Analysis and Modelling Methods of Urban Integrated Information System of Transportation

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Abstract—**Efficient and environmentally friendly management of mobility plays a significant role in the smart cities. As the transportation systems and the information systems link the components, their development is essential for realization of complex city operational schemes.**

Information is one of the most important inputs for the activities, especially in transportation. Logical and physical integration of transportation information systems and services are required by the increasing expectation of travellers and became possible by the development of the infocommunication technology. Since the results of comprehensive system and process-oriented scientific research on this area are slightly published, the devised analysis and modelling methods described here and their adaptation fill this niche.

Herewith the architecture of the entire integrated system and the model of the intelligent traveller with the personalized mobile application have been presented in more details, but the method is applicable for each subsystem with different resolutions. The results are of great importance contributing to the success of the top-down systems engineering.

Index Terms—**analysis, information system, integration, mobile application, mobility management, modelling, personalization, transportation.**

I. INTRODUCTION

In developed countries the urbanization rate is above 70%. The number of vehicles and the performance of transportation are increasing at a quick pace. On the other hand significant technological progress has been achieved in the field of innovative potentials and strategies, infocommunication technologies, integration of technologies and smart transportation.

Smart city can be defined as system of systems. Accordingly 'networking' and optimization as a consequence should be realized. It is possible on one hand on the physical layer by transportation and on the other hand on the information layer. These layers are the media of traffic as well as information flows. Complex systems can be developed and maintained only with difficulties, therefore appropriate top-down analysis and modelling are especially important in order to integrate data and processes between organisations and systems.

The transportation system is associated with the urban planning and the following management areas:

- energy,
- environment,
- human resources (education, social and healthcare services).

Smart transportation is to be defined as follows: the transportation systems are operated by dynamic (real-time) data, which include the human knowledge, intelligence and mechanism of decision-making in order to decrease/replace the human activities. Shortly: cooperative applications of advanced information and communication technologies by transport infrastructure, in vehicles and by travellers.

This topic is relevant nowadays because quality of transportation system has significant impact on both the city structure and the citizens' life. The transportation process links people's activities forming an activity chain and therefore saved times and costs can be utilized for other, more pleasurable activities. The smart solutions facilitate proactive management, where forecast of future situations is possible.

Most important challenges in field of transportation:

- demand prediction,
- optimization of transportation assets and infrastructure,
- providing wide range of convenience and economical services and therefore enabling choice and combination opportunities,
- improvement of operational efficiency while reducing environmental impact,
- ensuring safety and security.

The *objective* of the research was to determine all the required transportation information services and to analyse the system of data in order to model the entire urban integrated information system of transportation. Our work covers both the physical structure and the process structure (operational properties) of the integrated human-machine information system, as well as the required organisational developments. Key questions of the research (the discussion of the certain questions is indicated by the same number in round brackets in the following chapters):

General methods (in system approach):

1. What are the main *component types* of the integrated information system of transportation?

2. What kind of *analysis and modelling methods* are to be applied for complex, integrated systems?

Adaptation of the methods:

3. What kind of *functions* (information services) of transportation are required in an urban environment?

4. What are the most important *subsystems* of the entire system and how do they interact?

5. What *data groups* are managed in the information systems?

6. What are the *relationships between subsystems and functions* considering also the transmitted data groups (focusing on the interactive personal mobile device and travellers' ideal application)?

7. What is the *functional structure* of the intelligent traveller's application?

The presented modeling and analysis methods are consequences of continuous research work carried out at our department in the last years. The methods are continuously developed, improved and adapted in several fields (e.g. road, air transportation).

Two types of 'sources' have been employed. The experiences gained from our related previous research activity and from the up-to-date scientific results published in high quality journals. In the first regard we strived to cover the most relevant subsystems and operational areas of smart transportation mostly from travellers' aspect, which cover the following management areas:

*   road traffic [1],

*   parking [2, 3],

*   public transportation [4, 5],

*   journey planning and guiding [6, 7, 8].

These papers discuss just the integration issues of several subsystems, but the integration covering the entire transportation and the related areas has not been published yet.

A well-functioning smart transportation system requires operational and technological developments. During the literature review these two important aspects are being kept in mind. Determination of demands and expectations of the smart traveller is a key factor. Kramers [9] explored functionality that can be included in a multimodal traveller information system to support sustainability-oriented decisions. It has been assessed that travel patterns and also transportation choices are modified during the trip by provision information for the users. The individuals are rather willing to change their departure time than the duration of the activity or the route [10]. Users exhibit risk averse behaviour; they prefer the transfer routes with less uncertainty in the out-of-vehicle times [11].

