Advanced Model of Intelligent Transport Systems

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Abstract: Paper presents basic approach to advanced design of Intelligent Transport Systems (ITS) using predefined ITS architecture, interfaces and performance parameters assigned into each functions and processes. All described methods have direct impacts to economical analyze and effectiveness of ITS system and can be understood as the advanced model of complex ITS system.

Key-Words: Intelligent Transport Systems, ITS architecture, ITS interface, ITS performance parameters, ITS Standards

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 as it is shown in Fig. 1.

Fig. 1 Transport telematics / Intelligent transport systems definition

Fig. 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 subsystems for management of different organizations. The model shown in Fig. 2 is applicable to all kinds of transport including the multimodal transport. The model in Fig. 3 represents the hierarchical structure of an ITS system where each level has different control and management strategy. As an example, a telematics application (TA) is taken into account, with its decomposition illustrated in Fig. 4.
2 ITS Design Methodology

2.1 ITS System Model

The ITS system model is defined in Fig. 5 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.

2.2 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 aspects of the examined system, and therefore can be differentiated 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, organization structure, etc.).
• Communication architecture - defines the telecommunication links between physical devices (correctly selected communication architecture optimizes telecommunication tools),
• Organization architecture - specifies competencies of single management levels (correctly selected organization architecture optimises management and competencies at all management levels).

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.)

The physical ITS architecture is shown in Fig. 6. On the interactive web it is available on the web page www.its-portal.cz.

2.3 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. 7.

A Market Package ATIS04-Dynamic Route Guidence example is presented in Fig. 8. More information about the USA ITS architecture and 91 Market Packages is available on http://www.iteris.com.

2.4 ITS Standards
ITS standards are created within the well-known standardization 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 Abstract Syntax Notation Number One (ASN.1) is used in the standards to define all the above mentioned features. The example of ASN.1 syntax for personal data of ITS application is given:

```
Personal 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",
    PostCode 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 "parsers" BER (Basic Encoding Rules), DER (Distinguished Encoding Rules) and PER (Packed Encoding Rules) that can transform the standardized data structure written in ASN.1 into more than 150 programming languages.

## 2.4 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 attributes.

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

In Fig. 9, 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 (char(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. 10.

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 powerful instrument for the ITS systems implementation and maintenance. 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.

2.4 ITS 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

\[ P(|p_i - p_{m,i}| \leq \varepsilon_1) \geq \gamma_1 \]  

that the difference between the required system parameter \( p_i \) and the measured parameter \( p_{m,i} \) will not exceed the value \( \varepsilon_1 \) on probability level \( \gamma_1 \) where this definition is applicable for all \( N \) system parameters \( p_1, p_2, \ldots, p_N \).

• **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

\[ P(|\bar{q}_i - q_{m,i}| \leq \varepsilon_2, t \in (0, T)) \geq \gamma_2 \]  

that the difference between \( q_i \) and the vector of measured parameters \( q_{m,i} \) will not exceed the value \( \varepsilon_2 \) on probability level \( \gamma_2 \) in each time interval \( t \) from the interval \( (0, T) \).

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

\[ P(|q_{i} - q_{m,i}| \leq \varepsilon_3) \geq \gamma_3 \]  

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 \( \varepsilon_3 \) at the probability level \( \gamma_3 \).

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

\[ P(|r_i - r_{m,i}| \leq \varepsilon_4) \geq \gamma_4 \]  

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 \( \varepsilon_4 \) at the probability level \( \gamma_4 \).

• **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

\[ P(|S_{i} - S_{m,i}| \leq \varepsilon_5) \geq \gamma_5 \]  

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 \( \varepsilon_5 \) on the probability level \( \gamma_5 \).

• **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

\[ q_{m,i} = \frac{Q_i}{Q} \]  

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).
environment and potential risk, and then the safety can be defined as the probability

\[ P(W_i - W_{m,i} \leq \varepsilon_i) \geq \gamma_i \]  

(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 \( \varepsilon_i \) on the probability level \( \gamma_i \).

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.

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.

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. 11 ITS technological platform

The knowledge of available ITS market packages can be harmonized according to the ITS technological platform given in Fig. 11. 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 middleware 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.
4 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):**
  
  \[
  NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + r)^t}\]
  
  where \( CF_t \) represents cash-flow in the time period \( t \), \( r \) is the discount factor.

- **Internal Rate of Return (IRR):**
  
  \[
  0 = \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t}\]
  
- **Profitability Index (NPV/I):**
  
  \[
  \frac{NPV}{I} = \frac{(PV + C_{F_0}) + \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}}{(-C_{F_0})}\]

  then

  \[
  NPV/I = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}}{(-C_{F_0})}\]

  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.

4 Conclusion

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. Organizations 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. The processes which are not synchronized 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.

References:
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