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Model of Multimodal Mobility Coordination and Guiding System

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Abstract— ***Travelers manage information both before and during their journeys. There are advanced Information Technology (IT) solutions available for this purpose, but most current applications map transport alternatives only partially. They have functional imperfections and their personalization is limited. Most of the research in this field is confined to developing this type of limited application. Few scientific studies have been published regarding the interaction between traveler and operator function in the management of transport chains. Similarly, little research has been devoted to the comprehensive development of information flows. The aim of this research is the elaboration of the model of a Multimodal Mobility Coordination and Guiding System (MMCGS) on a logical-functional level. Applied methodology consists of the analysis of the information management of travelers and operators, the summary of existing and future infocommunication technologies and the investigation of co-operation between human and IT components. All this is executed using a system- and process-oriented approach. Results of the research: the system architecture of the proposed MMCGS and its model of operation are described in this paper. In consideration of this conclusion: it is possible to identify further research fields, as well as to coordinate future system and application development (supplemented with additional features). As a general consequence: the proposed system affords a promising opportunity for efficient (sustainable) and high quality passenger transport.***

Index Terms—**integrated information system, multimodal transportation, mobility management, personalization.**

I. INTRODUCTION

The goal of mobility management is to handle mobility demands, while efficiently utilizing all resources (energy, vehicle, transport network, time cost etc.). Mobility demands are determined by the need to connect users to their economic requirements (goods and services). Mobility management covers "movement" of persons, goods and information, namely, passenger transport (vehicular and ambulatory), freight logistics and infocommunication processes. Mobility management's fundamental requirement is the coordination of user demands and transport capacity (actual and predicted in both cases) in transport chains. Several publications have discussed this topic. They described the subsystems to different "depths" [21], nevertheless only a limited number of them have tried to model a complex system of multimodal mobility management (MMCGS) [7], [8]. The general methods introduced in these publications have been successfully applied not only in the field of public passenger transport, but also in other research work related to transportation [16], [17]. "Information Mapping" (the mapping of every component of the transportation system) is necessary for the development of the MMCGS, which requires a wide and comprehensive study of both transport and information management processes. Travel mode choice can be influenced by available multimodal options in the travel chain and personal preferences (needs and demands). A research study has investigated the effects of habit and past preference on transport users when making travel mode choices. Results indicate that habit has a strong influence over decisions made in travel situations [1]. The effects of modern information systems on commuters' readiness to use multimodal transit according to their circumstances and preferences have been revealed by the conduction of a survey. The results have been discussed in a study [2]. Another paper reports on research that introduced the concept of an integrated multimodal traveler information service applied to mixed socio-demographic groups of travelers. The research illustrates that mode choice is mostly habitual, therefore only an integrated service with provision of personalized information, which incorporates several additional information sets (comfort, cost, etc.) could persuade a modal change [12]. Other research shows that customers' desired integrated multimodal travel information requirements can vary throughout pre-trip, wayside and on-board stages of a journey. There are several factors that determine customers' information needs (i.e. characteristics of journey or persons) The main determinants are time savings (travel and planning time) and effort savings (physical, cognitive and affective effort) [10]. Building on such conclusions our proposed system (MMCGS) should be inserted, supplemental to existing transport measures. On the basis of results published in a study [5], relations between transport 'measure types' have been summarized. The terms 'hard' and 'soft' measures have been used to describe the following: a 'hard' measure can refer to physical components (e.g. transport infrastructure), a 'soft' measure can refer to operational components (e.g. information technology). Such concepts are summarized in Fig. 1. Individual and collective, as well as pedestrian and vehicle movements are determined by mobility demands. The effects of information on passengers may be