The users' trajectory analysis plays significant role to determine their demands. Different trajectory data types and their difficulties (data privacy, share, bias and modelling) are collected by Yue et al. [12]. Trajectory research based on smart phones and utilization of mobiles' data in smart cities were examined by Steenbruggen et al. [13]. Another technological way of collecting users' travel data is smart card. In this regard the data processing and data mining modes have been examined [12, 14].

Conceptual framework of smart city system has been examined from different aspects (system approach, technological approach, etc.). The analytical structure of the model of smart cities is a hierarchic and pyramidal structure; each step is described by the results of the step below [15]. Debnath et al. [16] determined smartness indicator in the field of smart transportation and compared existing smart cities based on these indicators. Smart city systems are supported by pervasive ICT subsystems; the different technological solutions (communication technologies, hardware solutions) are discussed in several paper [17, 18].

II. ANALYSIS AND MODELLING METHODS

In order to elaborate the general methods the component types (1) have been identified as:

*   information management *functions* (information services),

*   information managing *subsystems* (including human and/or machine elements),

*   *data groups*.

Between the components in most cases more-more (•-•) type connections are/should be realized. It raises difficulties in the case of exact categorization or illustration. Appropriate techniques have been devised for this purpose.

We have elaborated analysis and modelling methods (2), which have been categorized by the following aspects in several steps:

- *architecture*

  Only the components and the hierarchy or even their connections are mapped.

- *subsystem structure/functional structure*

  In order to represent structures connections can be revealed and analysed between subsystems, between subsystems and functions or between functions. As subsystems may include humans and/or machines various pairing of organizations and machine subsystems are to be investigated. Machine subsystems are connected in most cases to human elements (e.g. intelligent driver).

- *data structure*

  As cooperations are realized by flowing data the data groups, their properties and interrelations are to be explored. Data transmission can be characterized by: direction, volume of data-flow, soundness, rate, duration, reliability, communication technology, etc.

- *temporal features of operation (static/dynamic)*

  In the case of the connections, where either of the components is a function, its temporal features are also to be studied. Two basic cases can be distinguished: the operation is unaltered in time (static) or the operation is adapting itself due to changing situations (dynamic). Temporal features of the operation significantly influence the input and output data.

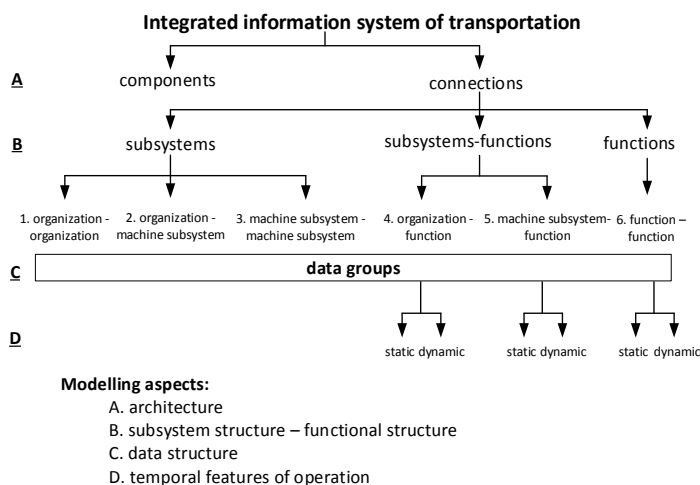Figure 1. summarizes the categorization of the model types.

Fig. 1. Categorization of model types

The analysis and modelling can be performed by several aspects, with different resolutions (break-ups) in aggregated approach or with considerations to the elements. In the initial phase of the research the enhancement of the resolution of the component types was disregarded (macro models). Analysis and modelling with high resolution can be performed just in a well-defined, smaller subsystem within the entire transportation information system. For example during the design and development of an intelligent (smart) traveller application on mobile device the full resolution is required.

The following resolution levels are distinct by the component types (in top-down approach):

- functions
    - process,
    - procedure,
    - action,
- human subsystems (organizations)
    - organizational unit,
    - employee,
- machine subsystems
    - data collection element,
    - data transmission element,
    - data storing/processing element,
    - human-machine interface,
- data groups
    - databasis,
    - data table,
    - record,
    - data element.

Taking the applying purposes into consideration the most appropriate analysis and modelling methods are to be selected. During the adaptation we have applied several ones and the results have been summarized. In order to illustrate adaptation of the methods

- the architecture of the entire integrated system – model of the smart transportation system (section III) and

- the models of the intelligent (smart) traveller with the personalized mobile application (section IV)

have been presented in more details. In titles of the models the types are indicated according to Fig. 1.

