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Advanced approach to Intelligent Transport Systems design

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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. Described approach to the ITS design is revealed by example of the hybrid electronic toll collection system design.

***Keywords*—** Intelligent Transport Systems, ITS architecture, ITS interface, ITS performance parameters, ITS standards, hybrid electronic toll collection system.

I. 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.

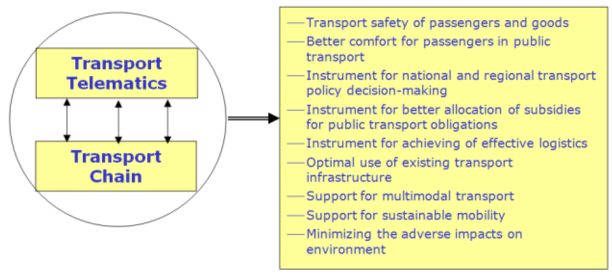

Fig. 1 Transport telematics / Intelligent transport systems definition

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,

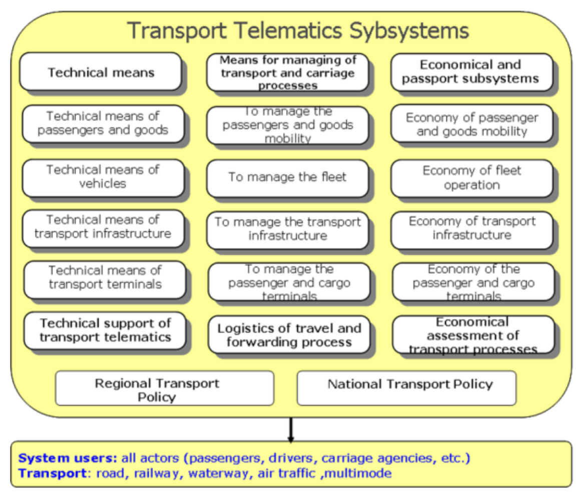

Fig. 2 Organizational decomposition of ITS system

there are technical means, means for management (SW, control strategies, etc.) and economical/passport subsystems for management of different organizations.

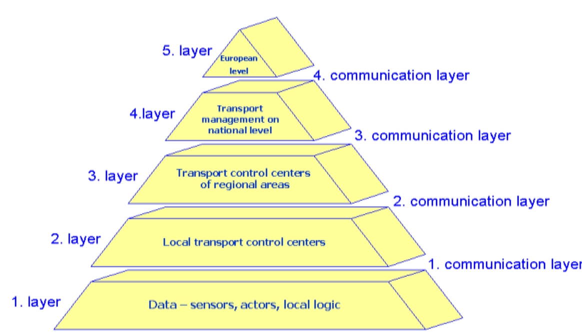

Fig. 3 Hierarchical decomposition of ITS system

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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.

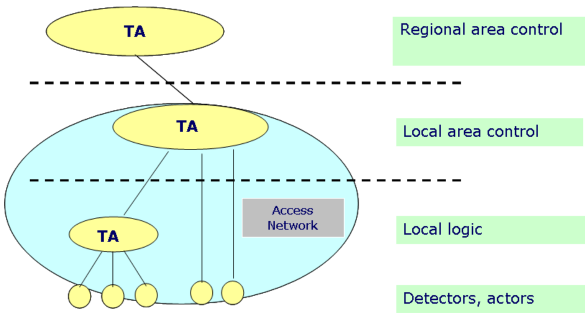

Fig. 4 Decomposition of telematics application (TA) into three hierarchical levels

II. ITS Design Methodology

A. *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.

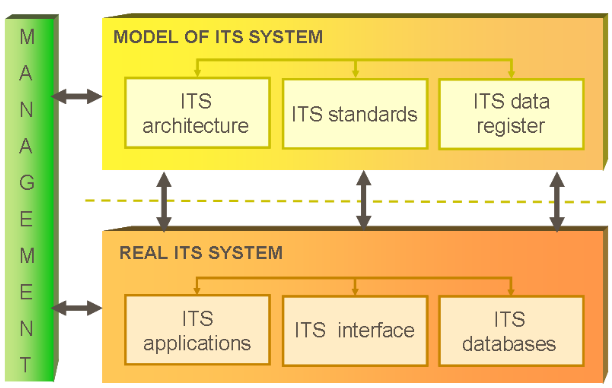

Fig. 5 ITS System Model

The management issue shown in Fig. 5 represents the methodology of smart ITS design and maintenance with help of a well-tuned model of an ITS system. We can summarize the basic management issues as follows:

