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STRUCTURE OF TRANSPORT MODEL ON STRATEGIC LEVEL OF MANAGEMENT FOR ASSESSMENT OF ITS CONFIGURATION

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Abstract

The aim of the article is to present the issues related to the use of the transport model for ex-ante evaluation of the functional and operational configuration of ITS. Variants of ITS configuration have been presented based with use of ITS user needs from FRAME methodology and with use of ITS user services implemented in cities of Poland. The structure of the transport model on strategic level of traffic management has been presented in the context of the following impact of ITS configuration: changes in the use of paths in network, changes in the use of transport system modes, changes in the destinations of trips, and changes in the number of trips for various purposes. The results of transport model enable a comparison, using an incremental method, results of transport decisions of users, obtained in specified forecast horizons for the ITS variants of configuration. Structure of transport model presented in article is suitable for strategic level of traffic management with long-term results. While transport models for tactical level of traffic management with medium-term results, and for operational level of traffic management with short-term results are used to determine the characteristics, describing traffic conditions in a transport network, for example expected smoothness of traffic flows, and to determine dynamic characteristics describing for example information spread processes in dynamic traffic networks.

Keywords: *ITS configuration, intelligent transport systems, transport model, ITS user services, ITS configuration*

1. Introduction

Intelligent transport systems are complex solutions that use a wide variety of technical and telematics systems, which are supposed to fulfil the aspirations of many different stakeholders, including [5, 19]:

- local authorities, operators, organizers of public transport, freight transport – expecting to improve efficiency and safety of transport,
- national and local authorities and institutions dealing with norms and standards – stakeholders interested in elaboration of the rules and standards in the field of ITS,
- manufacturers, suppliers and integrators of equipment and systems – stakeholders interested in the elaboration, construction, maintenance and development of ITS,
- end users: travellers, drivers, shippers, managers of public transport – stakeholders using or will use the services of ITS

The list of ITS users' needs based on methodology FRAME [5] has been presented on Fig. 1.

In the literature there are many papers describing the functionality of ITS systems [5, 8, 13, 16-19], ITS system design methodology [5, 19, 24] and transport modelling [2, 6, 7, 12, 20-22, 25].

There are, however, few studies on the selection of ITS components that incorporate different configurations tailored to the needs of urban areas and their users [9, 10, 23].The aim of the article is to present the issues related to the use of the transport model for ex-ante evaluation of the functional and operational configuration of ITS.

