TRAVELLING COST AN ASSESSMENT CRITERION OF THE MODEL OF CITY LOGISTICS

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Abstract

A description of a complex reality in a simplified form, which can be used in research, constitutes the basic purpose of modelling. A system of city logistics interpreted as a system of elements involved in the flow of people, freight and information in urbanized areas is such a complex picture in urbanized areas. In the modelling process of the system of city logistics, mathematical modelling was used, which consists in the creation of mathematical models of the systems analysed and further in the use of the mathematical apparatus on the stage of experimenting with these models. The article includes the presentation of a model of city logistics together with one of the most important assessment criteria of the model presented of urbanized areas that are essential to users, i.e. travelling costs. This quantity reflects subjective perception of the nuisance of travelling in the urban reality. A reference was made to travelling costs, where the total generalized travel costs and the total external travel costs were determined as components.

Keywords: City logistics, model of city logistics, travel costs

1. INTRODUCTION

The issues of city logistics constitute an essential element of the present-day urban transport policy. The use of ideas, methods and techniques of logistics management on the stage of an improvement and streamlining of the flow of people, freights and information in towns has become an important element of this policy. City logistics as a town's management conception constitutes the whole of activities and processes related to the management of the flows of people, cargo and information inside an urban logistics system [8]. The superior objective of the conception presented herein is to satisfy those needs that are the result of the activity of the users of urban areas, which are manifested in the need to travel, the effect being travels in towns [4]. In the perspective of the theories of systems, we identify the city logistics system, which is interpreted as a set of elements (users, infrastructure, rates, regulations etc.) involved in the flow of people, freights and information in urban areas [7].

The present article offers a proposal of the construction of a model of city logistics in relation to the flow of people. In the model, the guidelines were used of the conception of the formation of mobility in the urban area in the aspect of environmental protection [2]. The economic assessment criterion in the form of the travelling cost was defined in a great detail as an extension of indicator mobility assessment [3].

2. ASSUMPTIONS OF THE MODEL OF CITY LOGISTICS

The model is the tool of an analysis and assessment of the functioning of existing or designed systems of city logistics. The properties of the city logistics system, which are essential from the perspective of the research objective, are reflected in the model. The issues of city logistics modelling were presented in the studies [1, 5, 6, 7, 9, 10].

Taking into consideration the specific nature as well as the objectives realized by the city logistics system in the perspective of the transport of people, it is essential that the following properties are reflected in its model:

- the resources of the system that represent the elements of urban infrastructure of transport and the users of the urban area who travel,

- the structure of the urban logistics system that represents the activeness points of users, connections between those points and the characterizations of the individual elements of the structure,
- tasks performed by city logistics,
- the organization that represents the way in which trips are realized and manner in which the travel flow is distributed.

The model of city logistics an formally be written as an arranged four in the following form:

$$\boldsymbol{MLM} = \langle \boldsymbol{ZS}, \boldsymbol{SL}, \boldsymbol{ZR}, \boldsymbol{OR} \rangle. \quad (1)$$

On the stage of an organization of travels in the urban area, single-modal travel was distinguished, where there is no possibility to change the transport subsystem (e.g. travelling by car). Another travel type is a double-modal travel, where it is possible to change the transport subsystem (e.g. travels in Park&Ride system). For practical purposes, all trips were numbered and recorded in the form of a set of the numbers of single-modal travel:

$$\boldsymbol{HJ}^{pj} = \{ hj^{pj} = 1, 2, \dots, HJ^{pj}\}, \quad pj \in \boldsymbol{PJ}, \boldsymbol{PJ} = \{1, \dots, pje, \dots, PJE\}, \quad (2)$$

and set of the numbers of double-modal travel:

$$\boldsymbol{HD}^{pd} = \{hd^{pd} = 1, 2, \dots, HD^{pd}\}, \quad pd \in \boldsymbol{PD}, \boldsymbol{PD} = \{1, \dots, pde, \dots, PDE\} \quad (3)$$

where: $\boldsymbol{PJ}$ set of the numbers of types single-modal travel, while $\boldsymbol{PD}$ set of the numbers of types double-modal travel.

