The travel modelling in a mobility system in the urban areas

1. INTRODUCTION

Universally applied travel modelling based on four components [1, 2, 11, 12, 13, 15, 16, 17], i.e. the generation of a travel, the spatial arrangement of the travel, the division of transport tasks and the arrangement of traffic in the transport network of the area analyzed is not able to meet the requirements of the increasing set of input data. Furthermore, taking into consideration the additional aspects of the new culture of mobility in urban areas [10], we face a situation where the trip model is unable to take into account the impact of the factors of this type. A situation of this type occurs in the model of the mobility system in urban areas proposed in the paper [3, 5, 6, 7, 8, 9]. Therefore, there is an evident necessity to alter the approach to travel modelling that is oriented onto the mobility of the users of urban areas. The approach as proposed in the paper to the issues of travel was presented with an example of travel in the mobility system in urban areas. The system and its elements were formalized in the publication [4], and in the article presented, a direct reference was made to those travels that are detailed in the mobility system in urban areas.

2. THE TRAVEL OF SYSTEM MOBILITY IN URBAN AREAS

We interpret travelling as a movement from the departure point \( p(p \in P) \) of the source of the travel to the end point \( k(k \in K) \) of the purpose of the travel. All the remaining points of the travel are defined as intermediate points \( z(z \in Z) \). Furthermore, when using the notion of the travel in the mobility system in urban areas, we mean a travel where the departure point \( p \) is not the end point \( k \), \( p \neq k \).

Obviously enough, any travels can be determined between two points \( p \) and \( k \) that are singled out. Therefore, the set of all the travels that connect the departure point \( p \) to the end point \( k \) can be written as follows:

\[
H(p, k) = \{h(p, k): p \in P, k \in K\}
\]  

(1)

We interpret the set of the numbers of travels in the mobility system in urban areas as a set:

\[
H = \{h: h = 1, 2, \ldots, H\}
\]

(2)

where \( H \) is the size of set \( H \), and condition \( H(p, k) \subset H \) is met.

Due to the various reasons of the occurrence of travels, they are most often grouped according to motivation, e.g. home-work, home-school etc. In connection with this, we accept for the needs of the research conducted that the travel motivation expresses the relationship between the departure point \( p \) and the end point \( k \). Hence the pair \( (p, k) \) is known as the travel motivation, where the first element is known as the beginning of the travel, and the second element of the pair is the end of the travel. The elements of the pair \( (p, k) \) are the elements of the structure of the mobility system in urban areas, where \( p \in P, k \in K, P, K \in W \) and \( p \neq k \).

Taking into consideration the above, the set \( M \) of travel motivations in the mobility system in urban areas formed as a subset of the Cartesian product \( P \times K \) can be written in the following form:

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\[ M \subseteq P \times K = \{(p, k): p \in P, k \in K\} \quad (3) \]

It is also essential that the travel motivation is justifiable only in the case when the end point \( k \) can be reached from the departure point \( p \), i.e. there exists at least one travel that joins point \( p \) with point \( k \). Therefore, a set of travels that joins the departure and end points singled out is determined for each travel motivation \( (p, k) \in M \). We accept that the travel motivation is justifiable when the condition as presented below occurs:

\[ \forall (p, k) \in M \quad H(p, k) \neq \emptyset \quad (4) \]

2.1. Parameterization of travels in the structure of the system mobility in urban areas

Taking into account the specificity of travels in urban areas, we distinguish walking travels and non-walking travels. Considering such a diversification of travels in urban areas, we assume that the set \( HS \) of the numbers of the methods of travels in urban areas takes the following form:

\[ HS = \{hs: hs = 1, 2\} \quad (5) \]

where:
\( hs = 1 \) – walking travel,
\( hs = 2 \) – non-walking travel.

It is essential for an analysis of travels in the mobility system to define the set of walking travels \( HP \) and the set of non-walking travels \( HN \), i.e.:

\[ HP = \{hp \in H: hs = 1, for hs \in HS, h \in H\} \quad (6) \]
\[ HN = \{hn \in H: hs = 2, for hs \in HS, h \in H\} \quad (7) \]

Non-walking travels are those travels in which travellers use means of transport both in an individual manner and in an integrated manner. Taking into consideration such a diversification of the use of means of transport, we assume that the set of the numbers of the forms of non-walking travels in urban areas has the following form:

\[ HF = \{hf: hf = 1, 2, 3\} \quad (8) \]

where:
\( hf = 1 \) – single means of transport travel,
\( hf = 2 \) – inter-modal travel,
\( hf = 3 \) – multi-modal travel.

In this case, too, it is essential for an analysis of travels in the system of mobility in urban areas to define the set of travels done by with a single means of transport \( HT \), a set of inter-modal travels \( HO \) and a set of multi-modal travels \( HM \), i.e.:

\[ HT = \{hn \in H: hf = 1, for hf \in HF, hn \in HN\} \quad (9) \]
\[ HO = \{hn \in H: hf = 2, for hf \in HF, hn \in HN\} \quad (10) \]
\[ HM = \{hn \in H: hf = 3, for hf \in HF, hn \in HN\} \quad (11) \]

Travels done with single means of transport can be realized with individual, group and collective means of transport. Considering the diversified use of the individual means of transport, it was assumed that the set of the numbers of the forms of travels with a single means of transport in urban areas is a set in the following form:

\[ HR = \{hr: hr = 1, 2, 3\} \quad (12) \]

where:
\( hr = 1 \) – travel with individual means of transport,
\( hr = 2 \) – travel with group means of transport,
$hr = 3$ – travel with public means of transport.