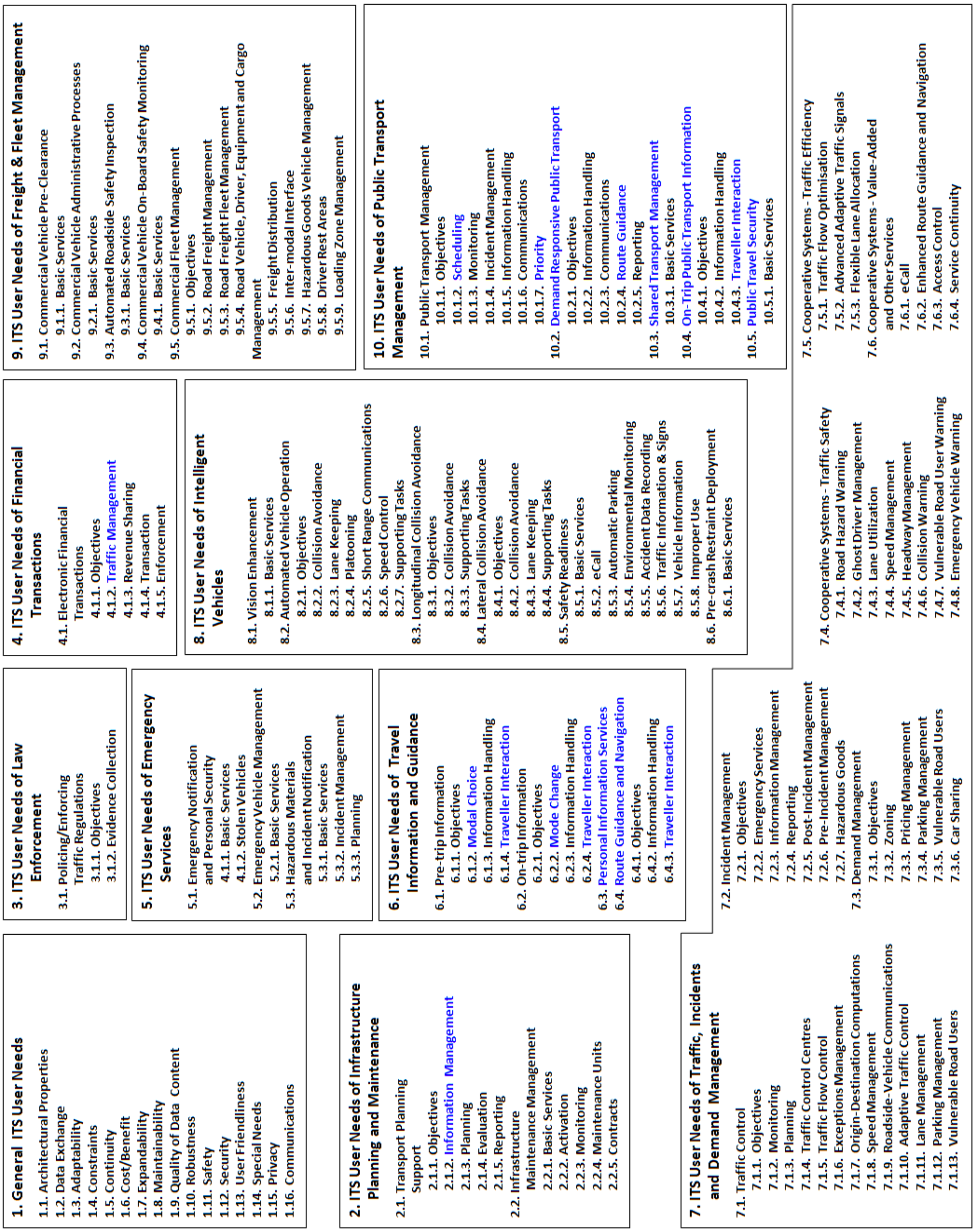

Fig. 1. ITS User Needs based on FRAME Methodology of ITS Architecture Development, source: based on FRAME User Needs VS. [5]

2. Intelligent Transportation Systems – aspects of ITS configuration

The functional and operational configuration of ITS [11, 26] is understood at the conceptual stage of ITS system design as designed logical (functional) and physical architectures of ITS, which implement the specified set of ITS services. This ITS services should satisfy stakeholders aspirations – especially ITS user's needs – see Fig. 1.

There may be several designs of functional and operational variants of ITS configuration consisting of packages of ITS services [26], because user needs can be catered for by ITS services implemented using various transport telematics systems. An additional reason for defining several variants of ITS configuration is the need for stepwise deployment of ITS systems – among others for organizational and financial reasons. Then the next steps in implementing ITS are the variants of ITS configuration. The examples of variants of implemented ITS configuration have been presented in Tab. 1. The implemented ITS user services is marked with "+" and these are components of variants of implemented ITS configuration.

Tab. 1. ITS user services as components of variants of ITS configuration in implemented ITS systems (in Poland)

Location of implemented ITS and projected ITS (proposals)	**ITS user services / ITS subsystems / components of ITS configuration**							
	Traffic Control	**Public Transport management**	**Law Enforcement**	**Traveller information**	**Parking management**	**Controlling access to restricted traffic zones**	**Weight in-motion**	**Monitoring of weather conditions**
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Bialystok city	+	+		+				
Bydgoszcz city	+	+		+	+			
Centralny System Automatycznego Nadzoru nad Ruchem Drogowym			+					
Gdansk-Gdynia-Sopot urban agglomeration	+	+	+	+	+			+
Gliwice city	+							
Grudziądz city		+		+				
Jastrzębie city - area of public transport organizer		+		+				
Kalisz city	+		+					
Katowice city (**proposal**)	+	+	+	+	+			
Koszalin city	+		+		+			
Krakow city	+	+				+		
KZK GOP - area of public transport organizer		+		+				
KZK GOP - (**proposal**)	+	+	+	+	+	+	+	+
Legnica city	+	+		+				+
Lublin city	+	+		+				
Łódzkie Voivodship			+				+	+
Lodz city		+						
Małopolskie Voivodship	+	+		+	+			+
Olsztyn city	+	+	+	+				+
Poznan city	+	+		+	+			
Rzeszow city	+	+	+	+				
Sieradz, Zduńska Wola - area of public transport organizer		+						
Szczecin urban agglomeration		+						
Szczecin city	+	+		+				
Tychy city (**proposal**)	+	+	+	+				
Wroclaw city	+	+	+	+				

The expected results of specified variant of ITS configuration can be specified as [26]:

- short-term results on operational level of traffic management – related to the current decisions of transport users (e.g. driver's choice of traffic lane at the approach of the intersections, decision on overtake on the section of the road etc.),
- medium-term results on tactical level of traffic management – related to the choice of path in the network and to the search for free parking places,
- long-term results on strategic level of traffic management – related to decisions of network users on travelling and on choice of means of transport and transportation modes.