A travel in the urban area is a chain of relocations (connections) identified as the stages of the travel. For the needs of modelling, the following sets were defined:

- a set of all the stages that belong to single-modal travel:

$$\boldsymbol{LHJ}(hj^{pj}) = \{(s, s'): \quad (s, s') \in \boldsymbol{LP}\}, \quad hj^{pj} \in \boldsymbol{HJ}^{pj}, \quad (4)$$

- a set of connections in the transport network in the urban area that belong to single-modal travel:

$$\boldsymbol{LSHJ}(hj^{pj}) = \{(s, s'): \quad (s, s') \in \boldsymbol{LT}\}, \quad hj^{pj} \in \boldsymbol{HJ}^{pj}, \quad (5)$$

- a set of all the stages that belong to double-modal travel:

$$\boldsymbol{LHD}(hd^{pd}) = \{(s, s'): \quad (s, s') \in \boldsymbol{LP}\}, \quad hd^{pd} \in \boldsymbol{HD}^{pd}, \quad (6)$$

- a set of connections in the transport network in the urban area that belong to double-modal travel:

$$\boldsymbol{LSHD}(hd^{pd}) = \{(s, s'): \quad (s, s') \in \boldsymbol{LT}\}, \quad hd^{pd} \in \boldsymbol{HD}^{pd}, \quad (7)$$

where:

- $\boldsymbol{LP}$ a set of connections of the structure of the city logistics system that occur between initial and through points,

$$\boldsymbol{LP}^{r} = \{(p, n_e^r): \quad p \neq n_e^r, \, p \in \boldsymbol{P}, \, n_e^r \in \boldsymbol{N}^r\}, \quad r \in \boldsymbol{R}, \quad (8)$$

- $\boldsymbol{R}$ a set of the numbers of transport subsystems,

$$\boldsymbol{R} = \{r: \quad r = 1, 2, \dots, r', \dots, R\}, \quad (9)$$

- $\boldsymbol{N}^r$ a set of the numbers of the through points of r-th transport network,

$$\boldsymbol{N}^r = \{n_e^r: \quad e = 1, 2, \dots, e', \dots, E(r)\}, \quad r \in \boldsymbol{R}, \quad (10)$$

- $\boldsymbol{LT}$ a set of transport network connections,

$$\boldsymbol{LT} = \{(s, s'): \quad s \neq s', \; s, s' \in \boldsymbol{PS}\}, \quad (11)$$

- $\boldsymbol{PS}$ a set of numbers of the points of the activeness of users in the structure of the city logistics system,

$$\boldsymbol{PS} = \{s:\ s = 1, 2, \dots, s', \dots, S\}, \tag{12}$$

- $\boldsymbol{P}$ a set of the numbers of the initial points, $\boldsymbol{K}$ a set of the numbers of the final points, $\boldsymbol{N}$ a set of the numbers of the through points,

$$\boldsymbol{P} = \{s \equiv p:\quad s \in \boldsymbol{S}\},\quad \boldsymbol{K} = \{s \equiv k:\quad s \in \boldsymbol{S}\},\quad \boldsymbol{N} = \{s \equiv n:\quad s \in \boldsymbol{S}\}, \tag{13}$$

- $\boldsymbol{LT}$ a set of connections of the city logistics structure that occur between through and final points,

$$\boldsymbol{LK}^r = \{(n_e^r, k):\quad n_e^r \neq k,\ k \in \boldsymbol{K},\ n_e^r \in \boldsymbol{N}^r\},\quad r \in \boldsymbol{R}, \tag{14}$$

- $\boldsymbol{LT}$ a set of connections of the structure of the city logistics system that occur between through points,

$$\boldsymbol{LN}^r = \{(n_e^r, n_{e'}^r):\quad e \neq e',\ n_e^r, n_{e'}^r, \in \boldsymbol{N}^r\},\quad r \in \boldsymbol{R}. \tag{15}$$