III.   SYSTEM ARCHITECTURE

The identified information management functions (3) have been categorized by:

- *application fields* and

- *aims to be achieved*.

Table I. summarizes the function groups by *application fields* and the associated information managing subsystems. Table II. unfolds the function groups into separated functions. Consistent notation has been introduced. First number of the index refers to the function group. Second number of the index makes the further differentiation possible. Functions indicated with bold letters and grey background serve directly the intelligent traveller (Section IV.). Nowadays the "communication intensive" service driven solutions with customer experience in focus are preferred.

TABLE I. FUNCTION GROUPS AND SUBSYSTEMS (B5 model type)

Function groups		Subsystems	
F_1	Intelligent (Smart) Traveller Functions	S_1	Intelligent Traveller (interactive personal mobile device)
F_2	Intelligent Infrastructure Functions	S_2	Intelligent Infrastructure
F_3	Intelligent Vehicle (+Driver) Functions	S_3	Intelligent Vehicle
F_4	Public Transportation Management	S_4	Public Transportation Management Centre
F_5	Traffic Flows' Management	S_5	Transportation Management Centre
F_6	Parking Management		
F_7	(Automated) Fare Collection		
F_8	Monitoring, Control and Enforcement		

Information managing subsystems and their relationships/interactions (4) are summarized in the model of smart transportation system (Figure 2). Only the most important human components have been indicated. E.g. dispatchers employed in the management centres are not highlighted. The intelligent traveller term covers the intelligent pedestrian, biker, passenger and driver too, laying emphasis on multimodal journey chains. The subsystems may communicate either through the transportation management centres (indirectly) or by short-range communication (directly). The cooperative ITS systems (C-ITS) are based on the latter one. The intelligent vehicles are equipped by on-board units (OBU); the intelligent travellers use personal devices (so called nomadic devices). The most relevant communication types: V2I (vehicle to infrastructure), V2V (vehicle to vehicle) and V2N (vehicle to nomadic device).

The all-around functions in the group F_1 (S_1) are mostly realized by information transmission between the traveller's device and the (public) transportation management centre (S_4, S_5), but the intelligent infrastructure (S_2) and the intelligent vehicle (S_3) may also communicate with this device. Beside the mobile device smart card can be used also in certain cases.

Functions in the group F_2 (S_2) are mostly realized by direct information transmission between the infrastructure element and the vehicle (driver) (S_3) as well as the traveller (S_1). The provided information is mostly collective and only one location on the transportation network is concerned. However the infrastructure elements may provide information also to the management centres (S_4, S_5).