Structure of transport model for ITS configuration on strategic level of traffic management has been presented in the next part of article.

3. Structure of transport model for ITS configuration – strategic level of traffic management

The variant of transport model $TM(V_{ITS\_CFG}, H_{FCST})$ for variant of ITS configuration V_{ITS_CFG} and forecast horizon H_{FCST}, as a 4-step trip based travel demand model, consists of sub-models (1)-(6): trip generation model, trip distribution model (origin-destination (O-D) matrix), mode choice (modal split) model, distribution of traffic flow on the transport network model (based on [2, 20]):

$$TM(V_{ITS\_CFG}, H_{FCST}) = d^i_{od}[s,h,m,k](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}), \tag{1}$$

$$\begin{aligned} d^i_{od}[s,h,m,k](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}) = {} & d^i_{o\bullet}[sh](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}) \\ & \cdot p^i[d/osh](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}) \\ & \cdot p^i[m/oshd](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}) \\ & \cdot p^i[k/oshdm](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}) \end{aligned}, \tag{2}$$

where:

i	–	the user's class (category of socioeconomic characteristics),
o, d	–	the TAZ's of trip origin and destination,
s	–	the trip purpose, or more properly the pair of purposes,
h	–	the time period in which trips are undertaken,
m	–	the time period in which trips are undertaken,
k	–	the trip path – the series of links connecting centroids o and d over the network and representing the transportation service provided by mode m,
ITS_CFG	–	index of ITS configuration *ITS_CFG*,
FCST	–	index of forecast horizon,
SE	–	vector of socioeconomic variables related to the activity system and/or the decision-makers,
T_{ITS_CFG}	–	vector of level-of-service attributes of the transportation supply system with effects of ITS in V_{ITS_CFG} - variant of ITS configuration,
V_{ITS_CFG}	–	variant of ITS configuration, where $V_{ITS\_CFG=0}$ is a variant without ITS in modelled area,
H_{FCST}	–	forecast horizon (e.g. a year), for which the transport model is prepared, where $H_{FCST=0}$ is the horizon for the current condition (state of art) – without ITS configuration,

$d^i_{od}[s,h,m,k](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST})$ – number of i-th class (category) users travelling between o, d, in the s-th motivation [purpose] and in the h-th time, using the m-th mode, by the k-th route in the transport network.

4. The effects of ITS configuration in transport model

The effects of V_{ITS_CFG} will be considered in $TM(V_{ITS\_CFG}, H_{FCST})$ inter alia in consecutive components, i.e. in $d_{od}^{i}[s,h,m,k](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST})$ and in:

- the number of users in class i who, from the origin zone o undertake a trip for purpose s in time period h:

$$d_{o\bullet}^{i}[sh](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}), \tag{3}$$

- fraction of users (estimated from (3)), who travel to the destination zone d:

$$p^{i}[d/osh](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}), \tag{4}$$

- fraction of users (estimated by sequence of calculations (3), (4)), who travel using the transport system mode m:

$$p^{i}[m/oshd](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}), \tag{5}$$

- fraction of users (estimated by sequence of calculations (3), (4) and (5)), who travel in the network by path k:

$$p^{i}[k/oshdm](SE, T_{ITS\_CFG}, V_{ITS\_CFG}, H_{FCST}). \tag{6}$$

The T_{ITS_CFG} – vector represents transportation systems with user needs implemented in ITS configuration as ITS user services. Instead, the outcomes of ITS user services are represented as the effect of their impact on transport decisions of users (4)-(6), taking into account SE – vector of socioeconomic variables related to the activity system and/or the decision-makers.

Improving traffic conditions in transport network and level-of-service of transport means and transportation modes m, by using a particular configuration of ITS, can change the distribution of flows in the transportation network. The changes in assignment of traffic flows will be caused inter alia by:

- changes in the use of paths in network (6),
- changes in the use of transport system modes - changes of fractions (5) of users travelling: on foot, by bike, by car, by public transport and multimodal use of modes,
- changes in the destinations of trips (4),
- changes in the number of trips for various purposes (3).

