a real database, we have a data element LKPR. In addition to the data element, a complete metadata description must be available in the data registry. In this case, three components can be identified: the name of the element (the airport ID), the definition of the data element (a unique code assigned to the airport) and the format of the data element (chart (4)).

In future-oriented ITS applications, the ITS data registry will be able to work automatically, as well as it will be able to collect metadata from real applications as it is shown in Fig. 2.15.



2.15 Automatic metadata collection by ITS data registry

The benefit of the ITS data registry can be summarized as follows:

- Data quality and access – reducing the ambiguity about similar data defined differently across systems
- Interoperability – today, system interfaces are customized between pairs of systems (expensive to build and maintain, inflexible) – solution is data structure definition
- Cost effectiveness – constrained budget can be used when data services can serve multiple systems rather than when each system develops its own data services locally
- Flexibility – common data services developed with automated tools allow system-wide access to metadata and the data behind them more easily and efficiently

The knowledge and smart combination of ITS architecture, ITS standards and ITS data registry can result in the full understanding of the ITS strategy when the designer has a powerfull instrument for the ITS systems implementation and maintanance. But it is not enough, as the question is not what the ITS should look like, but also how this system should work. In other words, we must define the ITS performance parameters for each ITS application to meet all the requirements of a designed ITS system.

2.2 ITS Performance Parameters

In this chapter, the emphasis is on the analysis of performance parameters, assigned to different system components, functions or processes, together with the methodology of their assessment based on limited measured samples, fulfilling the condition of normal distribution.

2.2.1 Definition of performance parameters

The methodology for the definition and measurement of following individual system parameters is being developed within the frame of the ITS architecture. The basic performance parameters can be defined as follows:

- **Accuracy** is the degree of conformance between system true parameters and its measured values that can be defined as the probability

$$P(|p_i - p_{m,i}| \leq \varepsilon_1) \geq \gamma_1 \qquad (1)$$

that the difference between the required system parameter p_i and the measured parameter $p_{m,i}$ will not exceed the value ε_1 on probability level γ_1 where this definition is applicable for all N system parameters $p_1, p_2, .., p_N$.

Reliability is the ability to perform a required function (process) under given conditions for a given time interval that can be defined as the probability

$$P\left(\left|\vec{v}_t - \vec{v}_{m,t}\right| \le \varepsilon_2\right) \ge \gamma_2, t \in \langle 0, T \rangle \qquad (2)$$

that the difference between required system functions (processes) represented by parameters $\vec{v}_t$ and the vector of measured parameters $\vec{v}_{m,t}$ will not exceed the value ε_2 on probability level γ_2 in each time interval *t* from the interval $\langle 0, T \rangle$.

Availability is the ability to perform required functions (processes) at the initialisation (triggering) of the intended operation that can be defined as the probability

$$P\left(\left|q_i - q_{m,i}\right| \le \varepsilon_3\right) \ge \gamma_3 \qquad (3)$$

that the difference between the required rate[1] of successful performing of the function *i* (process *i*) q_i and the measured $q_{m,i}$ will not exceed the value ε_3 at the probability level γ_3.

- **Continuity** is the ability to perform required functions (processes) without non-scheduled interruption during the intended operation that can be defined as the probability

$$P\left(\left|r_i - r_{m,i}\right| \le \varepsilon_4\right) \ge \gamma_4 \qquad (4)$$

that the difference between the required rate of successful performing of the function *i* (process *i*) without interruption r_i and the measured $r_{m,i}$ will not exceed the value ε_4 at the probability level γ_4.

- **Integrity** is the ability to provide timely and valid alerts to the user, when a system must not be used for the intended operation, that can be defined as the probability

$$P\left(\left|S_i - S_{m,i}\right| \le \varepsilon_5\right) \ge \gamma_5 \qquad (5)$$

that the difference between the required rate of successful performing of the alert limit (AL) *i* not later than predefined time to alert (TTA) S_i and the measured $S_{m,i}$ will not exceed the value ε_5 on the probability level γ_5.

- **Safety** can also be covered among the performance parameters, but the risk analysis and the risk classification must be done beforehand with a knowledge of the system environment and potential risk, and then the safety can be defined as the probability

$$P\left(\left|W_i - W_{m,i}\right| \le \varepsilon_6\right) \ge \gamma_6 \qquad (6)$$

that the difference between the required rate of *i* risk situations W_i and the measured ones $W_{m,i}$ will not exceed the value ε_6 on the probability level γ_6.

A substantial part of the system parameters analysis is represented by a decomposition of system parameters into individual sub-systems of the telematic chain. One part of the analysis is the establishment of requirements on individual functions and information linkage so that the whole telematic chain can comply with the above defined system parameters.

---

[1] $q_{m,i} = \frac{Q_i}{Q}$ where Q_i is the number of successful experiments (successful performing of the function *i*, successful performing of the process *i*) and Q is the number of all experiments (both successful and unsuccessful).

The completed decomposition of system parameters will enable the development of a methodology for a follow-up analysis of telematic chains according to various criteria (optimisation of the information transfer between a mobile unit and a processing centre, maximum use of the existing information and telecommunication infrastructure, etc.).

The following communication performance parameters quantify the quality of telecommunication service [16]:

- **Availability** – (i) Service Activation Time, (ii) Mean Time to Restore (MTTR), (iii) Mean Time between Failure (MTBF) and (iv) Virtual Connection Availability
- **Delay** - is an accumulative parameter effected by (i) Interfaces Rates, (ii) Frame Size, and (iii) Load / Congestion of all active nodes (switches) in the line
- **Packet/Frames Loss**
- **Security**

Performance indicators described for communications applications must be transformed into telematic performance indicators structure, and vice versa. Such transformation allows for a system synthesis.

Transformation matrix construction is dependent on detailed communication solution and its integration into telematic system. Probability of each phenomena appearance in the context of other processes is not deeply evaluated in the introductory period. Each telematic element is consequently evaluated in several steps, based on a detailed analysis of the particular telematic and communications configuration and its appearance probability in the context of the whole system performance. This approach represents a subsequent iterative process, managed with the goal of reaching the stage where all minor indicators (relations) are eliminated, and the major indicators are identified under the condition that relevant telematic performance indicators are kept within a given tolerance range.