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obligatory, advisory or informatory. This paper focuses on mobility management, but the Fig. 1 below introduces mobility management in a broader context. The Multimodal Mobility Coordination and Guiding system (MMCGS) is a "soft" measure. It coordinates the information regarding supply (derived from different, partly public, sources) and the information regarding demands (travelers' needs and personal preferences). The derived mobility chains are primarily planned according to the actual and predicted decisions and movements of travelers during their journey. One of the motivations for developing personalized travel information systems is to induce travelers to use environmental friendly, energy efficient and safe solutions. The term "infomobility" is used in study [3] to describe multimodal passenger transport systems integrated within an information system. It means the use and distribution of real-time and static multi-modal information (including parking facilities) to travelers and operators, both pre-trip and in-trip. (The term "operator" is used for transport companies.) Effect and efficiency of the proposed system may be assessed in a quantitative way by the analysis of the usefulness of the travel information to the user [6]. The successful realization of the system (MMCGS) is confirmed in the technological sense by U-ITS (Ubiquitous Intelligent Transportation System). Namely, 'intelligence' is available in every element of the transport system (road, vehicle, traveler and control center, etc.). In the developed model, information flows between these components and their potential for cooperation is determined to produce favorable travel solutions.

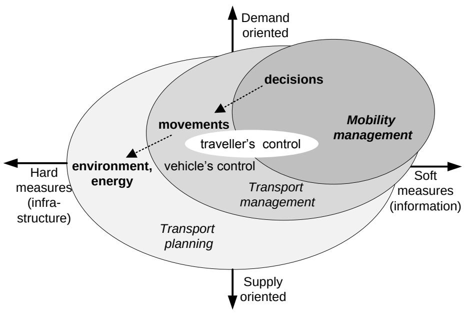

Fig. 1 Context of Transport Measures (source: partially own research, based on [5])

The research of this topic requires the continuous exploration and deep investigation of existing and planned IT solutions. An exemplary paper addresses the main national initiatives for integrated traveler information provisions in the UK. The key issues and lessons conveyed therein are a useful reference for European countries, where the public transport services are (still) not transferred into private management. It outlines integration between public transport and highway (car) transport information [14]. Another paper presents a multi-operator platform implemented to manage booking, payment and fleet monitoring of a network of long-distance passenger transport. Users and operators are able to monitor the position of buses in real time [9]. Additional to this, a further paper presents data envelopment analysis as a non-parametric linear programming method capable of the efficiency evaluation of decision making units, e.g. public transport companies [15]. One of the most advanced solutions is the WISETRIP system, which provides multimodal trip information sourced from various journey planners. Additionally, unique personalized service delivery is provided (i.e. alerts based on real-time events, which assist trip execution). User satisfaction of this service has been assessed, regarding the clarity and adequacy of information as well as the ease of use. Further developments (i.e. geographical and modal expansion, environmental criteria, trip strategies) incorporated into a newer version of the service, called "Enhanced WISETRIP" have been released [18]. An article describing the operational features of a multimodal trip planning system that includes driving, public transport, and driving-parking-then-public transport travel modes has been published. This system incorporates real-time traffic and transit information and it has been launched in the San Francisco Bay Area [13]. In this article, **the framework of an integrated information system aiding passenger transport has been summarized**. The relevant research fields (e.g. information technology, system organization) and their coherence have been analyzed.

II. METHODOLOGY

Telematics solutions for passenger transport can be summarized by following an **analytical approach**. The aim of multimodal operation in the creation of transport chains:

- enlargement of "variety" in passenger transport,
- Enhancement of the efficiency of transport chains by offering a combination of transport solutions, incorporating information about certain vehicles' benefits.

A. *System Architecture*

Intermodal traffic centers (interchanges) are important nodes on the transport network for information processing. At these points data regarding in, through, and out flow of passenger and vehicular traffic should be gathered. These data are then used to minimizing time cost to both passengers and vehicles. An additional aim is to minimize walking distance between vehicles, which should be aided by automatic equipment (elevator, escalator, etc.). For this purpose **precise mapping of all interchanges must be incorporated into the integrated database of the proposed system** (MMCGS).

The architecture of the mobility management system (for the achievement of the above-mentioned aims) is summarized in Fig. 2. Elements of information handling can be classified into three groups:

- passengers (information management of the other human components, e.g. driver, dispatcher etc. is not analysed in this paper),
- terminals which co-operate with the passengers in one-way communication (passive terminals) or two-way communication (interactive terminals),

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- Information management subsystems of transport operators (their inner structures and operations are not analysed in this paper).

