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MODELLING ELEMENTS OF A TELEMATIC TRANSPORTATION SYSTEM

Starting from a classical model of transport system its modification is presented, taking into account the fact of application of transport automation in it. Defined are transport telematics system and telematic relationships. Determined is telematic network of a transport system giving a full information concerning methods applied and telematic media distributed spatially in the transport system structure. A effect of model application may be creation of a formal description of transport network by using telematics synergy ratio or by formulation of new dependencies appropriate for specific solutions applied in this matter.

ELEMENTY MODELOWANIA TELEMATYCZNEGO SYSTEMU TRANSPORTOWEGO

Wychodząc z klasycznego modelu systemu transportowego przedstawiono jego modyfikację uwzględniającą fakt zastosowania w nim rozwiązań telematyki transportu. Zdefiniowano system telematyki transportu oraz relację telematyczną. Określono sieć telematyczną systemu transportowego dającą pełną informację o stosowanych metodach i środkach telematyki rozłożonych przestrzennie w strukturze systemu transportowego. Efektem zastosowań modelu może być stworzenie opisu formalnego sieci transportowej poprzez wykorzystanie współczynnika synergii telematyki lub sformułowanie nowych zależności właściwych dla stosowanych konkretnych rozwiązań w tej dziedzinie.

1. INTRODUCTION

Development of transport telematics is presently focused on implementations of even newer solutions [7]. It applies to such areas as transport management, city traffic management, parking system management, control of information media for travelers, management of city transportation routes (dynamic selection of routes for the present transport demand), monitoring of environment condition etc. Complete telematic solutions are established for the entire municipal centers, enabling overcoming of transport processes and reduction of hardships related with increased intensity of transport. It is supported by application of modern information means and utilization of tele-information networks transmission possibilities.

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These strong application tendencies are not accompanied to a sufficient degree by system approach, enabling development of decision issues solutions at using telematics means for transport systems. In order to make these actions rational, it is necessary to have knowledge concerning complete approach to the specific transport system segments, that will perform their tasks in specific conditions and at the precise level of telematics infrastructure saturation with specified functions and parameters. It has to be accompanied by skillful assessment of system properties depending of the degree of saturation with transport telematics means and applied methods of their use. In order to achieve this, it is necessary to develop the methods of transport system modeling taking into account the role, function and meaning of equipment with telematics means using various methods of application of these means for perfection of system operation. Certain attempts in this area may be attributed to the studies [1,2 3] concerning modeling of traffic intensity in the transport network, methods of assessment of intelligent transport systems or modeling of structure of a city passenger transport.

2. TRANSPORT SYSTEM

The transport system may be described as an ordered four in the following form

$$ST = \langle G, F, P, O \rangle \tag{1}$$

where:
G – structure of transport system described in form of a graph,
F – set of function determined at the nodes and/or arcs of structure graph,
P – traffic stream constituting a representation of load and/or people movement in the system,
O – organization i.e. distribution of traffic stream in the transport system.

The traffic stream is a representation of loads and/or people in the transport system. Measure of traffic stream may be a number of traffic stream units per time unit, for example, number of vehicles per hour on the highway.

Both traffic stream and organization are features of the entire transportation system. If the size of traffic stream for example relates to the specific arcs (connection between nodes) then its description should be performed using functions determined on each arc separately, which function then belongs to the set F.

As mentioned, the representation of transport system structure is a graph called *structure graph*.

$$G = \langle W, L \rangle \tag{2}$$

where:
W – set of nodes (vertexes) of a graph,
L – set of graph arcs.

The transport node (vertex of structure graph) may be a town in the geographic location sense. In a special case it may be a town where both railway and road connections are present, similarly as aerial and water ones. In general, no identification of nodes with the towns shall be performed, using locations instead, where location is still understood in a geographic sense, where the change of traffic streams occur, meaning their connection, branching, appearance or disappearance.

The nodes may be decomposed from the point of view fulfilled in the traffic stream flows into three subsets:

$$W = A \cup V \cup B \tag{3}$$

where:

A- set of nodes that are the initial transport nodes, where traffic stream appears as a result of beginning of transport task realization; these nodes are sources of traffic,

B – set of nodes constituting the targets of transport, where the traffic stream disappears, they are destination nodes and constitute traffic outlets,

V – set of intermediate nodes, where change of traffic streams may occur by their joining or branching.

Definition of various types of nodes enables a appropriate description of organization. The organization is determination of ways of traffic stream movement at the fulfilled assumed conditions of traffic realization and existing restrictions. Without organization the only thing that is known is which node is source of the traffic stream and which one is the outlet. Intermediate nodes are unknown, as several routes may exist between nodes. The purpose of organization is to determine the road that is the most advantageous from the described criteria point of view.

In the expression (2) arcs symbolize the roads between nodes. Existence of an arc between the neighbor nodes means that it is possible to realize a transport between them using the predefined type of transport.

If there are real value functions determined on the nodes and/or arcs of the graph (2), then this graphs represents a transport network. Thus *transport network* is:

$$TN = \langle G, F_W, F_L \rangle \tag{4}$$

where:

G – is a structure graph described in (2),

F_W – is a set of functions determined on the vertexes of a structure graph,

F_L – is a set of functions determined on the arcs of a structure graph.

Of course $F = F_W \cup F_L$. Functions from set F represent the characteristics of transport network, for example technical ones (throughput, capacity), economic ones (cost of mixing, time of travel) or mathematical ones (probability of transition from one node to the next) or others that characterize the transport network in a desired way.

3. TELEMATIC TRANSPORT SYSTEM

The item 2 represents a formal description of transport system based on [4,5]. Presently the attempt will be made to describe a telematic transport system, thus such transport system that is substantially equipped with modern telematic solutions influencing the quality of transport services rendered in an easily discernible way.