2.2.2 Quality of measured performance parameters

In this chapter, unified approach applicable for all above mentioned performance parameters [18] will be introduced.

Absolute measuring error (μ_a **)** is the difference between a measured value and the real value or the accepted reference

$$\mu_a = x_d - x_s \tag{7}$$

x_d - measured dynamic value, x_s - corresponding real value or accepted reference

Relative measuring error (μ_r **)** is the absolute measuring error divided by a true value given by

$$\mu_r = \frac{x_d - x_s}{x_s} \tag{8}$$

Accuracy (δ) of a measuring system is the range around the real value in which the actual measured value must lie. The measurement system is said to have accuracy δ if:

$$x_s - \delta \le x_d \le x_s + \delta \tag{9}$$

or straightforwardly:

$$-\delta \le \mu_a \le +\delta \tag{10}$$

Accuracy is often expressed as a relative value in $\pm\ \delta$ %.

Reliability (1-α) of a measuring system is the minimal probability of a chance that a measuring error μ_a lies within the accuracy interval $[-\delta, \delta]$:

$$(1-\alpha) \le P(|\mu_a| \le \delta) \tag{11}$$

where P(.) means the probability value.

Error probability (α) of a measuring system is the probability that a measured value lies further from the actual value than the accuracy:

$$\alpha \geq P(|\mu_a| > \delta) \tag{12}$$

The reliability of measuring system is often controled by the end-user of the measurement system while error probability is generally assessed by the International Organization for Legal Metrology (OIML).
Dependability (β) of an acceptance test is the probability that - on the basis of the sample - a correct judgement is given on the accuracy and reliability of the tested system:

$$P(\alpha \leq P(-\delta < \mu_a < \delta)) \geq \beta \tag{13}$$

The desired dependability determines the size of the sample; the higher the sample, the higher the dependability of the judgement.

2.2.3 Estimation of performance parameters

Tests of normality

With regard to [12] normal distribution will be expected, because using different kinds of statistics, such as order statistics (distribution independent) for small sample sizes, typical for performance parameters, the result may be fairly imprecise. Testing normality is important in the performance parameters procedure, because in analyses containing a lot of data this data is required to be at least approximately normally distributed. Furthermore, the confidence limits assessment requires the assumption of normality. Several kinds of normality tests are available, such as [1]:

- Pearson test (Chi-Square Goodness-of-Fit Test)
- Kolmogorov-Smirnov test
- Anderson-Darling and Cramer-von Mises test

All the above mentioned tests for normality are based on the *empirical distribution function* (EDF) and are often referred to as *EDF tests*. The empirical distribution function is defined for a set of *n* independent observations $X_1, X_2, ..., X_n$ with a common distribution function F(x). Under the null hypothesis, F(x) is the normal distribution. Denote the observations ordered from the smallest to the largest as $X_{(1)}, X_{(2)}, .., X_{(n)}$. The empirical distribution function, $F_n(x)$, is defined as

$$\begin{aligned} &F_0(x) = 0,\ x < X_{(1)} \\ &F_i(x) = \frac{i}{n},\ X_{(i)} \leq x < X_{(i+1)},\ i = 1,....,n-1 \\ &F_n(x) = 1,\ X_{(n)} \leq x \end{aligned} \tag{14}$$

Note that $F_n(x)$ is a step function that takes a step of height *1/n* at each observation. This function estimates the distribution function F(x). At any value x, $F_n(x)$ is the proportion of observations less than or equal to x, while F(x) is the probability of an observation less than or equal to x. *EDF statistics* measure the discrepancy between $F_n(x)$ and F(x).

In the following part the *Pearson test* (Chi-Square Goodness-of-Fit Test) will be introduced as a practical example of EDF tests. The chi-square goodness-of-fit statistic χ_q^2 for a fitted parametric distribution is computed as follows:

$$\chi_q^2 = \sum_{i=1}^{L} \frac{(m_i - n \cdot p_i)^2}{n \cdot p_i} \tag{15}$$

where L is the number of histogram intervals, m_i is the observed percentage in *i*-th histogram interval, *n* is the number of observations, p_i is the probability of *i*-th histogram interval computed by means of theoretical distribution. The degree of freedom for the chi-square test χ^2 is equal to L-r-1, where r is parameters number of theoretical distribution (in case of normal distribution r=2).

Estimation of measuring system's accuracy, reliability and dependability

Let us assume we have a normally distributed set of *n* measurements of performance parameters $\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n}$ (absolute error between prescribed and measured parameters as defined in (7)).

If the mean value or a standard deviation is not known we can estimate both the mean value $\overline{\mu}_a$ and standard deviation s_a from the measured data as follows:

$$\overline{\mu}_a = \frac{1}{n}\sum_{i=1}^{n}\mu_{a,i}$$
$$s_a = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\mu_{a,i} - \overline{\mu}_a\right)^2} \qquad (16)$$

Let *n* be non-negative integer, α, β are given real numbers $(0 < \alpha, \beta < 1)$ and let $\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n}, \mu_{a,y}$ be *n+1* independent identically distributed random variables.

Tolerance limits $L = L(\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n})$ and $U = U(\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n})$ are defined as values so that the probability is equal to β that the limits include at least a proportion $(1-\alpha)$ of the population. It means that such limits L and U satisfy:

$$P\{P(L < \mu_{a,y} < U) \geq 1 - \alpha\} = \beta \qquad (17)$$

A *confidence interval* covers population parameters with a stated confidence. The *tolerance interval* covers a fixed proportion of the population with a stated confidence. *Confidence limits* are limits within which we expect a given population parameter, such as the mean, to lie. *Statistical tolerance limits* are limits which we expect a stated proportion of the population to lie within.