The system structure is simplified by representing only one element from each type in Fig. 2. (The exact number of the components can only be determined as a result of the planning process.) The components are interconnected by telecommunication channels as indicated. **The installation of an integrated mobility control center is the paramount solution recommended in this paper.** Its function is the management of transport processes, and (in a wider interpretation) the management of mobility demands. The control centers of all transport operators may also be functionally integrated into the proposed mobility control center. This architecture, namely the distinction of the three types of control centers in Fig. 2, follows the most commonly established organizational structures. The system's functions are distributed between the control centers; however, these centers can be integrated in the future.

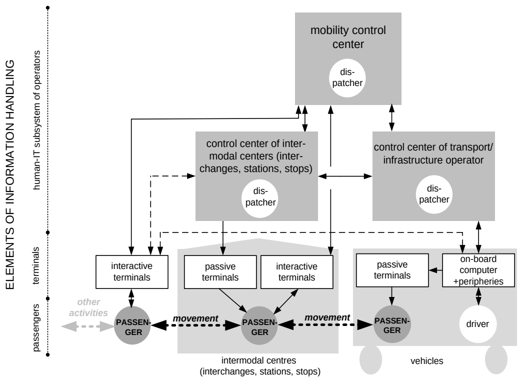

Fig. 2 System Architecture of Integrated System for Mobility Management (source: own research)

B. System Operation

Mobility demands result from the way in which passengers can only satisfy their needs (for goods and services) in certain places. Locomotion is a required action to link such places. Mobility management may cover:

- selecting the appropriate mode of transport; or in a wider approach
- Selecting the location and time to satisfy their demands for goods and services (considering "dynamic transport potential" of the certain spots and dynamic features of goods and services there).

Dynamic utility values of the objects can be determined by their worth to the user, their location on the network, as well as the transport options available to reach them and existing passenger transport personal preferences. Considering these utility values as "virtual distances" the objects can be visually illustrated in a dynamic "subjectivity map". For various mobility requirements, different modes (transport chains) may be suitable. All objects in motion (vehicles, passengers) should be tracked by the proposed system. Guidance and influence of passengers can be separated into movements with and without vehicles. During travel, the collection of information regarding transport vehicles is sufficient so long as passenger information regarding embarking and disembarking is collected on board the vehicle. (Passenger movements on board can be ignored during demand management considering a "network approach"). The operation of the proposed integrated system is summarized in Fig. 3. The numbers 1-3 represent the movements. Travel by public transport vehicle is usually the intermediate element of the chain. It is preceded and followed by individual movements. Ways of intervention into the transport process may vary between "soft" and "hard" forms. In the former case it is possible to take published information into account; in the latter case it is obligatory to do the same. Control of vehicles usually belongs to the"hard" forms.

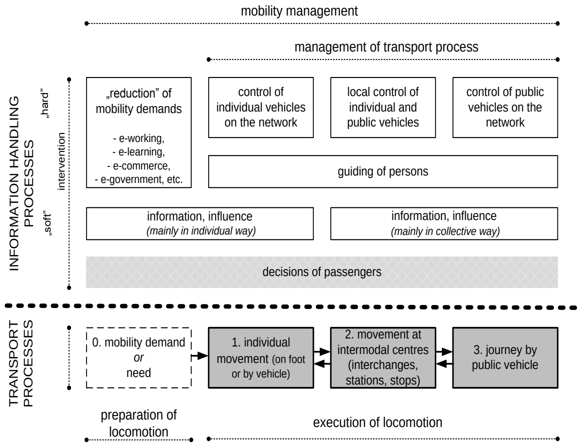

Fig. 3 Operation of Integrated System for Mobility Management (source: own research)

Efficiency of mobility management depends on the effectiveness of interventions, namely, reactions of the passengers.

"Information quality" is influenced by:

- handled information itself (reliability),
- processing (rate of value-added information),
- Visualization (human-IT interface).

