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SELECTED ASPECTS OF MODELLING OF SUSTAINABLE URBAN TRANSPORTATION SYSTEM

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Summary. The article refers to a system approach which is used in an analysis of transport issues. A proposal for the construction of a model of a sustainable urban transportation system was presented.

Keywords: urban transportation system, sustainable urban transportation system.

INTRODUCTION

The dominating issue in the European transport policy is a vision to create a future oriented sustainable transport system with a high level of safety, one which is environment friendly and energy-efficient [11]. The so-called clean city transport constitutes a distinguished area in this policy. An implementation was initiated of a sustainable urban transport system, one which does not involve any hazards to the health of communities and ecosystems, and at the same time fulfils the needs connected with the mobility of the residents of a urban structure, while making use of the following [2]:

- renewable resources on the level of their regeneration,
- non-renewable resources on the level of replacing them with renewable substitutes.

All the activities related to the realization of a sustainable development of a urban transport system can be defined as the realization of the following objectives [10]:

- a reduction of the quantity of the pollution emitted by the means of transport up to such a level which is not dangerous to health and does not cause a reduction of the quality of the environment,
- a limitation of the emissions of those greenhouse gases from transport,
- an improvement of safety in transport,
- an improvement of the acoustic climate through actions leading to a reduction of the noise from transport,
- a minimization of the results of the congestion phenomenon,
- an elimination of bottlenecks and deficiencies in the infrastructure in the individual EU Member States,

– an improvement of the mobility of citizens and overcoming differences in the access to the transport infrastructure.

URBAN TRANSPORTATION SYSTEM

The object whose description is defined as a set of interrelated elements and the environment in a manner which permits the achievement of a specific goal is known as a system [9]. The system analyzed in this study is a transport system whose purpose is a migration of people. This migration concerns both the residents of a given city and areas which surround a given city. By isolating the urban transport system from the existing reality, we have divided this reality into the system and the environment. The process carried out in this way results in an establishment of the boundaries of the system, i.e. a determination of those elements (objects) which are included among the elements of the system and those which are included in the environment. Obviously enough, this depends from the purpose the of research and therefore those relations which due to the defined purpose of the research are not essential, are omitted. At the same time, the impact of the environment on the transport system and vice versa occurs through external stimuli (input quantities) and reactions (output quantities) [5].

Taking into account the assumption that the system is a distinguished set of elements and a set of relations that are determined on its elements in the present deliberations, the structure of the transport system will be defined as an arranged pair in the following form [1, 5, 6, 9]:

$$S = \langle A, R \rangle, \tag{1}$$

where:
S – transport system,
A – a set of elements of the transport system [5],

$$A = \{a_i : \ i = 1,2,...,n\}, \tag{2}$$

R – a set of relations defined on the elements of the transport system [5],

$$R = \{R_j : \ j = 1,2,...,m\}, \tag{3}$$

for whom R_j relation is a subset of the Cartesian product in the following form [5],

$$R_j \subset A \times A \quad \text{dla } j = 1,2,...,m. \tag{4}$$

The set of relations defined on the elements of the transport system depends from the purpose or the purposes which a given system realizes, which may include the following [6]:

– finding of the rules which decide about the processes which occur in the system analyzed, which will permit obtaining information that may constitute data for further research,
– an identification and optimization of the structure and control of the system analyzed.

MODEL OF A SUSTAINABLE URBAN TRANSPORTATION SYSTEM

The model of a sustainable urban transportation system will be written as an arranged triple in the following form [1, 5, 7, 8, 9]:

$$\mathrm{MZMST} = \langle \mathrm{G}, \mathrm{F_W}, \mathrm{F_O} \rangle, \tag{5}$$

where:
MZMST – model of a sustainable urban transportation system,
G – graph,
F_W – the set of the functions determined on the set of the vertices of graph *G*,

$$\mathrm{F_W} = \{\phi_1, \phi_2, ..., \phi_u\}, \quad u = 1, 2, ..., U, \tag{6}$$

U – the number of representations determined on the set of the vertices of graph *G*,
F_O – the set of the functions determined on the set of the connections of graph *G*,

$$\mathrm{F_O} = \{\gamma_1, \gamma_2, ..., \gamma_z\}, \quad z = 1, 2, ..., Z. \tag{7}$$

Z – the set of the representations determined on the set of the connections of graph *G*.