For the purpose of this chapter we will present only results derived under the following assumptions:

- $\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n}, \mu_{a,y}$ are *n+1* independent normally distributed random variables with the same mean μ_0 and variance σ_0^2 (equivalently $\mu_{a,1}, \mu_{a,2}, ..., \mu_{a,n}, \mu_{a,y}$ is a random sample of size *n+1* from the normal distribution with mean μ_0 and variance σ_0^2).
- The symmetry about the mean or its estimation is required.
- The tolerance limits are restricted to the simple form $\overline{\mu}_a - k \cdot s_a$ and $\overline{\mu}_a + k \cdot s_a$, where *k* is a so called *tolerance factor*, $\overline{\mu}_a$ and s_a are *sample mean and sample standard deviations*, respectively, given by (16).

Under the above given assumptions, the condition (17) can be rewritten as follows:

$$P\left\{\Phi\left(\frac{U-\mu_0}{\sigma_0}\right) - \Phi\left(\frac{L-\mu_0}{\sigma_0}\right) \geq 1 - \alpha\right\} = \beta \qquad (18)$$

where Φ is the distribution function of the normal distribution with mean zero and standard deviation equal to one:

$$\Phi(u) = \frac{1}{\sqrt{2 \cdot \pi}} \int_{-\infty}^{u} e^{-\frac{1}{2} \cdot t^2} dt \qquad (19)$$

The solution of the problem to construct tolerance limits depend on the level of knowledge of the normal distribution, i.e., on the level of knowledge of mean deviation $\overline{\mu}_a$ and standard deviation s_a.

In the following part the *accuracy, reliability and dependability of the measuring system* will be mathematically derived for a known mean value and standard deviation, for a known mean value and unknown standard deviation, and for both an unknown mean value and standard deviation.

Known mean value and standard deviation

We can start with the equation [3]:

$$P\left\{P\left[\mu_0 - z_{(1-\alpha/2)} \cdot \sigma_0 \le \mu_{a,y} \le \mu_0 + z_{(1-\alpha/2)} \cdot \sigma_0\right] \ge (1-\alpha)\right\} = 1 \tag{20}$$

where $\mu_{a,y}$ is the measured value, μ_0, σ_0 are known mean value and standard deviation and $z_{(1-\alpha/2)}$ is a percentile of normal distribution (e.g. for $\alpha = 0.05$ we can find in statistical table $z_{0.975} = 1.96$).

Based on (20) we can decide that measuring system's accuracy $\delta = z_{(1-\alpha/2)} \cdot \sigma_0$ is guarantied with measuring system's reliability $(1-\alpha)$. Because the mean value and standard deviation are known, the measuring system's dependability is equal to $\beta = 1$.

Known standard deviation and unknown mean value

Now we expect that the mean value is estimated according to (16). Then we can write the equation [3]:

$$P\left\{P\left[\overline{\mu}_a - k \cdot \sigma_0 \le \mu_{a,y} \le \overline{\mu}_a + k \cdot \sigma_0\right] \ge (1-\alpha)\right\} = \beta \tag{21}$$

where σ_0^2 is the known variance and *k* is computed from the following equation:

$$\Phi\left(\frac{z_{(1+\beta)/2}}{\sqrt{n}} + k\right) - \Phi\left(\frac{z_{(1+\beta)/2}}{\sqrt{n}} - k\right) = 1 - \alpha \tag{22}$$

where the function $\Phi(u)$ was defined in (19) and sample $\overline{\mu}_a$ computed according to (16).

Based on the equation (22) we can say that for the predefined values of measuring system's reliability $(1-\alpha)$ and dependability β and the number of measurements *n* the accuracy of measuring system will be

$$\delta = \left(z_{1-\frac{\alpha}{2}} + \frac{1}{\sqrt{n}} \cdot z_{\frac{(1+\beta)}{2}}\right) \cdot \sigma_0 \tag{23}$$

Known mean value and unknown standard deviation

For a known mean value and unknown standard deviation we can write the equation:

$$P\left\{P\left[\mu_0 - \left(z_{(1-\alpha/2)} \cdot \left(\frac{n}{\chi^2_{(1-\beta)}(n)}\right)^{\frac{1}{2}}\right) \cdot s_a \le \mu_{a,y} \le \mu_0 + \left(z_{(1-\alpha/2)} \cdot \left(\frac{n}{\chi^2_{(1-\beta)}(n)}\right)^{\frac{1}{2}}\right) \cdot s_a\right] \ge (1-\alpha)\right\} = \beta \tag{24}$$

where s_a is estimated according to (16), $\chi^2_{(1-\beta)}(n)$ means chi-quadrate distribution with *n* degree of freedom.

Based on the equation (24) we can say that for predefined values of measuring system's reliability $(1-\alpha)$ and dependability β and the number of measurements *n* the accuracy of measuring system will be:

$$\delta = \left(z_{(1-\alpha/2)} \cdot \left(\frac{n}{\chi^2_{(1-\beta)}(n)} \right)^{\frac{1}{2}} \right) \cdot s_a \tag{25}$$

Unknown mean value and standard deviation

This variant is the most important in many practical cases, but the solution is theoretically very difficult. However, a lot of approximation forms exist based on which the practical simulation could be feasible.

We start by the task description

$$P\{P[\overline{\mu}_a - k \cdot s_a \le \mu_{a,y} \le \overline{\mu}_a + k \cdot s_a] \ge (1-\alpha)\} = \beta, \tag{26}$$

where the sample mean value $\overline{\mu}_a$ and sample standard deviation s_a are estimated from *n* samples according to (16).