Behavior and movements (m) of passengers depend on the features of the needs (n) and information handling (h) required to this. Equation (1) illustrates the nexus:

$$m=f(n, h). \qquad (1)$$

Information about transport options and processes is transmitted to passengers via different kind of IT components. Fig. 4 shows the elements of the proposed system and information handling processes functioning in and among them in a simplified way. Each type of element stores and processes information, namely **the "intelligence" is distributed among the exemplified various levels**. Accordingly, equation (2) shows this distribution:

$$h=h_I+h_{II}+h_{III}, \qquad (2)$$

Where Roman numerals in the index refer to the element types. Distribution "rates" of operations affect the performance of data transmission. "Rate" of processing operations in passengers' mind (h_I) depends on personal characteristics:

- preliminary knowledge of the transport system,
- reliance on the published information,
- Demand for value-added information services.

"Rate" of information handling processes in terminals (h_{II}) is affected by:

- quantity of dynamic information,
- design and location of equipments, (functionality)
- In case of interactive solutions, the number of interactions required and the speed of response time.

Information handling of a human-IT background (core) as a subsystem (h_{III}) has two roles. On one hand, it contributes to individual information and corresponding influence over passenger choice (preliminary partial processing and Transmission of data, to achieve "local" aims).

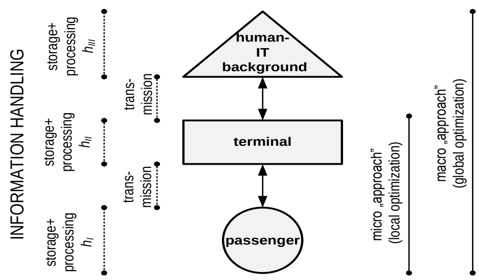

Fig. 4 Distribution of Information Handling Processes between the Components (source: own research)

On the other hand, it aids the efficient handling of the resources in the transportation system (complex processing and transmission of data to achieve "global" aims). (One of these aims is the reduction of energy consumption.) In this latter case, it

- sets the target-values,
- perceives realized values,
- compares target-values and realized values,
- In case of deviation, intervenes to eliminate this deviation.

Dealing with passengers in details, the most important objective is to achieve the maximal "utility" of travel; namely to spend as short time in the transport system as possible. The potential travel time savings, using information systems, has been evaluated already [20].

III. RESULTS – MODEL DEVELOPMENT

A. *Metamodel*

The distributed information systems with high complexity can be represented in an efficient way using a metamodel. This is needed for a higher level of abstraction and may contain several layers. The metamodel helps to identify:

- the essential subsystems,
- their features,
- the connections between them and
- their functions.

Metamodel is a common method of representation. It facilitates the modelling of the subsystems in a more detailed way. One subsystem model should fulfil the requirements and interrelations determined in the metamodel. The main information flows and processes of the proposed integrated system are summarized in the metamodel, illustrated in Fig. 5. Organizations as producers and consumers of information are designated by Arabic numbers. The cooperation requires data accessibility of each organization as well as data quality (probability nature, reliability, raw or value-added nature, etc.). Data processes are illustrated in two "layers":

I. travelers' functions: uppermost level (in the center of the figure),
II. Operators' functions: lowest level (basis of the entire figure).

These two layers are interconnected by telecommunication systems (in the middle, colored by light grey). They not only transfer data, but they may also be sources of data regarding the movement of objects (persons, vehicles). Data processing modules (functions) and their interrelations (in context of travelers) are designated by capital letters in the middle of the figure. Processes in the modules, the input and output data are summarized in Table 1. Most of the modules have functions in both layers. Since data are stored in a decentralized (distributed) way among IT components and organizations, they are not represented.