An important property of telematic systems in transport is synergy. Modification of a transport system consisting in appropriate implementation of new solutions in telematics does not result in a normal additive increase of useful properties of the system. It is due to the fact that it creates a new quality resulting in the overall effect being more than total of separate actions of particular constituents. This new quality is something that usually exceeds the hitherto solutions in a so significant way that we may expect stepwise improvement of certain transport system parameters..

Application of telematic solutions influences the values of functions describing the vertexes and/or arcs of the transport network graph or appearance of altogether new functions enabling the description that is in accordance with the solutions. For instance, operation of devices of electronic road fees system on the highways may be compared with the previously used manual system using the same functional dependencies. Whereas for instance implementation of road guides to the car transport system resulted in appearance of new habits among the drivers, modifying their previous behavior. This new situation is mostly incomparable to any other, as such technical possibilities were earlier simply nonexistent. Description of this phenomenon requires application of new functional dependencies characterizing nodes and arcs of the transport system graph.

Thus we may state that the transport network description given in (4) has to be revised. This network, consisting of a transport system structure graph and two sets of functions determined on the nodes and arcs of this graph. Modification of its description has to take into account two phenomena: one consisting in change of value of the existing parameters by magnitudes resulting from telematics synergy, and a second one accepting new methods of describing the nodes and/or arcs related with application of new ways and methods of transport telematics.

Thus *the transport network containing solutions of transport telematics* is:

$$TN = \langle G, H_W, H_L \rangle \tag{5}$$

where:

G – is a structure graph described in (2),

H_W – is a set of functions determined on the vertexes of structure graph, whose values depend of the transport telematics solutions applied.

H_L – is a set of functions determined on the arcs of structure graph, whose values depend of the transport telematics solutions applied.

Similarly as before $H = H_W \cup H_L$.

Now let's consider a situation where in the transport network (4) and transport network (5) the same functional dependencies are used, describing arcs and/or vertexes. Then the specific elements of the set $H_W = \{h_{Wi}\}$ for i=1÷n and set $H_L = \{h_{Lj}\}$ for j=1÷k may be determined on the basis of knowledge of set elements values $F_W = \{f_{Wi}\}$ and $F_L = \{f_{Lj}\}$ as well as corresponding *telematics synegy ratios* s_i or s_j, where:

$$\forall (h_{Wi} \in H_W, f_{Wi} \in F_W) \;\; \exists s_i : h_{Wi} = f_{Wi} \cdot s_i \tag{6}$$

$$\forall (h_{Lj} \in H_L, f_{Lj} \in F_L) \;\; \exists s_j : h_{Lj} = f_{Lj} \cdot s_j \tag{7}$$

Telematics synergy rations have empiric character. They are selected based upon analysis of effects of implementation of predetermined telematics solutions on specific road sections.

In the situation where network (5) is described with a set of new functional dependencies non appearing in (4), then:

$$\forall w_i \in W, \exists h_{Wi} : \; h_{Wi} \in H_W \tag{8}$$

$$\forall l_j \in L, \exists h_{Lj} : h_{Lj} \in H_L \tag{9}$$

Of course, when a mixed situation occurs i.e. such that a part of nodes and arches described will be already used functional dependencies, and part new ones, then in the transport network description (5) elements will occur that are described by one (6), (7) and another (8), (9) system of dependencies.

Transport telematics system of a transport network may be described as follows:

$$T = \langle G, H, R, M \rangle \tag{10}$$

where:
G – is a structure graph described in (2),
H – is a set of functions determined on the vertexes and/or arcs of structure graph,
R – telematics measures applied in the transport system,
M – methods of use of telematics measures.

Transport telematics system may be also understood as a segment of equipment of transport network infrastructure and the transport means themselves enabling application of modern information and telecommunication technologies for the purpose of perfecting the transport process courses.

Let's have a cartesian product of measures and methods of transport telematics $R \times M$. In this product a representation *e* is given, that assigns elements from a $\{0,1\}$set to the products elements in such a way that:

$$e : R \times M \rightarrow \{0,1\} \tag{11}$$

while *e*(r,m)=1 when and only when the means with number r apply methods with number m. Pair *e*(r,m) is named *telematic relationship*. We assume that a set RT of telematic relationship is determined i.e.:

$$RT = \{(r, m) : e(r, m) = 1,\ (r, m) \in R \times M\} \tag{12}$$

Now me may determine *the telematic network of a transport system* as:

$$STST = \langle G, RT \rangle \tag{13}$$

where:
G – is a structure graph described in (2),
RT – telematic relationship described on the nodes and/or arcs of the structure graph.

As we see from (13) the telematic network of a transport system contain the system graph whose nodes and/or arcs are described by telematics relationships. This relationship indicates what means and methods of transport telematics are used on specific road sections (arcs) and at the specific locations where change in the traffic streams occur (nodes).

A result of application of methods and means of transport telematics in accordance with (13) is a change of value and/or type of functions describing the network (5). This gives the picture of impact exerted by these solutions on transport network properties.

4. CONCLUSION

The correct description of constituents of the transport telematics system (10) enables development of a description characterizing the system on a general level. This gives information about the structure of transport system, about functions describing specific nodes and/or arcs and about the set of means and methods of telematics applied in the system. This description does not give yet a possibility to state on which nodes and/or arcs of the transport system structure graph (describing their territorial location) the solutions from transport telematics area are used. This possibility is given by determination of a telematic relationship and then determination of transport system telematic network (13). This network yields a full information about the telematics methods and means spatially distributed in the transport system structure. Effects of their application are shown in the functional description of the network (5), among other by using the telematics synergy ratio or formulation of a new functional description appropriate for the solutions applied [6].

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