Howe [4] defines a very simple approximation form for *k*:

$$k \approx \left(\frac{n+1}{n} \right)^{\frac{1}{2}} \cdot z_{(1-\alpha/2)} \cdot \left(\frac{n-1}{\chi^2_{(1-\beta)}(n-1)} \right)^{\frac{1}{2}}. \tag{27}$$

Bowker [5] defines:

$$k \approx z_{(1-\alpha/2)} \cdot \left[1 + \frac{z_\beta}{\sqrt{2n}} + \frac{5 \cdot z_\beta^2 + 10}{12n} \right]. \tag{28}$$

Ghosh [6] defines the next approximation form:

$$k \approx z_{(1-\alpha/2)} \cdot \left(\frac{n}{\chi^2_{(1-\beta)}(n-1)} \right)^{\frac{1}{2}}. \tag{29}$$

If we take the approximation forms for z_x for x>0.5 [2][2]:

$$\begin{aligned} z_x &= u_x - \frac{2.30753 + 0.27061 \cdot u_x}{1 + 0.99229 \cdot u_x + 0.04481 \cdot u_x^2} \\ u_x &= \left[\ln(1-x)^{-2} \right]^{\frac{1}{2}} \end{aligned} \tag{30}$$

and for $\chi^2_x(\gamma)$ [3][3] (the number of degree of freedom is usually $\gamma = n-1$):

$$\begin{aligned} \chi'^2_x(\gamma) = {} & \gamma + z_x \cdot \sqrt{2} \cdot \gamma^{\frac{1}{2}} + \frac{2}{3} \cdot (z_x^2 - 1) + \frac{1}{9\sqrt{2}} (z_x^3 - 7 \cdot z_x) \cdot \gamma^{-\frac{1}{2}} - \frac{1}{405} (6 \cdot z_x^4 + 14 \cdot z_x^2 - 32) \cdot \gamma^{-1} + \\ & + \frac{1}{4860\sqrt{2}} \cdot (9 \cdot z_x^5 + 256 \cdot z_x^3 - 433 \cdot z_x) \cdot \gamma^{-\frac{3}{2}} \end{aligned} \tag{31}$$

or a much simpler approximation form from [3]:

$$\chi'^2_x(\gamma) = \frac{1}{2} \cdot \left[z_x + (2 \cdot \gamma - 1)^{1/2} \right]^2, \tag{32}$$

---

[2] the approximation error is not greater than 0.003

[3] for $x \in \langle 0.01, 0.99 \rangle$ and $\gamma \ge 20$ the absolute error of approximation is not greater than 0.001

then the analytical equation for the estimation of measuring system's accuracy δ based on an estimated mean value and standard deviation of *n*-sample data with the predefined measuring system's reliability $(1-\alpha)$ and measuring system's dependability β can be computed.

2.2.4 Illustrative examples - simulation results

Example 1:

A very important question can be addressed with regard to accuracy: How the measuring system's accuracy δ depends on the number of measurements for the prescribed measuring system's reliability and measuring system's dependability? We consider the following prescribed values for α, β:

a) $\alpha = 0.3, \beta = 0.5$

b) $\alpha = 0.05, \beta = 0.99$

From (26) the measuring system's accuracy δ is given $\delta = k \cdot s_a$. For finding the parameter *k* the equations (30), (31) and (32) were used. The Fig. 2.16 and Fig.2.17 show the dependence of the parameter *k* on the number of measurements *n* for cases a) and b) respectively.

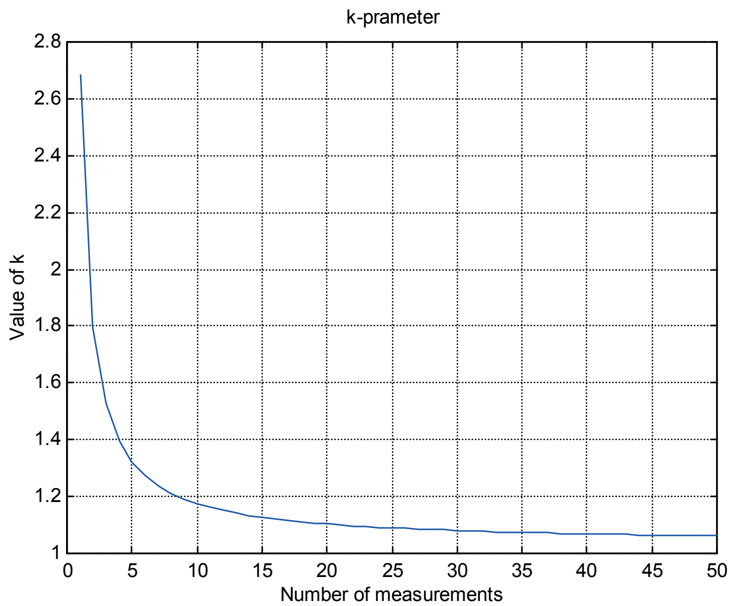


Fig. 2.16 Dependence of parameter k on number of measurements $(\alpha = 0.3.\beta = 0.5)$

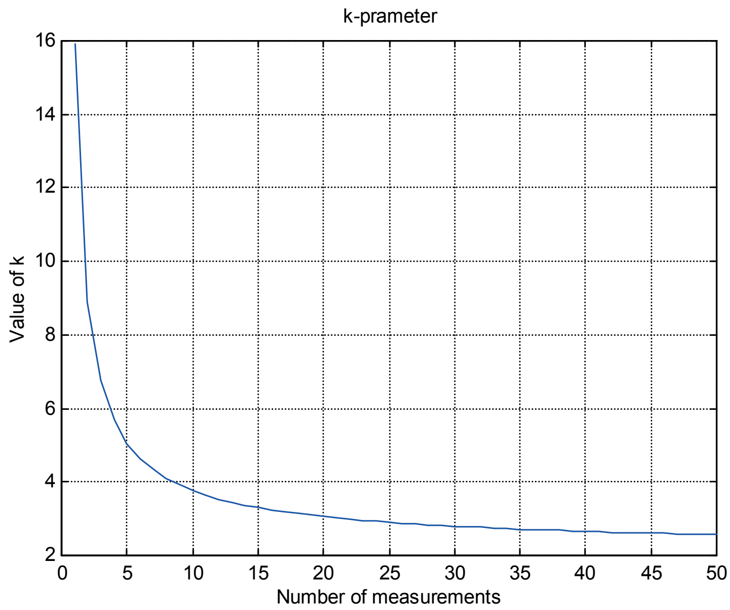


Fig. 2.17 Dependence of parameter k on number of measurements $(\alpha = 0.05.\beta = 0.99)$

Example 2:

Can the results from example 1 be proved by a simulation, if the number of measured values is n=30?