- Optimization 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-licenses)
- Recommendation of favorable investment strategy
- Protocol definitions for the whole set of ITS applications
- Continual comparison between an ITS model and the reality

B. *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),

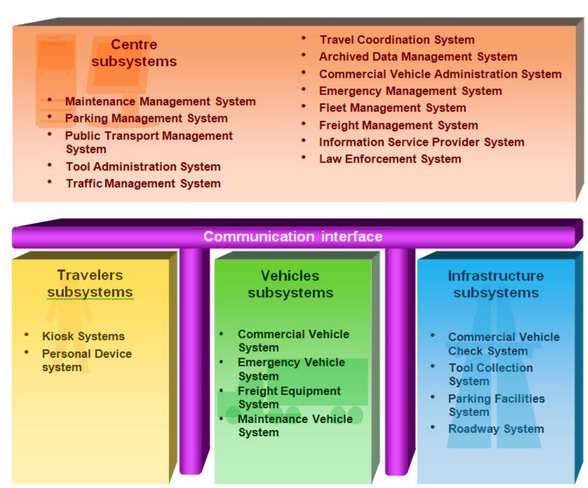

Fig. 6 ITS physical architecture

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

Organization architecture - specifies competencies of single management levels (correctly selected organization architecture optimizes management and competencies at all management levels).Provide Electronic Payment Facilities (toll collection system based on GNSS/CN, DSRC, etc.)

ITS architecture covers the following makro-functions:

- 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.)

C. *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 Guidenance example is presented in Fig. 8. More information about the USA ITS architecture and 91 Market Packages is available on http://www.iteris.com.

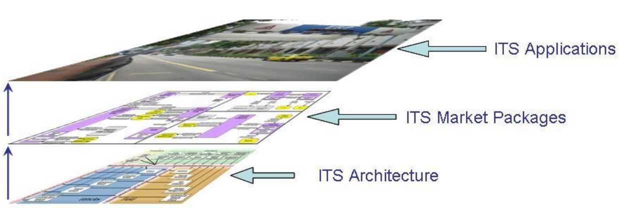

Fig. 7 ITS architecture, ITS market packages and real ITS applications

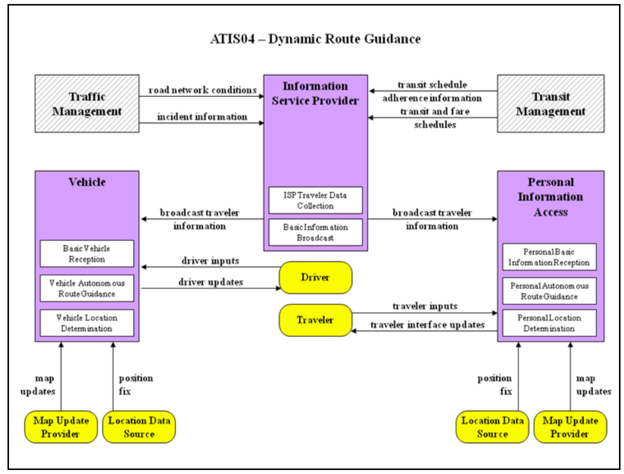

Fig. 8 Example of the "Dynamic Route Guidenance" market package

D. *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“,
  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 "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.

E. *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)).

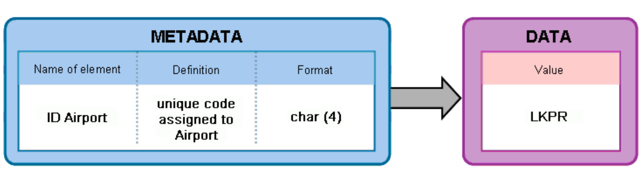

Fig. 9 ITS data registry

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

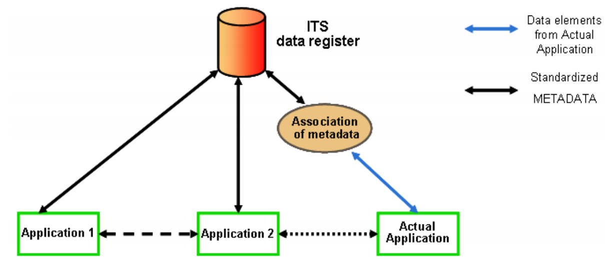

Fig. 10 Automatic metadata collection by ITS data registry

- 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 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.

F. *ITS Performance Indicators*

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
$$P\left(\left|p_i - p_{m,i}\right| \le \varepsilon_1\right) \ge \gamma_1 \quad (1)$$
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
$$P\left(\left|\vec{v}_t - \vec{v}_{m,t}\right| \le \varepsilon_2\right) \ge \gamma_2, t \in \langle 0, T \rangle \quad (2)$$

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 initialization (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.