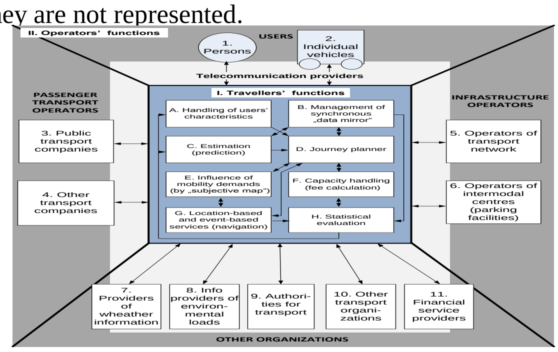

Fig. 5 Metamodel of Multimodal Mobility Coordination and Guiding System (source: own research)

Information relations between participants have two types:

- B2C (business to customer) – between transport companies and travellers, and
- B2B (business to business) – between transport organizations (operators).

Information management processes regarding travelers are summarized in the next chapter and processes regarding transport companies are summarized in the subsequent chapter.

B. *Characteristics of Mobility Demands – Travelers' Function*

Transportation and information services have become increasingly user-centric instead of operator-centric. Namely, the services are adjusted to users' demands. For this purpose **detailed mapping of travelers and their mobility demands (habits, expectations) is required** [11]. Preliminary or

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actual data input (stated preferences method), as well as data gathered from the analysis of completed movements (revealed preferences method) can be applied. In the latter case e.g. data-mining or incremental machine learning techniques can reveal the relationship between data elements collected by users' terminals. For posterior evaluation the event-based data collection is sufficient, whereas for revealing actual demands and for guidance the actual position of users have to be sampled in a time-cycle. The travelers' expected behavior can be forecasted by the application of the behavioral (decision-based) prediction model. If personal parameters are not available, then recommendations for the travelers may be based on statistical values. Main variables of the traveler:

- preferred transport mode (e.g. private car, bike, public transport),
- walking velocity,
- Disability (visually-impaired, hearing-impaired, wheelchair user, etc.),
- time cost,
- Readiness to transfer, etc.

Variables assigned to a person (p) can be represented in a vector (notation $\underline{a}_p$). Main features of the travels:

- place of departure and arrival,
- temporal features (e.g. departure, arrival time or time-independent),
- purpose (e.g. work, leisure time),
- frequency (e.g. commuter or occasional traveller),
- carried objects (e.g. luggage, child car),
- Expected information (preliminary knowledge available or not), etc.

Variables assigned to one journey (between points A and B) of one person (p) can be represented in a vector (notation $\underline{b}_{p,AB}$).

Table 1. Detailed Description of Modules (source: own research)

	name	operation/processing	input data	output data
A	handling of users' charac-teristics	handling of personal features, travel habits, evaluations, categories	user profile, habitual and actual travel demands (pre-stored or as result of self-learning); feedbacks	characteristics of persons (categories)
B	management of synchronous "data mirror"	management of dynamic data associated with locations; comparison of planned-actual data; data fusion	planned and actual position and status of persons, vehicles, infrastructure	synchronous "data mirror" (geo-data); data of incidents, accidents and their causes
C	estimation (prediction)	calculation of demand predictions and traffic forecasts	synchronous "data mirror"; historical data; (arrival, travel times, etc.)	forecasted "data mirror"; data of incidents, accidents and their causes	position and status of objects in the near future
D	journey planner	multi-level grouping of zones and nodes; preliminary planning of journeys (between zones); actual planning at origin and destination points	users' characteristics; actual and forecasted travel demands; synchronous and forecasted "data mirror"	journey plans (spatial, temporal, payment information)
E	influence of mobility demands (by "subjective map")	management of dynamic utility values of objects (considering location, transport accessibility, personal features)	actual demands for products, services or entertainment; information about objects and services	suggestions for sequence and locations of activities
F	capacity handling (fee calculation)	coordination of demands and capacities (with iteration); management of seat reservations	planned seat-capacities; demands for reservation; historical data	utilization and income data
G	location-based and event-based services (navigation)	positioning; information about services (parking facilities, accommodations, etc.), out-door and in-door guidance to destination	journey plans; location data of persons and vehicles	information about objects and services
H	statistical evaluation	information acquisition about capacity exploitations (vehicle movements) and travelers	synchronous "data mirror"; utilization and income data	statistics (e.g. users' habits, traffic data)