For both cases a) $\alpha = 0.3, \beta = 0.5$ and b) $\alpha = 0.05, \beta = 0.99$ the values of *k* were found in Fig. 2.16 and Fig. 2.17 respectively:

a) k=1.0584,

b) k=2.797.

In MATLAB, a set of 1000 samples of normal distribution with zero mean and standard deviations equal to one was generated. From the first 30 samples the mean value and standard deviation were estimated (16). Then the interval $(\overline{\mu}_a - k \cdot s_a, \overline{\mu}_a + k \cdot s_a)$ was selected in accordance to (26) and the probability of falling into interval was computed from the whole set of 1000 samples - which is a procedure of how to compute measuring system's reliability.

The above mentioned procedure was repeated 5 000 times, and the probability of exceeding the predefined measuring system's reliability limit was computed - thus the test of measuring system's dependability was performed.

The obtained results for measuring system's dependability through simulation will be summarized as follows:

a) $\beta = 0.553$

b) $\beta = 0.9864$

The test was repeated many times and the predefined parameters for measuring system's reliability and dependability were achieved in all experiments.

2.2.5 Assessment of safety performance parameters

We can suppose N sensors data available where the probability of right error detection is marked as P_{RD} and the probability of non-correct error detection as P_{FD}. Because of the enormous safety and economical impact in case of non-correct error alert, the method of filtering *"M from N"* will be presented.

Let us have N sensors and for simplicity let us suppose the same probabilities of correct P_{RD} and non-correct error detection P_{FD} on each sensor. If this assumption is not fulfilled the method can be easily extended to a more general case.

As mentioned above, the hypothesis H_0 represents perfect system behaviour (non system error, no sensor error) and hypothesis H_1 as a state with detected error (error of system, or error of sensors).

In the next equation, the probability of error detection on *k* sensors of *N* sensors (*N-k* sensors do not detect errors) is given in case the system does not display any error (conditioned by hypothesis H_0):

$$P[k \mid H_0] = \binom{N}{k} \cdot P_{FD}^{k} \cdot (1 - P_{FD})^{N-k} \tag{33}$$

In the same way, the probability of error detection by *k* of *N* sensors is given in case the system is in an error state (conditioned by hypothesis H_1):

$$P[k \mid H_1] = \binom{N}{k} \cdot P_{RD}^{k} \cdot (1 - P_{RD})^{N-k} \tag{34}$$

The main idea of "M from N" filtering is in selection of value M (threshold) defining the minimum number of sensors that detected error. If M sensors detect error then this error is taken as the real system error and the system starts sending error alert signals. The threshold M should be selected with respect to the following probabilities:

$$\begin{aligned} P_F &= \sum_{k=M}^{N} \binom{N}{k} \cdot P_{RD}^{k} \cdot (1 - P_{RD})^{N-k} \\ P_D &= \sum_{k=M}^{N} \binom{N}{k} \cdot P_{FD}^{k} \cdot (1 - P_{FD})^{N-k} \end{aligned} \tag{35}$$

where P_F, P_D means probability of a *false alert* (an error is detected but the system works without any errors) and the probability of the *right detection* (the system error is correctly detected).

The number of detectors N and the threshold M can be chosen based on sensors parameters P_{RD}, P_{FD} and required probabilities P_F, P_D.

Methods of data fusion and comparison are the main tools for estimation of system performance parameters (accuracy, reliability, integrity, continuity, etc.) and can be used for a derivation of an exact definition of false alert and right detection probabilities.

2.2.6 Illustrative example - geo-object detection

<u>Example 3:</u>

In this example the measurement data comparison will be used as a tool for better geo-object detection in, e.g., electronic tolling application.

We can suppose N available position measurements of a geo-object where the probability of the right geo-object detection is marked as P_{RD} and the probability of non-correct (false) geo-object detection as P_{FD}. Let the hypothesis H_0 represent the assumption of a perfect geo-object detection (no detection error reported). The hypothesis H_1 represents a non-correct geo-object detection (error caused, for example, by wrong position accuracy, etc.).

The probability of *k* non-correct geo-object detections of *N* measurements for the final assumption that the geo-object is perfectly detected (conditioned on the hypothesis H_0) can be given:

$$P[k \mid H_0] = \binom{N}{k} \cdot P_{FD}^{k} \cdot (1 - P_{FD})^{N-k} \tag{36}$$

The probability of *k* correct geo-object detections of N measurements for the final assumption of non-correct geo-object detection (conditioned on hypothesis H_1) is given:

$$P[k \mid H_1] = \binom{N}{k} \cdot P_{RD}^{k} \cdot (1 - P_{RD})^{N-k} \qquad (37)$$

The main idea of "M matches from N measurements" principle is in the selection of the threshold M with respect to the following probabilities:

$$P_F = \sum_{k=M}^{N} \binom{N}{k} \cdot P_{FD}^{k} \cdot (1 - P_{FD})^{N-k}$$
$$P_D = \sum_{k=M}^{N} \binom{N}{k} \cdot P_{RD}^{k} \cdot (1 - P_{RD})^{N-k} \qquad (38)$$

where P_F, P_D means the probability of a *false alert of geo-object detection* (the geo-object is detected even though the vehicle did not go through it) and the probability of a *right geo-object detection* (the right geo-object is detected based on the measured data, and the vehicle went through it).

The number of measurements N and the threshold M can be chosen based on the position probabilities P_{FD}, P_{RD} and the required probabilities P_F, P_D. Futher discussion will be presented within an illustrative example below.

There are two parallel roads (one under tolling, the other one free of charge) and the distance D between them of 20 meters, as it is shown in Fig 2.18. The length L is supposed to be 1 kilometre.