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 (optimization of the information transfer between a mobile unit and a processing center, 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.

III. 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.

[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 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.

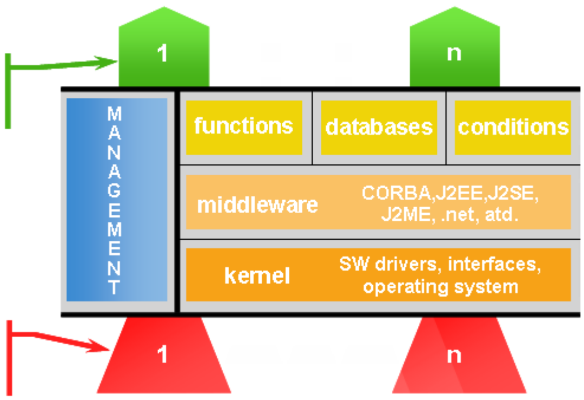

Fig. 11 ITS technological platform

The proposed technological platform enables flexible changes of ITS applications with respect to user requirements.

IV. 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):

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \tag{7}$$

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

- Internal Rate of Return (IRR):

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \tag{8}$$

- Profitability Index (NPV/I):

$$NPV/I = \frac{(PV + CF_0)}{(-CF_0)} = \frac{CF_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}}{(-CF_0)} \tag{9}$$

then

$$NPV/I = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}}{(-CF_0)} \tag{10}$$

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.

V. Hybrid Electronic Toll Collection System Design

As an example we introduce development strategy of hybrid Electronic Toll Collection (ETC) system in conjunction with 17 575 standard introduced by the CEN TC204/WG1 and ISO TC204/WG5. By the end of 2005 there was only one real document, which bound the contractors to some design and technologies – the European Directive 2004/52/CE. Because of uncertainties in the standardization process and the delivery of toll system upgrade in the Czech Republic, Expert Group of the Ministry of Transport had chosen and recommended the hybrid approach by the end of 2006. The hybrid system was a compromise between DSRC based toll collection system and GPS/CN based system and most of its definitions uses ISO 17575 approach. To overcome the problem of coordination of DSRC and GPS/CN based systems, the new roles had been defined, based on the data flow inside the system – see Fig. 12 – essential change in the view of the system remains in identification of three main parts: EFC data provider, EFC data processor and EFC data user. As can be seen, the roles are chosen according data flow and one important role is added – the end user of the data collected from the system. Also, the way of getting the data from infrastructure is fully in the responsibility of the data provider. Based on this categorization, it was possible to define interfaces on more convenient abstract level than it was done within other project. New approach introduced in this example is independent of data collection method and opens the space for the competitive market in the EFC data collection service as well as in

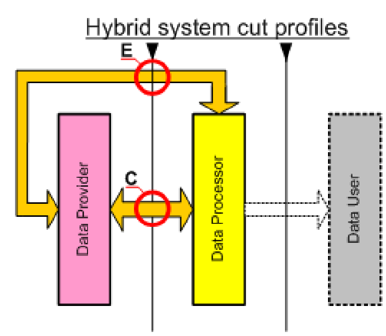

Fig. 12 Internal cuts in Hybrid System architecture

telematic services market. Also, more then one data provider can be incorporated into the design of the system as well as more than one data user. It facilitates an ability to integrate different EFC data providers no matter which technology was used for data collection. The hybrid design doesn't bound the technology of data collection and focus the scope of the design onto two major interfaces:

- Toll System Standard Interface (TSSI) – the interface between Data Provider and Data Processor, where the unified data collected by data provider should be transmitted into the system,
- Telematic Application Standard Interface (TASI) – or standard interface for telematic services is the interface on the output of the system, where processed data could be provided to the different Data Users – providers of telematic services.

The second interface – TASI is out of scope of TS 17 575 so only TSSI interface will be considered in this white paper.

Hybrid system specification could be easily explained on the layered architecture according to Fig. 12, where both interfaces are specified. The different terminology used in the drawing of hybrid solution is more "data processing" oriented and focused on the data flow in the system, then role oriented. The data flow oriented design is more straightforward and provides better background for security design. But, as will be shown, there are many similarities in both approaches.

Individual function in data chain are dedicated as follows:

- **Data Provider**, the functionality with major goal in providing trusted data from the data collection environment to the central part of system for data processing. Data Provider subsystem has to form a trusted system from the point of view of the security and by this way provides trusted non-repudiated data to the central system.
- **Data Processor**, where all the data are processed by applying at least minimum set of means necessary for toll collection. The Data Processor can provide all basic toll collection functions based on data provided and it is not expected to broader its functionality beyond some extend.
- **Data User**, is free collection of functionalities of different kind, using data from Data Processor for further calculations and applications, mostly user oriented.