TABLE II. INFORMATION MANAGEMENT FUNCTIONS

		Functions
F_1	$F_{1,1}$	**Management of travellers' characteristics/user profile/account**
	$F_{1,2}$	**Real-time traffic and travel information (alerts)**
	$F_{1,3}$	**Personalized multimodal door-to-door predictive routing**
	$F_{1,4}$	**Location and event based services, navigation (in- and out-door)**
	$F_{1,5}$	**Weather and environmental information**
	$F_{1,6}$	**Tourist information (accomodation booking)**
	$F_{1,7}$	**Traveller's feedback; (active, passive) crowd sourcing, traveller's tracking**
	$F_{1,8}$	**Emergency signal/calling/alert**
F_2	$F_{2,1}$	Hazardous location warnings (intersection safety warning)
	$F_{2,2}$	Road works warning
	$F_{2,3}$	Traffic light priority
	$F_{2,4}$	Traffic light optimal speed advisory
	$F_{2,5}$	Speed alert (roadside infrastructure based)
	$F_{2,6}$	Recharging of e-vehicles
F_3	$F_{3,1}$	Perception aiding (sight, dead angle, watchfullness, road sign recognition)
	$F_{3,2}$	Driver assistant (tempomat, adaptive distance-keeping, gear-change indicator)
	$F_{3,3}$	Driver comfort enhancement (speed-sensitive servo wheel, rainfall sensitive windshield wiper, head-up display, speech recognition)
	$F_{3,4}$	Slow or stationary vehicle warning
	$F_{3,5}$	Emergency vehicle warning
	$F_{3,6}$	Speed alert (navigation system based)
	$F_{3,7}$	Override (longitudal) collision warning (electronic break light)
	$F_{3,8}$	Lateral collision (lane outdistancing) warning, lane change assistant
	$F_{3,9}$	Head-on collision warning
	$F_{3,10}$	Driving dynamics aiding (ABS, EBD, ESP, ASR)
	$F_{3,11}$	Vehicle diagnostics (e.g. tyre pressure monitoring)
	$F_{3,12}$	Control of consumption and emissions
	$F_{3,13}$	Emergency assistant (passenger shielding)
	$F_{3,14}$	Adaptive headlight adjustment
	$F_{3,15}$	Self-drive vehicles
F_4	$F_{4,1}$	Operational management and control (by service provider)
	$F_{4,2}$	Operational management and control (by intermodal traffic centre operator)
	$F_{4,3}$	(Network wide) Traffic control (public transport priority, management of interchanges)
	$F_{4,4}$	Management of safety and security issues
	$F_{4,5}$	**Management of seat reservation (check-in)**
	$F_{4,6}$	**Demand responsive transportation management (taxi)**
	$F_{4,7}$	**Management of driver service**
	$F_{4,8}$	**Management of shared mobility (car and bike sharing, rental, car-pooling)**
F_5	$F_{5,1}$	Probe vehicle data (floating data) collection
	$F_{5,2}$	Connected fleet management
	$F_{5,3}$	Evaluation and prediction of traffic patterns (short/long term)
	$F_{5,4}$	Traffic messages and control (ramp metering)
	$F_{5,5}$	eCall
	$F_{5,6}$	Analysis and planning of traffic and transportation (analytics)
F_6	$F_{6,1}$	**Park&ride information (static/dynamic)**
	$F_{6,2}$	**Parking booking, management – dynamic pricing**
	$F_{6,3}$	**Management of park-sharing**
	$F_{6,4}$	Parking assistance
	$F_{6,5}$	Video surveillance
F_7	$F_{7,1}$	**Toll collection (usage-based, various rate schemes))**
	$F_{7,2}$	**Parking fee collection**
	$F_{7,3}$	**Public transport fee collection (e-ticketing)**
F_8	$F_{8,1}$	Enforcement of driving rules and regulations
	$F_{8,2}$	Enforcement of parking rules

Smart City

Smart Transportation

Transportation Management Centre S_5

Energy

Environment

Human resources

⋮

Other subsystems (e.g. authorities)

information flows

traffic flows

Intelligent Traveller S_1

interactive personal mobile device

Public Transportation Management Centre S_4

Intelligent Vehicle

Intelligent Vehicle S_3

Driver

Passenger

Driver

Intelligent Infrastructure (parking lots, itermodal traffic centres) S_2

Legend: ◄- -► movements   ◄——► information flow

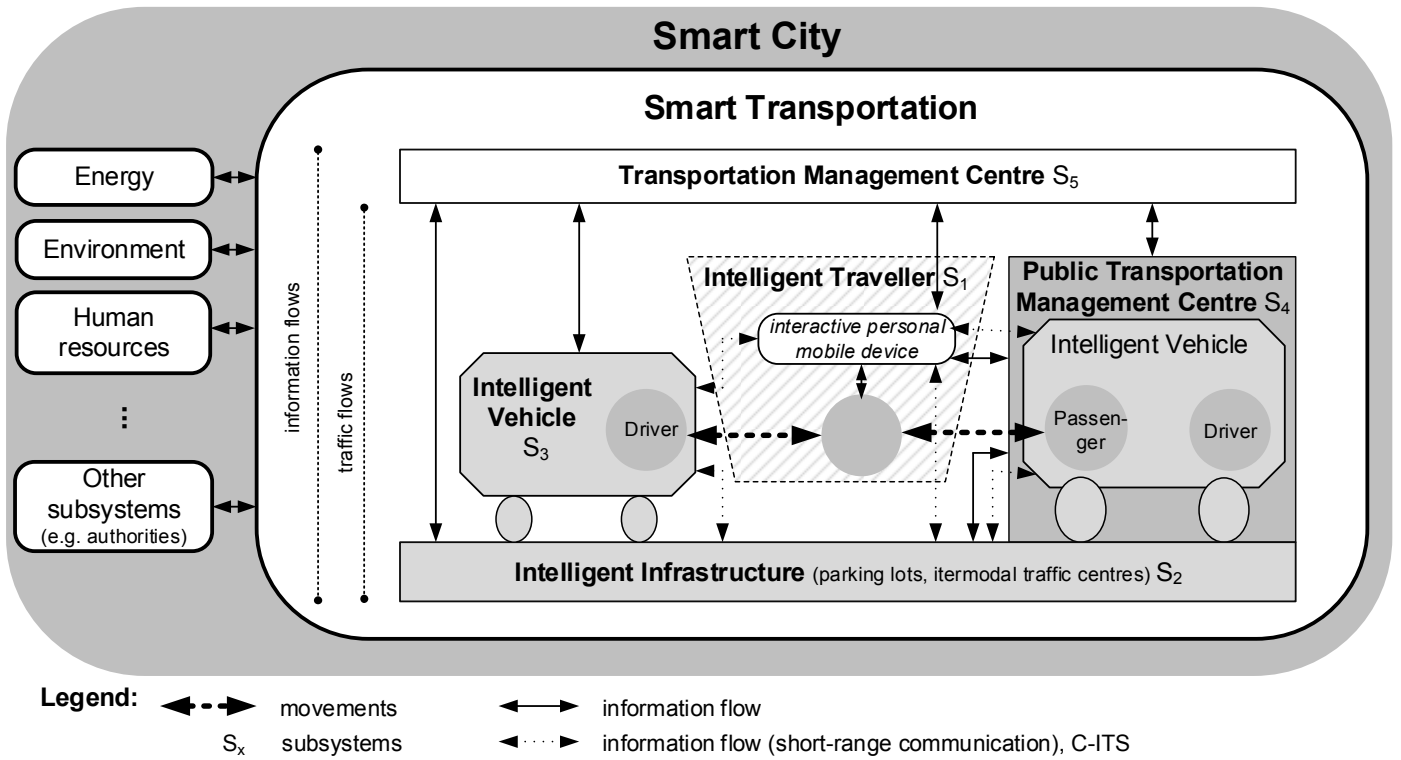S_x subsystems   ◄····► information flow (short-range communication), C-ITS