In this example, we will try to tune the parameter *M* to increase the probability of the correct toll road detection in order to reach the expected value of more than 99%.

We expect a maximum vehicle speed of 200 km/h or 55 m/s. If the length is 1000 m and the GPS receiver monitors the position every second, we can obtain as many as 18 position measurements per one road. The road can be distinguished by GPS received with probability app. 70% (we can assign the measurement to the right road, if the error is lower than D/2 which is in our case 10 meter - this accuracy is typically achieved by a GPS receiver at a probability level of 70%).

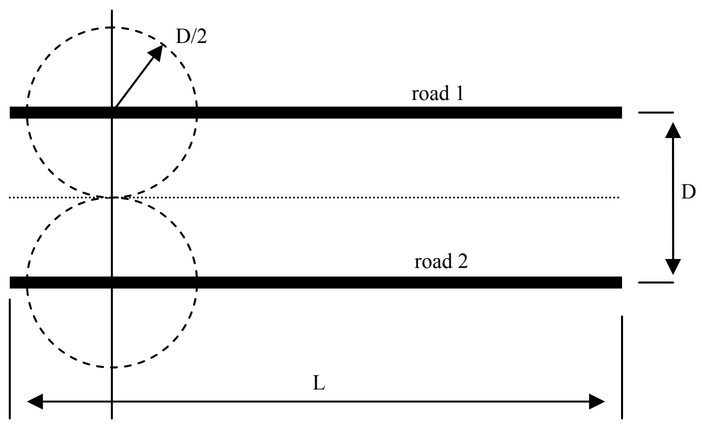


Fig.2.18 Two parallel roads and Toll detection being on one of the roads

Based on the above mentioned assumptions, we can summarize the following parameters:

$$P_{RD} = 0.7, P_{FD} = 0.3, N = 18. \qquad (39)$$

Using the equations (38), the probabilities P_F, P_D for different parameters M will be as given in Tab.1.

If the parameter M is 6 or 8, we can achieve the requested probability of the geo-object detection higher than 99%. On the other hand, for M=6 the probability of lost vehicles is higher (the vehicles used the toll road, but the system did not detect them). For M=8 we can achieve a better balance between both probabilities P_F, P_D. If the user needs to minimize the loss of a vehicle and to keep the acceptable detection probability, the variant M=10 could be a good compromise.

Tab.1 Probabilities P_F, P_D ***and their dependence on parameter M***

Parameter M	P_D	P_F
6 from 18	0.9997	0.4656
8 from 18	0.9939	0.1407
10 from 18	0.9404	0.0210
12 from 18	0.7217	0.0014

2.2.7 Illustrative example - cluster of ITS applications using GNSS

Transport telematics architecture displays the arrangement of subsystems and functional blocks, including information relationships according to the defined point of view. The task also covers the selection of representative telematics applications ("*cluster*") that shows identical systems requirements.

Among the individual representative applications using GNSS (Global Navigation Satellite Systems) the following may be included:

- Securing the movement of a means of transport in a transport infrastructure (from the point of view of performance parameters within the GNSS, it is a question of securing accuracy, reliability, availability, integrity, etc., at exactly defined points of the transport infrastructure – the application lays high stress both on the locator proper and the information transmission and processing systems; the solution should comply with the “fail-safe” principle; for typical transport telematics applications we may refer to railway interlocking technology, monitoring the transport of dangerous goods, or monitoring the movement of means of transport at the airport.
- Navigation of the means of transport in a transport network (from the point of view of performance parameters, it is a matter of coverage with a signal, time lag in on-line navigation, requirements as for the exactly working maps of an entire geographical area, requirements on the speed of information processing, both within a mobile unit and the processing centre, as well as minimisation of the delay when establishing the position – TTFF - Time to Fix Face); as typical transport telematics applications, the following may be referred to: the navigation of safety and rescue units for a localised accident place or dynamic and/or on-line automobile navigation.
- Monitoring and operating the maintenance of transport networks (from the point of view of performance requirements, it is particularly a matter of an exact transport infrastructure information retrieval, interoperability of individual GIS (Geographical Information Systems) systems of various organisations dealing with maintenance, and achievement of high statistical accuracy in establishing position); as it concerns typical transport telematic applications, the following ones should be mentioned: mapping the river channel by means of a measuring ship, or measuring the carriageway parameters by means of special measuring vehicles.
- Monitoring the movement of persons and goods in a transport infrastructure (from the point of view of performance requirements, it is a matter of transmission and central processing of large amount of information from resources of various accuracy, fast identification of individual sub-sets of the objects of transport, sophisticated information processing in the centre, for instance, the “Floating Car Data”); as typical transport telematic applications, the following can be referred to: the use of taxi cabs, public transport passenger vehicles or other utility vehicles equipped with the GNSS systems for traffic flow modelling, or the use of localised mobile telephones for modelling the mobility of persons.
- Transport infrastructure charging according to its utilisation (from the point of view of performance parameters, it is a matter of reliability, integrity and time lag because the GNSS system is used to calculate the amount of the charge and, furthermore, the application places demands on the “fail-safe” principle in terms of the distance covered – if there is an uncertainty about correct charging of the driver, the distance covered is not taken account of); as a typical transport telematic application, it is electronic charging of the transport infrastructure according to the vehicle parameters and distance covered.

As a follow-up to the completed analysis and decomposition of performance parameters to individual subsystems, a table can be obtained containing performance requirements of the above mentioned representatives as for the locator proper, telecommunications environment or the information processing centre.

The next step, following the architecture design, is a cluster analysis of individual requirements as for individual subsystems of transport telematics chain, including the locator, according to the pre-defined criteria. The selection of criteria makes a substantial part of the design because if the architecture is to play an integrative and optimisation role, it is necessary to look for stabile optimisation criteria, for instance, the selection of the most exacting criteria of all the representative applications, weighted average of all the most exacting criteria, etc.