Variables of travelers' decision-making process: activities before and after the journey, purpose of travel, time and place of journey, available travel chains, costs, effects on the environment, statistical data of accidents, etc. Some activities (e.g. shopping) can be completed at multimodal traffic centers (interchanges). The proposed system allows a selection from available options by interactive operation. The selection is often influenced by obligatory pre-booking of certain transport modes, or it's required pre-boarding check-in time. The final outcome of the decisions is represented by human movements. Behavior and movement of travelers are jointly influenced by traffic and information conditions. Decision-making depends on the nature of the transmitted information and the understanding of this information. Decision-making is influenced by:

- when the information is introduced (phase of transit: preparation, walking, waiting, travelling, transfer),
- location of information (stop, station, interchange, multimodal traffic centre, on-board),
- type of information (qualitative - e.g. reported delay, quantitative - e.g. half an hour delay),
- content of information (informatory, advisory, mandatory, emergency, advertising),
- rate of personalization (e.g. personalization of webpage),
- Accuracy, reliability.

The information can be "produced" by the following query types:

- location-based (e.g. at station or stop),
- time-based,
- event-based (e.g. alteration of traveller's or vehicle's position; alteration of traveller's intention; traffic incident; emergency situation),
- user-based,
- Vehicle-based (considering the route, turn, etc.),
- Dependent on the phase of the travel chain (e.g. preparation, individual travel, P+R facility, and walking, public transport).

Two types of applications are:

- web based applications,
- Mobile phone based applications.

The latter ones can provide location-based services (navigation). The following positioning methods are available:

- GPS-based (for outdoor navigation with digital maps),
- WLAN-based (for indoor navigation with site plans).

Several scientific, technical and design issues arise if the interface between humans and computers is considered. The quality of the computer: whether it "computes" quickly and precisely or not. The quality of the human: how they think and feel. Efficient information management can be realized by the appropriate combination of these computational and human qualities. According to the widest interpretation, relevant transport chains and activity schedules can be presented (if the integrated system is interconnected with commercial, public administration, etc. databases). These schedules demonstrate the optimal sequence of activities considering the users' priorities.

C. Characteristics of Capacities – Operational Functions

The term "super networks" can be used to describe the capacity of several passenger transport modes. According to the macro approach, the "supernetwork's" nodes are the stations or stops and the links are the routes connecting them. According to the micro approach each node of the "supernetwork" can be analyzed further, and "subnodes" can be applied. "Subnodes" are the particular locations of the pedestrian movements (e.g. ends of escalators). The "sublinks" are the pedestrian routes connecting these points. All the elements of this kind of network can be described by time-varying parameters. The goal of an earlier research paper was to develop and test a generic multimodal transport network model for advanced traveler information systems applications. For this purpose the "supernetwork" technique has been introduced. Considering all modes, pedestrian networks play an important role in modelling transfer connections. For multi-criteria evaluation of routes a general representation has been elaborated [22]. In my research the capacity of macro networks have been determined by vehicle capacities (availability, number of free seats) and number of vehicle runs (planned, actual, predicted times and locations). This information about conditions and positions should be collected in the integrated system within a relatively short sampling time and this is the basis for calculating the predicted values. Travelers' assistant services can be realized by the introduction of "personal resistances" and with consideration given to the available network and vehicle capacities. Not only the features of network elements, but the features of travelers and journeys may vary chronologically. The following interrelation (3) has been proposed by us to illustrate the personal resistances:

$$R_{AB,w,p}(t) = \sum_{i=1}^{m} L_i(\underline{a_p}, \underline{b_{p,AB}}, t) + \sum_{j=1}^{n} N_j(\underline{a_p}, \underline{b_{p,AB}}, t) \qquad (3)$$

where,

$R_{AB,w,p}$ resistance value that belongs to the travel chain (w) between points (*A*) and (*B*), in time (*t*), in the case of person (*p*),

L_i resistance value of link *(i)*,

N_j resistance value of node *(j)*,

t planned (estimated) arrival time at the link or node,

m number of links,

n number of nodes (in general $n=m+1$).