3. ASSESSMENT CRITERIA OF THE CITY LOGISTICS MODEL

Seeking a solution to a decision issue requires an acceptance of an appropriate criterion function. This function will constitute a decisive criterion as to which permissible decision is the optimal decision. In the study, travel costs constitute the proposed criterion. Total generalized travel costs and total external travel costs are the components of the accepted assessment criterion. Total generalized travel cost is the cost that is directly borne by passengers. Total external costs are borne by society in the scale of the town, country and continent. All the costs are the result of the realization of single-modal and double-modal travels in towns. We assume that travel costs $\boldsymbol{KPM}$ are presented as the sum of costs, i.e.:

$$\boldsymbol{KPM} = \boldsymbol{CUK} + \boldsymbol{CKZ}, \tag{16}$$

3.1. Total generalized travel costs

On the stage of the determination of the travel costs, the notion of the generalized travel cost will be used. The accepted notion enables one to take into consideration all the factors which present a value to the passenger, including costs formulated in a financial form (e.g. the ticket cost, the cost of fuel) as well as in another form of equivalent values (e.g. waiting time, travel time). Taking into consideration the individual nature of the individual types of travel, the following travel costs were defined:

- generalized cost of single-modal travel:

$$\boldsymbol{KU}^{hj^{pj}} = \sum_{(s,s')\in \boldsymbol{LHJ}(hj^{pj})} ku_{uo}^{(s,s')} + \sum_{(s,s')\in \boldsymbol{LSHJ}(hj^{pj})} kb_{uo}^{(s,s'),yp} + \sum_{y\in \boldsymbol{Y}} kdj^{y,hj^{pj}},\quad uo \in \boldsymbol{UO}, yp \in \boldsymbol{YP}, hj^{pj} \in \boldsymbol{HJ}^{pj}, \tag{17}$$

- generalized cost of double-modal travel:

$$\boldsymbol{KU}^{hd^{pd}} = \sum_{(s,s')\in \boldsymbol{LHD}(hd^{pd})} ku_{uo}^{(s,s')} + \sum_{(s,s')\in \boldsymbol{LSHD}(hd^{pd})} kb_{uo}^{(s,s'),yp} + \sum_{y\in \boldsymbol{Y}} kdd^{y,hd^{pd}},\quad uo \in \boldsymbol{UO}, yp \in \boldsymbol{YP}, hd^{pd} \in \boldsymbol{HD}^{pd}, \tag{18}$$

where:

$ku_{uo}^{(s,s')}$ - generalized unit cost of the relocation of the travel stage (s, s'), which is an element of travel hj^{pj} or hd^{pd} perceived by the uo-th user of the urban area,

$kb_{uo}^{(s,s'),yp}$ - unit cost of the relocation of the travel stage (s, s'), which is an element of travel hj^{pj} or hd^{pd}, that constitutes a cost to the uo-th user the of urban area in the case of the realization of relocation in the yp-th manner,

$\boldsymbol{UO}$ - a set of the numbers of urban area users, $\boldsymbol{UO} = \{1, \dots, uo, \dots, UO\}$,

$\boldsymbol{YP}$ - a set of numbers of the manners of relocations, $\boldsymbol{YP} = \{1, \dots, yp, \dots, YP\}$,

$\boldsymbol{Y}$ - a set of numbers of additional travel costs, $\boldsymbol{Y} = \{1, \dots, y, \dots, Y\}$,

$kdj^{y,hj^{pj}}$ - additional unit y-th cost connected with the realization of hj^{pj}-th single-modal travel,

$kdd^{y,hd^{pd}}$ - additional unit y-th cost connected with the realization of hd^{pd}-th double-modal travel.

Each stage of the travel possesses specified attributes which, depending on various factors (time of the day, nervousness, tiredness etc.) can diversely be perceived by urban area users. The diversity of the perception of the specified attributes was taken into consideration in the form of the appropriate values of equivalent factors. As a result, the unit generalized cost of relocation on the accepted stage of travel (s, s') that is an element of travel hj^{pj} or hd^{pd} perceived by the uo-th user of the urban area will be defined as:

$$ku_{uo}^{(s,s')} = \sum_{z \in \boldsymbol{Z}} \mu_{uo}^{z,(s,s')} \cdot wz_{uo}^{z,(s,s')}, \quad uo \in \boldsymbol{UO}, z \in \boldsymbol{Z}, \quad (s,s') \in \boldsymbol{LHJ}(hj^{pj}) \vee (s,s') \in \boldsymbol{LHD}(hd^{pd}), \tag{19}$$

where:

$\mu_{uo}^{z,(s,s')}$ - an equivalent factor related to the z-th attribute of the stage of travel (s, s'), that is an element of travel hj^{pj} or hd^{pd}, perceived by the uo-th user of the urban area,

$\boldsymbol{Z}$ - a set of the numbers of attributes, $\boldsymbol{Z} = \{1, \dots, z, \dots, Z\}$,

$wz_{uo}^{z,(s,s')}$ - the value of the variable that corresponds to the z-th attribute of the stage of travel (s, s'), that is an element of travel hj^{pj} or hd^{pd}, perceived by the uo-th user of the urban area.