Two cross-sections are important for the hybrid system, specifically the point where these cross-sections are made:

- **Data Provider/Data Processor** cross-section, which effectively cuts the information flow between Data Provider and Data Processor used for data provisioning (interface "C") and
- **Data Processor/Data User** cut, which is not a part of this specification and has to be standardized as an interface for implementation of user specific functionalities.

A. Inside the hybrid design

Hybrid system architecture design goes behind the simple definition of the functionality of OBE, actually it doesn't specify OBE at all, with exception of the interface for validation of OBE – the enforcement interface. The hybrid design is viewing a Data Provider system as "black-box", defined by two major interfaces according to description above. That means, in hybrid design, the Data Provider is fully responsible for the quality of data, its non-repudiation and security. The communication between Data Provider and Data Processor is done via standard interface by means of standardized open protocols. From communication point of view, the client/server technology is used.

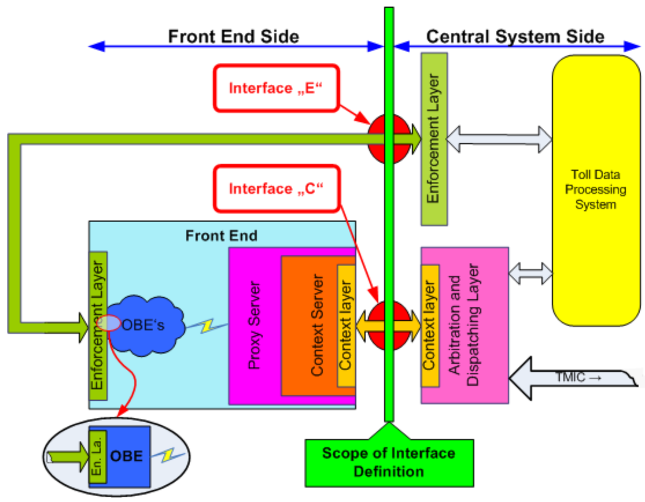

Fig. 13 Detail of the Data Provider/Data Processor interface

Coming closer to the design, we can analyze Fig. 13. In this picture, the thick green line points out the scope of the definition of the standard 17 575. We can see two distinct interfaces "E" and "C" which had been mentioned above. In this drawings the Data Provider subsystem communicates with Data Processor subsystem via set of layers defined as follows:

- Context Server Layer on the edge of the Data Provider subsystem provides an instrument of communication with the Data Processor subsystems by means of standardized protocol of the interface. The partner in this communication on the side of Data Processor subsystem is Dispatching and Arbitration Layer.
- Dispatching and Arbitration Layer on the edge of Data Processor system is only the place, where information from any outer subsystem can enter the Data Processor subsystem and where the information could be accepted or obtained. Major role of the layer is to arbitrate among information obtained from different sources – Context Servers (tolling information) and to dispatch information between Data Processor system responsible for tolling itself, and adjacent systems connected via Telematic Message Interactive Channel (TMIC).
- Enforcement Interface Layer on both Data Provider

subsystem and Data Processor subsystem is dedicated to the verification and validation of selected information from the Data Provider subsystem via enforcement specific channel. Enforcement Interface Layer on the side of the Data Processor Subsystem is handled by its own access and security means.

As had been shown in Fig. 12 and later in Fig. 13, definitions "C" and "E" are specific points of the interoperability, which has to be defined as standard. Definition "E" specifies information exchange on the enforcement level. There is also expectation, that as a part of the standard, the ISO/OSI layers should be defined for that standard interface, but in the hybrid design we had left this part to use the standard DSRC communication according to ISO relevant standards.

As it could be seen, the basic idea of the hybrid system architecture doesn't limit the Data Provider to any of predestinated technology of capturing data for electronic toll collection. It only describes edges of the "black box" seen as e.g. a proprietary system.

To unify the hybrid design and TS 17 575 some minor amendments are proposed to the TS 17 575.

VI. 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.

Hybrid Electronic Toll Collection (ETC) system design strategy in the Czech Republic in conjunction with ISO/CEN 17 575 standard was used as an example. Introduced approach is based on data collection method independency to open the space for the competitive market in the EFC data collection service as well as in telematic services market. Presented hybrid system architecture doesn't predestinate technology of for electronic toll collection data capturing. It only describes edges of the relevant subsystem understood as a proprietary part.

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