Fig. 2. Model of smart transportation system (B3 model type)

The intelligent vehicle functions (driver assistance and safety functions) in the group F_3 (S_3) are realized either by "kvasi" continuous communication with the management centres (S_4, S_5) or by event driven communication with other vehicles (S_3), the infrastructure (S_2) or the travellers (S_1). The functions based on vehicle-infrastructure communication are mainly assigned to group F_2, herein the emphasis is laid on the collision avoidance with the moving participants (vehicles, travellers). The intelligent vehicle functions require intensive obtaining of data from the sensors of the vehicle.

Functions in the group F_4 (S_4) regard to on one hand the public transportation management (operators) and on the other hand the passengers. As public transportation performs a significant rate of the entire transportation the data transmission between and the integration of the management centres (S_4, S_5) is essential. In this context the demand responsive transportation modes (including taxi), the driver service and the shared mobility travel modes also belong to the public transportation.

Function groups F_5-F_8 are realized predominantly either in or by cooperation of the transportation management centre (S_5). All the other subsystems (S_1, S_2, S_3 and S_4) are connected to this central subsystem. It means that huge amount of data about

the entire transportation system is received, stored and processed in complex dynamic way. Because all the monitoring, control, operative planning, prediction, optimization, fare collection, evaluation, emergency management, etc. functions are concentrated here the developments and innovations should be primarily focused on this field. Realization of this center implies technical and organizational advancements. Premises of cooperation includes among others legal regulations. This subsystem plays especially important role in regard of collaboration of transportation and other subsystems in the smart city.

Functions in the group F_5 cover all transportation modes, including notedly control of road traffic. Functions in the group F_6 are performed partly as intelligent infrastructure functions but the strategic decisions, the optimization and the personal advices increasingly require the comprehensive operation of the transportation management centre, especially in network-wide context. As the resource-efficient management of the transportation system (network, services) requires various, increasingly automated fare collection technologies these functions in the group F_7 are also to be integrated in the transportation management centre, especially in the case of multimodal journey chains. Such a complex

system, with thousands of participants as the transportation can be operated only by strict regulations. Therefore monitoring, control and enforcement functions in the group F_8 can provide information not only to the management centre, but to the authorities (e.g. police) too. The required data is collected by the vehicle, the infrastructure or other sophisticated methods and technologies are deployed.

The presented categorization of the functions is rather subsystem oriented. Operational models are in many cases based on the journey chain (temporal and/or logical order) or the information management process.

Table III. summarizes the *aims to be achieved*. Functions and aims can be associated to each other. For this purpose additional columns with header of aims ($A_1 - A_6$) are to be introduced in Table II. The new cells are filled out whether the function contributes to the achievement of the certain aim. (Herewith these results are not presented due to editing reasons.)

TABLE III. AIMS TO BE ACHIEVED

Aims	
A_1	Enhancement of transportation safety and security
A_2	Improvement of energy efficiency
A_3	Mitigation of environmental impact
A_4	Decrease of time consumption and costs
A_5	Higher utilization of capacities
A_6	Enhancement of comfort (aiding drivers' decisions and interventions; infotainment)

The data groups (5) map the base transportation system. Accordingly, they have been identified and classified following system and process-oriented approach. Table IV. summarizes the results.