The ITS architecture of transport telematics applications is based on GNSS results in the concept of space distribution of individual subsystems so that the representative transport telematics applications satisfies the established performance parameters, the infrastructure is utilised as efficiently as possible, and the in-vehicle mobile unit or the mobile unit on the object of transportation is able to deal with a whole spectrum of transport telematics applications (both existing and future ones).

2.3 ITS technological platform

Within the context of hardware implementation, each ITS market package is describable as a goal-directly defined group of hardware and software tools. These represent different technologically implemented means to ensure market package function achievement. In practice, here can be traffic detectors, on-board units, dedicated short-range communication beams, means of satellite communication, information systems, digital maps, etc.

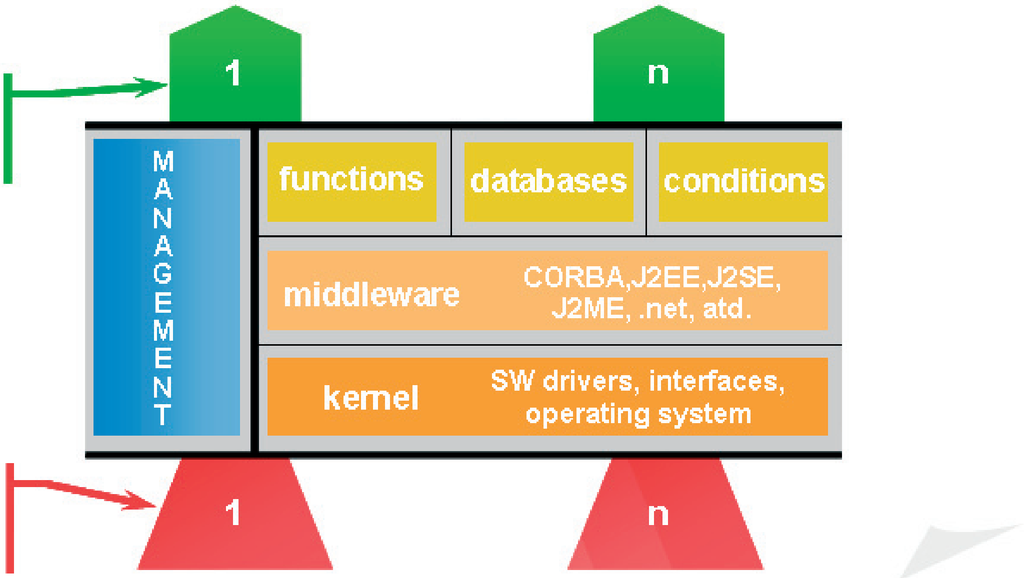


Fig. 2.19 ITS technological platform

The knowledge of available ITS market packages can be harmonized according to the ITS technological platform given in Fig. 2.19. At the lower level there are a lot of HW components, such as GSM, WiFi, DSRC, IR, GPS, etc. These components communicate with special SW drivers through the middlewave layer (Corba, etc.). Unified functions, databases or conditions (predefined algorithms, etc.) are available from the system analysis of the ITS model. Performance parameters or ITS application preferences are guaranteed through the management area. The advantage of a technological platform is that all ITS applications can use all features of the technological platform and all components - functions, databases or conditions can be shared by all ITS applications. The proposed technological platform enables flexible changes of ITS applications with respect to user requirements.

3. ITS Effectiveness Assessment

The ITS effectiveness definition is an essential issue, therefore, there is a strong focus placed on it. The internationally reputable methodology of cost-benefit evaluation (CBA) was chosen and connected with the effectiveness definition.

Effectiveness values are then represented by [14]:

Net Present Value (NPV)**:**

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \tag{40}$$

where CFt represents cash-flow in the time period *t, r* is the discount factor.

Internal Rate of Return (IRR):

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \tag{41}$$

Profitability Index (NPV/I):

$$NPV/I = \frac{(PV + CF_0)}{(-CF_0)} = \frac{CF_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}}{(-CF_0)} \tag{42}$$

then

$$NPV/I = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}}{(-CF_0)} \tag{43}$$

where *I* represents the total of investment costs, PV is a present value Pay-off Period.

CBA also takes into account the time factor (evaluation period - through the discount rate) and thereby an appropriate coverage of all activities associated with the implemental and operational ITS application phases. However, it is necessary to point out that CBA algorithm is not ready for use until all application impacts are known.

3.1 ITS Evaluation processes

From the point of view of the evaluation processes, the following key principles have to be taken into the consideration [14]: ex-ante and ex-post evaluation. Ex-ante evaluation is a process undertaken prior to implementation phase where the implementation phase can also represent physical realisation of the pilot studies. Its outputs are mainly based on information from several sources.

Expert inputs are actually needed during the ex-ante evaluation process. It is necessary to estimate the application benefits which, in economical comparison across the ITS alternatives, will offer one of the arguments to make an appropriate choice of the ITS solution. In other words, the ex-ante evaluation process is a tool for choosing suitable ITS applications or services.

On the other hand, there is an ex-post evaluation process which is realised after the implementation stage. Its main aim is to monitor, summarise and assess real application impacts.

3.2 ITS Effectiveness Analyse

Generally, we can say that ITS application benefits depend on many different aspects coming from the physical architecture and its influences on the transport-forwarding processes. Following this fact, benefit indicators can be defined to allow particular benefits determination. Here, not only deterministic quantitative indicators are defined, but also socio-economic and qualitative indicators are taken into account, which are characterized by an explicit level of uncertainty.

In contrast to ITS application benefits (from the evaluation point of view) ITS costs have to be assessed in detail. Analogically to the benefit indicators definitions, a set of costs indicators can be proposed. It is possible, through these indicators, to describe ITS application costs at an appropriate detail level and to create the second part of the needed background for the final evaluation.

We shall divide ITS system into three basic layers with description of expenditure connected with each layer:

- Collection of information (expenditure for sensor, creation of interface of single applications, creation of adjustment software, etc.)
- Transmission of information (expenditure for telecommunication services, investment cost of special telecommunication environment, etc.)
- Processing of information (expenditure for computer systems, knowledge systems at various levels of architecture, software and hardware, etc).