5. Assessment of variants of ITS configuration in the context of transport decisions of users

The ex-ante assessment of V_{ITS_CFG} outcomes requires preparing transport models for specified H_{FCST}, for which the planned results of V_{ITS_CFG} are assumed to occur, e.g. for the year 2018, 2019, 2020 ($H_{FCST=2018}, H_{FCST=2019}, H_{FCST=2020}, \ldots$). It is necessary to consider the process of V_{ITS_CFG} implementation, in which specific ITS subsystems with ITS user services can be implemented in various periods and the effects of their implementation will be observed only after certain specific time. The assessment of V_{ITS_CFG} is related to the comparison of transport processes simulation results with the use of several transport models $TM(V_{ITS\_CFG}, H_{FCST})$:

- transport model in the variant of $V_{ITS\_CFG=0}$ – for the existing situation (without ITS implementation),
- transport models in the variants of $V_{ITS\_CFG=1}$, $V_{ITS\_CFG=2}, \ldots$, $V_{ITS\_CFG=V\max}$ – for the proposed ITS configuration in variants: 1, 2, .., *Vmax*.

The presented assumptions are contained in a tabular form – see Tab. 2.

Tab. 2. Structure of transport models $TM(V_{ITS\_CFG}, H_{FCST})$ during the assessment of ITS configuration in several variants $V_{ITS\_CFG=1} - V_{ITS\_CFG=V\max}$ in the next forecast horizons $H_{FCST=1} - H_{FCST=H\max}$ with respect to the state of art $H_{FCST=0}$

V_{ITS_CFG} \ H_{FCST}	$H_{FCST=0}$	$H_{FCST=1}$	…	$H_{FCST=H\max}$
$V_{ITS\_CFG=0}$	$TM(V_0, H_0)$	$TM(V_0, H_1)$	…	$TM(V_0, H_{H\max})$
$V_{ITS\_CFG=1}$		$TM(V_1, H_1)$	…	$TM(V_1, H_{H\max})$
…		…	…	…
$V_{ITS\_CFG=V\max}$		$TM(V_{V\max}, H_1)$	…	$TM(V_{V\max}, H_{H\max})$

The results of transport models $TM(V_{ITS\_CFG}, H_{FCST})$ enable a comparison, using an incremental method, results of transport decisions of users (4)-(6), obtained in specified forecast horizons $H_{FCST=1} - H_{FCST=H\max}$ for the ITS variants of configuration $V_{ITS\_CFG=1} - V_{ITS\_CFG=V\max}$.

6. Conclusions

Changes in travel behaviour under the influence of ITS services are dependent, among others, from the nature of the transport needs – nature of the activities and purposes of trips, type of user activity (working, studying, learning, retired etc.), preferences in mode choice of transport users [4], kind of transport mode, transportation availability of objects that are sources and targets of journey [25], and utility functions describing the decision-making processes of users [2, 20].

The results of transport models for variants of ITS configuration and forecast horizons are input data for cost-benefit analysis. For example conducted cost-benefit analysis for variants V1-V4 of "ITS Katowice city" in relation to the option of abandoning the project (V0 variant) indicates the extremely high cost-effectiveness for variants V3 (64.1% BCR – benefits to costs ratio, 244.96% ERR – economic rate of return) and V4 (72.5% BCR – benefits to costs ratio, 252.42% ERR – economic rate of return). The largest shares in the economic benefits of these variants have the following factors [14]:

- savings resulting from the reduction in the cost of users travel time (remaining with the current transport mode and abandoning the car in favour of public transport),
- benefits resulting from travel cost savings of users (running costs of cars reduced by the cost of purchasing tickets due to increased use of public transport); mainly due to the resignation of the car in favour of public transport,
- the benefits of reducing pollution and reducing the number of accidents in the metropolitan network - relatively small, a total range up to a few percentage.

Therefore an important issue of evaluation of the functional and operational configuration of ITS is to perform the appropriate survey and measurements before and after the start of ITS. This is significant from the point of view of the identification of ITS user needs, and for transport model development. These issues are widely discussed in the literature, both in relation to the general methodology of model construction [1, 3] as well as in the design of models dedicated to the evaluation of ITS projects [14, 15].

Structure of transport model presented in article is suitable for strategic level of traffic management with long-term results. While transport models for tactical level of traffic management with medium-term results, and for operational level of traffic management with short-term results are used to determine the characteristics describing traffic conditions in a transport network, for example, expected smoothness of traffic flows [13], and to determine dynamic characteristics describing for example information spread processes in dynamic traffic networks [16].

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