When we take into consideration the structure of the travel flow in a given urban area, the following total generalized travel costs can be determined, i.e.:

- total generalized costs of single-modal travel:

$$\begin{aligned} \boldsymbol{CKU}^{hj^{pj}} == & \sum_{(s,s') \in \boldsymbol{LHJ}(hj^{pj})} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \left(ku_{uo}^{(s,s')} \cdot x1_{uo,t}^{hj^{pj},(s,s')} \right) + \\ & + \sum_{(s,s') \in \boldsymbol{LSHJ}(hj^{pj})} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \left(kb_{uo}^{(s,s'),yp} \cdot x1_{uo,t}^{hj^{pj},(s,s')} \right) + \sum_{y \in \boldsymbol{Y}} \left(kdj^{y,hj^{pj}} \cdot x1_{uo,t}^{hj^{pj},(s,s')} \right), \\ & yp \in \boldsymbol{YP}, hj^{pj} \in \boldsymbol{HJ}^{pj}, \end{aligned} \tag{20}$$

- total generalized costs of double-modal travel:

$$\begin{aligned} \boldsymbol{CKU}^{hd^{pd}} == & \sum_{(s,s') \in \boldsymbol{LHD}(hd^{pd})} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \left(ku_{uo}^{(s,s')} \cdot x2_{uo,t}^{hd^{pd},(s,s')} \right) + \\ & + \sum_{(s,s') \in \boldsymbol{LSHD}(hd^{pd})} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \sum_{yp \in \boldsymbol{YP}} \left(kb_{uo}^{(s,s'),yp} \cdot x2_{uo,t}^{hd^{pd},(s,s')} \right) \\ & + \sum_{y \in \boldsymbol{Y}} \sum_{yp \in \boldsymbol{YP}} \left(kdd^{y,hd^{pd}} \cdot x2_{uo,t}^{hd^{pd},(s,s')} \right), \quad hd^{pd} \in \boldsymbol{HD}^{pd}. \end{aligned} \tag{21}$$

where:

$x1_{uo,t}^{hj^{pj},(s,s')}$ - the size of the single-modal travel flow,

$x2_{uo,t}^{hd^{pd},(s,s')}$ - the size of the double-modal travel flow,

$\boldsymbol{T}$ - the set of the numbers of time intervals, $\boldsymbol{T} = \{1, \dots, t, \dots, T\}$,

Taking into consideration the above, the total generalized travel costs will constitute the sum of costs, i.e.:

$$\boldsymbol{CUK} = \sum_{hj^{pj} \in \boldsymbol{HJ}} \boldsymbol{CKU}^{hj^{pj}} + \sum_{hd^{pd} \in \boldsymbol{HD}} \boldsymbol{CKU}^{hd^{pd}}, \tag{22}$$

3.2. Total external travel costs

The external travel costs mean negative environmental impacts of the travel. In research, external costs are determined for the individual manners of relocation and in particular for relocations realized by the means of transport. External costs resulting from the individual external effects, factors, i.e. costs of air pollution, costs of noise, costs of congestion etc. are identified. The individual values of costs are written in the form of the following vector:

$$\mathbf{KZE} = \langle kze_{st}^{ezk,(s,s')}, \quad kze_{st}^{ezk,(s,s')} \in \mathbb{R}^{+}, \quad ezk \in \boldsymbol{EZK}, st \in \boldsymbol{ST}, (s,s') \in \boldsymbol{LSH}(h), h \in \boldsymbol{H} \rangle. \tag{23}$$

where:

- $kze_{st}^{ezk,(s,s')}$ it is the cost of ezk-th external effect that occurs in connection with the relocation of the accepted travel stage (s,s') by st-th means of transport,
- $\boldsymbol{ST}$ a set of the numbers of the means of transport,

$$\boldsymbol{ST} = \{1, \dots, st, \dots, ST\}, \tag{24}$$

- $\boldsymbol{EZK}$ a set of the numbers of external effects,

$$\boldsymbol{EZK} = \{1, \dots, ezk, \dots, EZK\}, \tag{25}$$

- $\boldsymbol{H}$ a set of the numbers of travel,

$$\boldsymbol{H} = \{1, \dots, h, \dots, H\}, \tag{26}$$

- $\boldsymbol{LSH}(h)$ a set of connections in the transport network in the urban area which belong to travel h,

$$\boldsymbol{LSH}(h) = \{(s,s'): \quad (s,s') \in \boldsymbol{LSHJ}(hj^{pj}) \cup \boldsymbol{LSHD}(hd^{pd})\}, \quad h \in \boldsymbol{H}. \tag{27}$$

On this basis, we interpret the external costs for the individual types of travel as:

- external costs of single-modal travel:

$$\boldsymbol{KZ}^{hj^{pj}} = \sum_{(s,s') \in \boldsymbol{LSHJ}(hj^{pj})} \sum_{ezk \in \boldsymbol{EZK}} kze_{st}^{ezk,(s,s')}, \qquad kze_{st}^{ezk,(s,s')} \in \mathbf{KZE}, hj^{pj} \in \boldsymbol{HJ}^{pj}, \tag{28}$$

- external costs of double-modal travel:

$$\boldsymbol{KZ}^{hd^{pd}} = \sum_{(s,s') \in \boldsymbol{LSHD}(hd^{pd})} \sum_{ezk \in \boldsymbol{EZK}} \sum_{st \in \boldsymbol{ST}} kze_{st}^{ezk,(s,s')}, \qquad kze_{st}^{ezk,(s,s')} \in \mathbf{KZE}, hd^{pd} \in \boldsymbol{HD}^{pd}. \tag{29}$$

When we take into consideration the structure of the travel flow in a given urban area, the following total external travel costs can be determined, i.e.:

- total external costs of single-modal travel:

$$\boldsymbol{CKZ}^{hj^{pj}} = \sum_{(s,s') \in \boldsymbol{LSHJ}(hj^{pj})} \sum_{ezk \in \boldsymbol{EZK}} \sum_{st \in \boldsymbol{ST}} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \left(kze_{st}^{ezk,(s,s')} \cdot x1_{uo,t}^{hj^{pj},(s,s')} \right), \qquad hj^{pj} \in \boldsymbol{HJ}^{pj}, \tag{30}$$

- total external costs of double-modal travel:

$$\boldsymbol{CKZ}^{hd^{pd}} = \sum_{(s,s') \in \boldsymbol{LSHD}(hd^{pd})} \sum_{ezk \in \boldsymbol{EZK}} \sum_{st \in \boldsymbol{ST}} \sum_{uo \in \boldsymbol{UO}} \sum_{t \in \boldsymbol{T}} \left(kze_{st}^{ezk,(s,s')} \cdot x2_{uo,t}^{hd^{pd},(s,s')} \right), \qquad hd^{pd} \in \boldsymbol{HD}^{pd}. \tag{31}$$

Taking into consideration the above, total external travel costs will constitute the sum of external costs generated by the individual types of travel in a given urban area:

$$\boldsymbol{CKZ} = \sum_{hj^{pj} \in \boldsymbol{HJ}} \boldsymbol{CKZ}^{hj^{pj}} + \sum_{hd^{pd} \in \boldsymbol{HD}} \boldsymbol{CKZ}^{hd^{pd}}. \quad (32)$$

4. CONCLUSIONS

Optimal solutions in the area of the formation of city logistics require a comprehensive approach based on multi-criterion optimization. Taking into consideration the assumptions of the sustainable development idea, all the criteria which are essential from the perspective of various entities involved in the process of an analysis, formation and planning of city logistics can be divided into economic, environmental and social criteria. The present study focuses on the formal description of the economic partial criterion in the form of travel costs. This quantity reflects subjective perception of the nuisance of travelling in the urban reality. A reference was made to travelling costs, where the total generalized travel costs and the total external travel costs were determined as components.

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