TABLE IV. DATA GROUPS

Data group		Description
D_1	Traveller (passenger, driver) data	permanent characteristics, actual demands and expectations (preferences), contacts, payment and billing data
D_2	Infrastructure data	infrastructure basic data; planned restrictions (construction works, events, etc.); actual situation
D_3	Vehicle (driver) data	registered data, position, speed, cabin, cargo, seat occupancy, diagnostics data (pulse, eye activity)
D_4	Operational data of public transportation	management strategies, schedule, vehicle and crew data, maintenance data, reservation/capacity (utilization) data; traffic data
D_5	Traffic data	historical, actual, and predicted traffic data, emergency data
D_6	Parking data	location, capacity, (actual) occupancy, conditions, operator, fares
D_7	Weather and environmental data	actual data of measurements and forecasted data
D_8	Fare collection data	pricing strategies, reservation and actual occupancy data
D_9	Data of controls and enforcement	location, time, violation, date of payment, concered authorities
D_{10}	City and tourism data	service data (opening, contact, tariff, capacity)

Increases in numbers and types of sensors make possible collection of big amount of data with low frequency. The basic challenge: how is it possible to utilize these valuable data for improvement of processes? Data management issues can be interpreted as follows:

- *volume* – data at rest; data collection technologies are the driving forces of the developments,

- *velocity* – data in motion; small time interval to respond for inquiry is required,

- *variety* – data in many forms; structured or unstructured,

- *veracity* – data in doubt; uncertainty due to data inconsistency, incompleteness, ambiguities.

The collected data are stored either in centralized or decentralized way depending on whether they are stored either by the owner organization or in a central database. The presentation of flowing data is possible only in much smaller context. Therefore for this purpose the 'subsystem' of the intelligent traveller has been chosen.

IV. INTELLIGENT TRAVELLER

The model of the integrated smart transportation system contains all types of machine components considering both the short and long range communication technologies, especially c-its solutions. As one of the most important elements, the interactive personal mobile device and travellers' ideal application was chosen to illustrate the relationships between functions and subsystems considering the transmitted data groups (6). The most important novelties of this intelligent application:

- value-added,

- location-based,

- door-to-door and

- personalized information services;

- with decision support,

- using real-time and

- predicted data.

During development special attention should be paid to the appropriate *human-machine interface* with consideration to the traveller's disabilities.

In most cases the relationships between the component types were investigated. In order to visually illustrate the coherences some 'two component type' models have been presented. However results regarding connections of all the three component types (functions, subsystems, data groups) have been elaborated in 'multi-dimensional' matrices.

The relationships between functions and subsystems have been revealed and described in matrix (Table V). One row presents the co-operation of the subsystems regarding the certain function. The automated data transmission in case of a function is indicated by grey background.

TABLE V. RELATIONSHIPS BETWEEN SUBSYSTEMS AND INTELLIGENT TRAVELLER FUNCTIONS (B5 model type)

		Subsystems				
		S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
Intelligent Traveller Functions	F$_{1,1}$	+	-	-	+	+
	F$_{1,2}$	+	+	+	+	+
	F$_{1,3}$	+	-	-	+	+
	F$_{1,4}$	+	+	+	+	+
	F$_{1,5}$	+	+	+	-	-
	F$_{1,6}$	+	-	-	-	-
	F$_{1,7}$	+	-	-	+	+
	F$_{1,8}$	+	+	+	+	-
	F$_{4,5}$	+	-	-	+	-
	F$_{4,6}$	+	-	-	+	-
	F$_{4,7}$	+	-	-	+	-
	F$_{4,8}$	+	-	-	+	-
	F$_{6,1}$	+	+	-	-	+
	F$_{6,2}$	+	-	-	-	+
	F$_{6,3}$	+	-	-	-	+
	F$_{7,1}$	+	+	-	-	+
	F$_{7,2}$	+	+	-	-	+
	F$_{7,3}$	+	+	-	+	-

Legend:
+: involved in the function,
-: not involved in the function,
grey background: automated data transmission.

The subsystems handle different data groups. Their coupling has been revealed in matrix (Table VI).

The relationships between subsystems considering the data groups have been described in matrix (Table VII). We have focused only the Intelligent Traveller subsystem (S$_1$) as the only row heading; but analysis for the other subsystems can be performed in the same way. The data groups as the 'third dimension' have been projected into the plane. Since the connections are realized by the flowing data groups they have been assigned to both the origin and the destination subsystems as output and input data. In this case the temporal properties of the data transmission (event-driven or time cycle) and the approximate volume of data have been determined.