The structure of a sustainable urban transportation system will be presented by means of graph *G*, where each connection is represented in the form of a graph arc. Destination points will be represented in the form of the vertices of this graph. This graph is written in the following form [1, 5, 7, 8, 9]:

$$\mathrm{G} = \langle \mathrm{W}, \mathrm{L}, \mathrm{R} \rangle, \tag{8}$$

where:
W- set of components of graph *G*,
L – set of connections of graph *G*,
R – relation $W \times L \times W$.

For the purpose of the uniqueness of further considerations, we accept the following notation of the vertices and connections in graph *G*:

$$\mathrm{W} = \{\mathrm{w(i)} \equiv \mathrm{i}: \ \mathrm{i} = 1, 2, ..., \mathrm{I}\}; \ \ \mathrm{i} = \{1, 2, ..., \mathrm{i}, \ \mathrm{j}, ..., \mathrm{I}\}, \tag{9}$$

$$\mathrm{L} = \{(\mathrm{w(i)}, \mathrm{w(j)}): \ \mathrm{w(i)}, \mathrm{w(j)} \in \mathrm{W}, \ \ \mathrm{w(i)} \neq \mathrm{w(j)} \ \ \mathrm{i}, \mathrm{j} \in \mathrm{I}\}. \tag{10}$$

As it can be seen from the above, the sustainable transport system in question possesses *I* graph vertices and *K* graph connections. Representation *R* transforms Cartesian product $W \times O \times W$ into set *{0, 1}* [1, 2, 3, 5, 7]:

$$\mathrm{R}: \mathrm{W} \times \mathrm{L} \times \mathrm{W} \rightarrow \{0, 1\}. \tag{11}$$

Any triplet $(w(i), o(k), w(j)) \in W \times L \times W$ such that $R(w(i), l(k), w(j))=1$ is interpreted in the following manner: arc *l(k)* which connects vertex *w(i)* with vertex *w(j), w(i)ı w(j)* or arc *l(k)* is included

between vertices *w(i)* and *w(j)*. At the same time, any triplet *(w(i), l(k), w(j))* $\in W \times L \times W$ such that *R(w(i), l(k), w(j))=0* is interpreted in the following manner: arc *l(k)* does not connect vertex *w(i)* with vertex *w(j), w(i)ı w(j)* or arc *l(k)* is not included between vertices *w(i)* and *w(j)*.

At the same time, graph *G* needs to possess an asymmetry property and an acclivity property in the meaning of roads [5, 7, 9]. Graph *G* is known as an asymmetric graph if the following condition is fulfilled for the arches of this graph:

$$\begin{gathered} \forall\big(\mathrm{l(k)} \in \mathrm{L}\big) \quad \exists\big(\mathrm{w(i)}, \mathrm{w(j)} \in \mathrm{W} : \mathrm{w(i)} \neq \mathrm{w(j)}\big), \\ \mathrm{R}\big(\mathrm{w(i)}, \mathrm{l(k)}, \mathrm{w(j)}\big) = 1 \Rightarrow \forall\big(\mathrm{l(k')} \in \mathrm{L} : \mathrm{l(k')} \neq \mathrm{l(k)}\big), \\ \mathrm{R}\big(\mathrm{w(j)}, \mathrm{l(k')}, \mathrm{w(i)}\big) = 0. \end{gathered} \tag{12}$$

INVESTIGATIONS INTO THE INITIAL STATE OF URBAN TRANSPORTATION SYSTEM

The investigations into the initial state of the urban transport system were carried out based on the monitoring of social attitudes concerning a sustainable transport [12], they covered an analysis of the communication behavior of city dwellers. The communication behavior of the city dwellers constitutes the realization of the given transport tasks with a division into two following scopes:

- transport tasks realized in the period from Monday to Friday,
- transport tasks realized on Saturdays and Sundays.