Transmission of information expenditures are considerably affected by the following factors:

- Absence of a system approach to create a system,
- Redundancy of messages in all parts of ITS system,
- Duplicity of transmitted information,
- Absence of knowledge of telecommunication technologies, namely with regard to building own telecommunication networks (integrated LAN and WAN networks).

Another serious reason for the growth of cost in transmission of information, which is not less important, is the absence of the offered services meeting the specified requirements on availability, reliability and security of transmission. Organisations are forced to build their own telecommunication networks either on leased circuits or even on their own lines.

Building ITS systems using optimum methods of processing of information is a necessary condition of an efficient information processing. Extraction of knowledge consists of the estimation of the so-called markers that describe the current situation much more economically than the measured data itself. The whole concept of the architecture of ITS systems must be focused on acquisition of the markers from the lowest layer of an ITS system. Higher layers already work with these markers and their comparison enables acquisition of knowledge necessary for managerial decisions. Based on various levels of knowledge, we can create a model of a multidimensional system.

The reason for the low rate of expenditures on information processing is a lack of correctly designed architecture and its processes as described above in this book. The processes which are not synchronised cannot be further processed efficiently (i.e., knowledge cannot be obtained) and therefore there is no will to invest money in the information processing systems. To change this situation, it is necessary to guarantee that the investment in information processing will be profitable.

A correctly conceived ITS process specially designed for a corporation will have a direct impact on the following factors:

- Efficient building of telecommunication environment and corporal networks will reduce the expenditures;
- Considerable reduction of transmitted information will reduce transmission costs;
- Defining the requirements on the part of the corporation will force the operators to offer services above standard, which will result in reduction of expenses on building a special telecommunication environment;
- Economical convenience of new solutions in information transmission will lead to an increased demand for new technologies of telecommunication networks, namely in the field of access networks;
- It will be possible to provide modular development of ITS in single branches as well as throughout institutions using the same existing systems.

The above mentioned factors have an immense impact on the economy of building ITS systems. A correctly conceived architecture, which utilises an advanced information processing system, logically leads to reduction of expenditures on information collection and transmission. Fig. 3.1 shows the change in the ratio of economic exigency of single segments within an ITS system.

Obviously, the saved financial means can be invested in information processing systems. Then, the organisations can use this information for better decision-making at all levels thus being more competitive. We would like to stress that in terms of economy, achievement of this condition is as important as operating the existing systems.

Generally, we can say that single branches are significantly stigmatised by the same mistakes in the development of ITS systems. In all studied cases, the dominant mistake was a dynamic development of information technologies without knowledge of the basics of telecommunication technology (system convergence of informatics and telecommunication branches with a direct impact on economy of organisations).

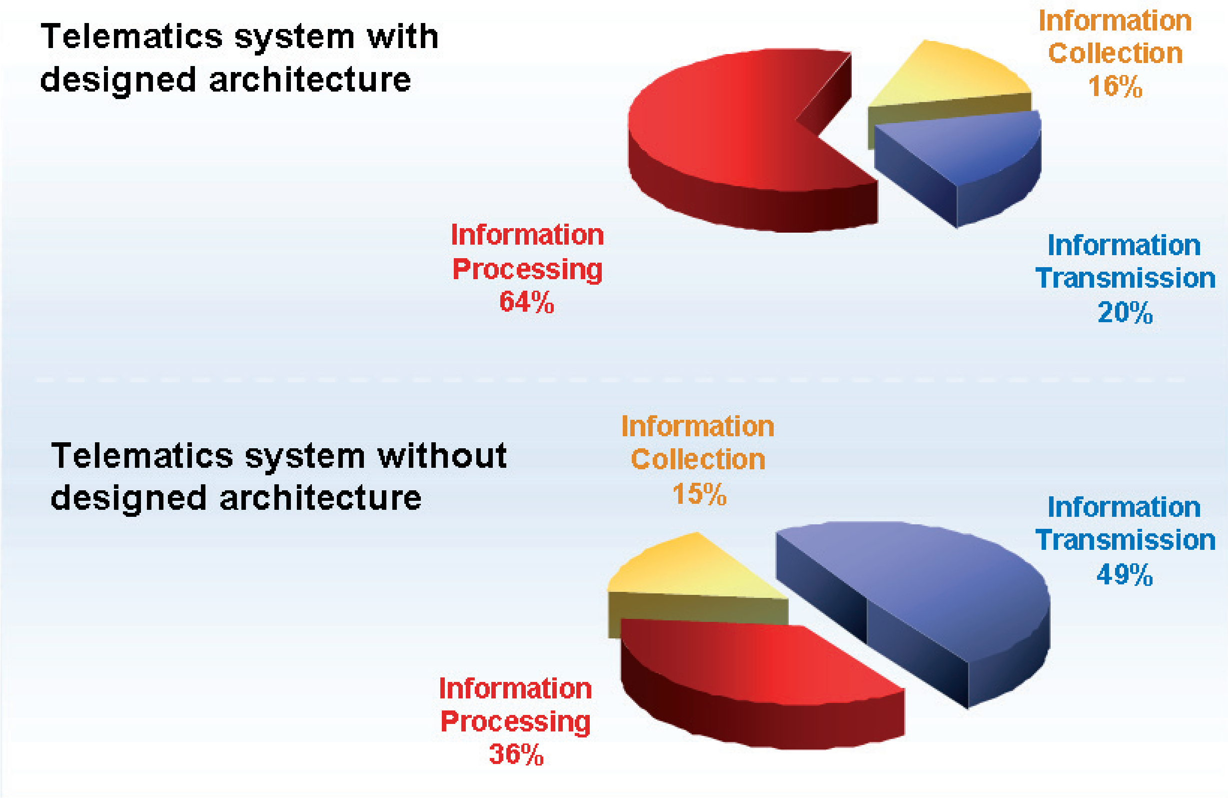


Figure 3.1: The ratio of expenditures on collection, transmission and processing of information in ITS [15]

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