In the future the direct communication of personal (nomadic) mobile devices plays an increasing role, especially in emergency situations (e.g. D$_5$). Some data, which are important for the traveller, but related indirectly to the transportation (e.g. D$_{10}$) are stored not in the transportation management centre.

TABLE VI. ASSOCIATION OF SUBSYSTEMS AND DATA GROUPS (B 'subsystems'-C model type)

		Subsystems				
		S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
Data groups	D$_1$	+	-	-	+	+
	D$_2$	-	+	-	+	+
	D$_3$	-	-	+	+	+
	D$_4$	-	-	-	+	-
	D$_5$	+	+	+	+	+
	D$_6$	-	+	-	-	+
	D$_7$	+	+	+	+	+
	D$_8$	+	+	-	+	+
	D$_9$	+	-	-	+	+
	D$_{10}$	+	-	-	-	-

Legend:
+: handle the data group,
-: do not handle the data group.

TABLE VII. CONNECTIONS BETWEEN SUBSYSTEMS CONSIDERING THE DATA GROUPS (B3-C model type) - excerpt

Sub-system	Data groups	Subsystems				
		S$_1$	S$_2$	S$_3$	S$_4$	S$_5$
S$_1$	D$_1$	-	-	-	↗	↗
	D$_2$	-	↙	-	↙	↙
	D$_3$	-	-	↗	↙	↙
	D$_4$	-	-	-	↙	-
	D$_5$	↗	↙	↙	↔	↔
	D$_6$	-	↙	-	-	↙
	D$_7$	-	↙	↗	↔	↔
	D$_8$	-	↗	-	↗	↗
	D$_9$	-	-	-	↗	↗
	D$_{10}$	-	↙	-	-	-

Legend:
↗: input data of the machine subsystem (from S$_1$),
↙: output data of the machine subsystem (to S$_1$),
↔: input and output data (bidirectional data-flow),

white background: event-driven transmission,
grey background: event-driven or time-cycle transmission,
size of the arrowhead corresponds to the volume of data-flow (small, medium, large).

The relationships between the functions have been illustrated in the functional model (7) of the travellers' ideal integrated application (Figure 3). The primary logical relationships have been revealed and indicated. If there are sequential dependency between several functions, only the relationships between the consecutive functions are illustrated.

This model facilitates also planning of the menu structure of the application, where the arrows correspond to the steps between the pages/queries.
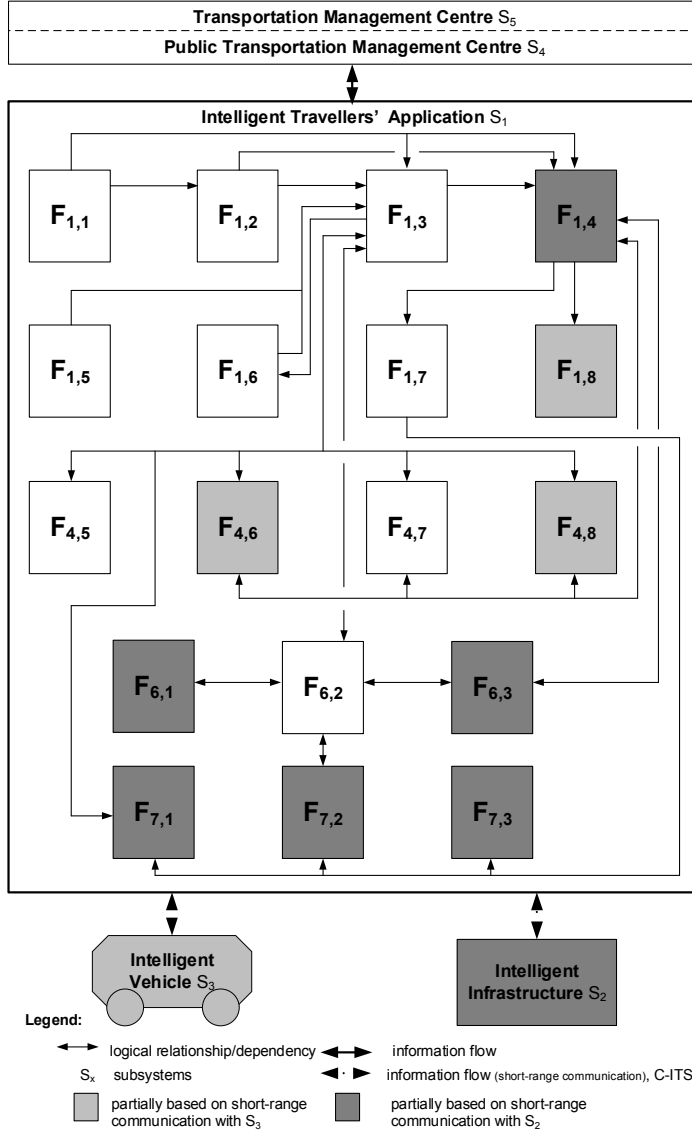