The graph in the following form represents the transport tasks realized from Monday to Friday (Fig. 1):

$$\mathrm{G1} = \langle \mathrm{W1}, \mathrm{L1} \rangle, \tag{13}$$

where:
W1 – set of components of graph *G1*,

$$\mathrm{W1} = \{\mathrm{w1}_1, \mathrm{w1}_2, \mathrm{w1}_3, \mathrm{w1}_4, \mathrm{w1}_5, \mathrm{w1}_6, \mathrm{w1}_7, \mathrm{w1}_8\}, \tag{14}$$

L1 – set of connections of graph *G1*,

$$\mathrm{L1} = \{\mathrm{ll}_1, \mathrm{ll}_2, \mathrm{ll}_3, \mathrm{ll}_4, \mathrm{ll}_5, \mathrm{l}_6, \mathrm{ll}_7, \mathrm{ll}_8, \mathrm{ll}_9, \mathrm{ll}_{10}, \mathrm{ll}_{11}\}. \tag{15}$$

At the same time, the graph in the following form represents the transport tasks realized on Saturdays and Sundays (Fig. 2):

$$\mathrm{G2} = \langle \mathrm{W2}, \mathrm{L2} \rangle, \tag{16}$$

where:
W2 – set of components of graph *G2*,

$$\mathrm{W2} = \{\mathrm{w2}_1, \mathrm{w2}_2, \mathrm{w2}_3, \mathrm{w2}_4, \mathrm{w2}_5, \mathrm{w2}_6\}. \tag{17}$$

L2 – set of connections of graph *G2*:

$$L2 = \{l2_1, l2_2, l2_3, l2_4, l2_5, l2_6, l2_7, l2_8\}. \tag{18}$$

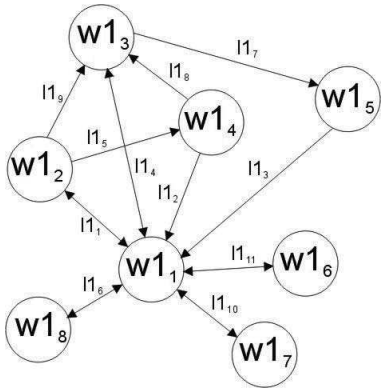

Fig. 1. The graph *G1* in the following form represents the transport tasks realized from Monday to Friday

CONCLUSIONS

A model approach to the urban transport system may successfully be used to solve optimization problems concerning a limitation of the environmental impact of the city transport. Such investigations are conducted by the author of this article, and the purpose of this research is a sustainable migration of city dwellers in the aspect of a minimization of the external costs of the urban transport. The external costs are costs connected with the negative environmental effects of the functioning of a urban transport system, and in particular costs connected with the following [4, 13]:

- air, water and soil pollution [14],
- noise emission,
- traffic collisions and road accidents,
- the occupancy of the area.

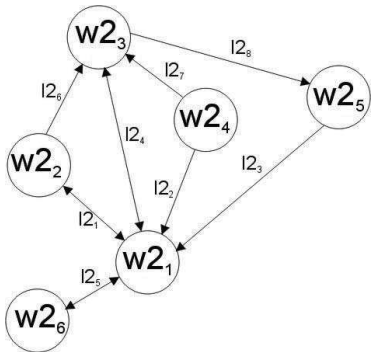

Fig. 2. The graph *G2* in the following form represents the transport tasks realized on Saturdays and Sundays

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WYBRANE ASPEKTY MODELOWANIA ZRÓWNOWAŻONEGO MIEJSKIEGO SYSTEMU TRANSPORTOWEGO

Streszczenie. Artykuł odwołuje się do systemowego podejścia wykorzystywanego w analizie zagadnień transportowych. Przedstawiona została propozycja budowy modelu zrównoważonego miejskiego systemu transportowego.

Słowa kluczowe: miejski system transportowy, zrównoważony miejski system transportowy.