Time dependency is especially important during the journey. The movements can be altered as a consequence of the "modified resistances", which changes the capacity utilization and thereby the resistances. Accordingly, balancing of demand and supply requires the quick processing of a large amount of real-time data as well as flexible reaction by transport operators. Additionally, the modified capacity reacts for the demand. The fee of the mobility services (infrastructure toll, travel fee, etc.) is a sharp regulatory tool between these two elements. It can also be altered in time for a refined intervention.

The resistance values of the certain journeys (L_i) can be determined by considering the specific parameters of the different travel modes (operators). The most important of these:

- temporal availability,
- time duration,
- distance,
- fees,

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- comfort (sense of congestion),
- sense of security,
- safety,
- energy consumption,
- environmental impacts,
- Guarantee of getting to the destination – mobility guarantee (compensations in case of incidents, refunds) etc.

A deeper, more exact determination of the variables and an elaboration of the computing algorithm to give the optimal solution for passengers (e.g. minimizing "resistances") is an element of our further research activity. The interrelation between these variables (3) constitutes the basis of this forthcoming work. One of the key elements is the estimation of travel time, which can be calculated by historical data [4] using a combination of several mathematical methods [19]. The optimization task of the operators is to supply services that satisfy individual expectations with as low operational costs as possible considering all cost-types. Since waiting time increase travelers' "costs" operators often enhance temporal availability (e.g. extension of operational time) to approximate flexibility of individual transport. (In the case of individual transport the availability is only restricted by parking limitations.) For this reason often Demand Responsive Transport (DRT) and demand responsive headways are introduced. The preconditions of this are the recognition of real and predicted mobility demands as well as advanced operative planning (scheduling), traffic control and passenger information. In the case of passenger cars the communal use of vehicles can be observed on the following ways (to reduce the costs):

- by enhancement of exploitation of time (car-sharing), as well as
- By enhancement of exploitation of seats (car-pooling).

The "freedom feeling" of private cars should be partially compensated at these mobility forms. Advanced telematics technology has made this development possible.

The proposed integrated system (MMCGS) supports the coordination of capacity between the transport operators. The free capacity can be "advertised" through a so called "mobility exchange". (In this way the drivers can be transported by the free capacity of other operators). In this context the pricing can also be harmonized (with the introduction of discounts), as well as standardized sales solutions (fee collection) can be introduced. As a consequence all of the authorities responsible for transport operation can access comprehensive analyses regarding the entire public transport system.

IV. CONCLUSION

The decisions of the passengers cause their movements. Some mobility options are chosen due to information deficiency, whereas better solutions are available. Transport choices can be influenced by the more appropriate and value-added information provision. In order to achieve these aims the followings are required: assessment of users' behavior and integrated development of current information systems. This paper has presented methods to describe the structure and operation of this complex system. This work has identified the main system-elements, their features and their interrelations. The research results have been illustrated in figures. In particular the human components have been deeply investigated, because the success of the entire operation depends mainly on the perception and understanding of the disseminated information. The main result of this work is the elaborated metamodel, which summarizes the main functions of the proposed system (MMCGS). It indicates (as a basis) further research fields and the needed developments. Our future work is going to concentrate on the modelling of the described subsystems and their functions, with special regards to their integration. We intend to focus on:

- Analysis of humans' information management (travellers, drivers, dispatchers of transport operators, etc.),
- application of the results of artificial intelligence research in transportation,
- analysis of the reliability of information based on plausibility theory (especially in the case of forecasted traffic situations),
- assessment of soundness of information transmitted between the subsystems (revealing distortions),
- Analysis of the activity patterns and the travellers' personal needs (identification of the mandatory and flexible activities).

We are elaborating a real-time decision-support method aiding travelers before and during their movements. This method incorporates the result of the analyses of transportation network, transport modes and personal characteristics.

The results discussed in this paper contribute to the realization of the proposed integrated system, which cover all transportation modes and several regions, countries or even continents.

V. ACKNOWLEDGMENT

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