Fig. 3. Functional model of the intelligent traveller's application
(B6 model type)

Management functions (e.g. $F_{4,5}$, $F_{4,6}$, $F_{4,7}$, $F_{4,8}$, $F_{6,2}$ and $F_{6,3}$) include information provision and payment options. Routing function ($F_{1,3}$) involves the selection of the desired route and in this way implicates reservation/booking and payment.

The input data of these functions are primarily originated from (public) transportation management centre (S_4, S_5). However when the mobile device is used as a 'nomadic' C-ITS device, the intelligent infrastructure or vehicle (S_2, S_3) or another mobile device (S_1) with short range communication

provides the required input data. The concerned functions are indicated by different kinds of grey background. Because of the communication intensive and thin-client solutions the operation of the personal mobile device generates a great volume of data-flow. In the future automated, direct communication of mobile devices in a grater rate is probable.

The intelligent traveller with his mobile device increasingly serves as data source. In this regard functions $F_{1,1}$, $F_{1,7}$, $F_{1,8}$, $F_{4,8}$, $F_{6,3}$ play important role (e.g. advertising the free capacities - $F_{4,8}$, and $F_{6,3}$ functions or traveller's tracking - $F_{1,7}$ function). The output data are mainly transmitted to the (public) transportation management centres (S_4, S_5). The mobile device send data only in some cases directly to the intelligent infrastructure or vehicle (S_2, S_3) or another mobile device (S_1) with short range communication (e.g. intelligent biker's emergency alert at a dangerous crossing).

In this model the abstraction level did not allow detailed investigation of temporal features of both the data transmission [event-driven or time cycle] and operation (aspect D on Figure 1). The analysis and modelling of static/dynamic or even adaptive operation requires much more detailed disaggregation.

V. CONCLUSIONS

The discussed integration of information subsystems of transportation and its placement into the smart city system consists of several steps requiring long time. Results summarized here are the first step of this process. The so called inner and outer integration of the transportation can be realized at the same time.

The main contributions:

- categorization of model types
  (devising a framework structure of modelling),

- models with different coverage and resolution (disaggregation) of the entire transportation system. These models are of value in themselves proving also the applicability of model types.

The key findings:

- identification, categorization, revealing and illustration of component types and their relationships require wide knowledge and adequate level of abstraction in order to elaborate timeless analysis and modelling methods,

- as the traveller (the citizen) is the key element researches regarding the behaviour and decision-making as well as developments of integrated personalized applications significantly affect the efficiency of smart transportation.

The lessons learnt:

- only few scholar publications are related directly to the topic what made very hard the thorough, comprehensive literature review,

- new functions fade in and the existing ones evolve day by day, therefore flexible models had to be devised,
- the appropriate analysis (categorization) may reveal the still missing components, which will unveil in the near future,
- relationships between the components are not always definite, the dominance has to be taken into consideration.

Further research directions:

- enhancement of resolution depth in each direction to attain to the elementary components,
- elaboration of analysis and modelling methods regarding temporal features of data transmission and operation (aspect D on Figure 1) as well as its adaptation,
- detailed analysis of behaviour and decision-making of travellers based on results of questionnaires in order to elaborate the intelligent traveller's application (information from/about the passengers significantly facilitates the developments in operational side),
- elaboration of key performance (quantitative and qualitative) indicators from travellers' point of view and their measuring/evaluation methods, which are used for assessment of operation of smart transportation,
- determination of development phases regarding the integration based on logical, technological aspects and travellers' expectations.

The achieved results facilitate the planning and implementation of this complex system revealing the lacking components and the imperfections of existing solutions. In this way the utilization of the available and new data can be improved resulting advantages at both the travellers and the operators. The interpreted smart system contributes to the high standard urban living.

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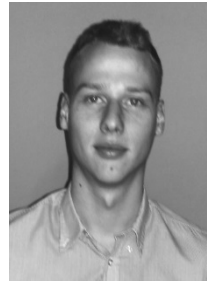
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