Taking into consideration the set (12) in the mobility system in urban areas, we can define the set of travels done with individual means of transport $HI$, the set of travels with group means of transport $HG$ and the set of travels with public means of transport $HZ$:

$$HI = \{ ht \equiv hi: \ hr = 1, \text{for } hr \in HR, \ ht \in HT \} \tag{13}$$

$$HG = \{ ht \equiv hg: \ hr = 2, \text{for } hr \in HR, \ ht \in HT \} \tag{14}$$

$$HZ = \{ ht \equiv hz: \ hr = 3, \text{for } hr \in HR, \ ht \in HT \} \tag{15}$$

It is essential for the needs of the research to establish the hourly ranges that result from the life cycle of urban areas, where the stream of travelers appears in the source and in the outlet. Taking this into account, a set of the numbers of hourly ranges was defined, where starting of a travel is possible in urban areas:

$$HA = \{ ha: \ ha = 1,2,...,HA \} \tag{16}$$

where $HA$ is the number of those hourly ranges that were singled out.

When attributing the individual travels in urban areas to the hourly ranges singled out, it was accepted that mapping $\delta^{ha}$ was given on the set $H$ of the elements of the numbers of travels, which transforms the elements of this set into the elements of set $\{0, 1\}$, i.e.:

$$\delta^{ha}: H \rightarrow \{0,1\} \tag{17}$$

whereas if $\delta^{ha}(h) = 1$, the starting hour of the travel with number $h(h \in H)$ belongs to the $ha$ hourly range; otherwise, it belongs to $\delta^{ha}(h) = 0$.

In view of the above, the set of the numbers of travels whose travel starting hours are attributed to the $ha$ hourly range is a set that is defined in the following manner:

$$\forall ha \in HA \quad H^{ha} = \{ h: \ \delta^{ha}(h) = 1, h \in H \} \tag{18}$$

For example, $ha = 1$ is starting of the travel in the hourly range from 0:01 to 6:00, $ha = 2$ is starting of the travel in the hourly range from 6:01 to 7:00 etc. The set of travels in urban areas realizes the following dependence:

$$H = \bigcup_{ha \in HA} H^{ha} \tag{19}$$

Taking into consideration the life cycle of urban areas, a set was defined of the numbers of hourly ranges, in which a completion of the travel in urban areas is possible, i.e.:

$$HB = \{ hb: \ hb = 1,2,...,HB \} \tag{20}$$

where $HB$ is the number of those hourly ranges that were singled out.

When attributing the individual travels in urban areas to the hourly ranges singled out, it was accepted that mapping $\delta^{hb}$ was given on the set $H$ of the elements of the numbers of travels, which transforms the elements of this set into the elements of set $\{0, 1\}$, i.e.:

$$\delta^{hb}: H \rightarrow \{0,1\} \tag{21}$$

whereas if $\delta^{hb}(h) = 1$, the completion hour of the travel with number $h(h \in H)$ belongs to the $hb$ hourly range; otherwise, it belongs to $\delta^{hb}(h) = 0$.

In view of the above, the set of the numbers of travels whose travel completion hours are attributed to the $hb$ hourly range is a set that is defined in the following manner:

$$\forall hb \in HB \quad H^{hb} = \{ h: \ \delta^{hb}(h) = 1, h \in H \} \tag{22}$$
For example, $h_b = 1$ is completion of the travel in the hourly range from 0:01 to 6:00, $h_b = 2$ is completion of the travel in the hourly range from 6:01 to 7:00 etc. The set of travels in urban areas realizes the following dependence:

$$H = \bigcup_{h_b \in HB} H^{h_b} \quad (23)$$

In the analysis of travels in urban areas, a division was made into travels realized from Monday to Friday and at the weekend. Hence, taking such a division into consideration, the following sets of travels were defined:

- a set of travels realized from Monday to Friday:
  $$H_{PP} = \{hpp: hpp = 1, 2, ..., H_{PP}\} \quad (24)$$
  where $H_{PP}$ is the size of set $H_{PP}$, and condition $H_{PP} \in H$ is met,

- a set of travels realized at the weekend (Saturdays and Sundays):
  $$H_{SN} = \{hsn: hsn = 1, 2, ..., H_{SN}\} \quad (25)$$
  where $H_{SN}$ is the size of set $H_{SN}$, and condition $H_{SN} \in H$ is met.

3. **Analysis of Travels in the Selected Urban Areas**

The analysis of travels for the selected urban area was carried out based on questionnaire surveys among those travellers that realize travels in this area [14]. In the 8039 travels analyzed and realized from Monday to Friday and 4547 travels realized on Saturdays and Sundays, non-walking travels constitute a vast majority. Travels realized with means of transport, i.e. non-walking travels, constitute 81.46% from Monday to Friday and 85.43% on Saturdays and Sundays. Thereby, walking travels in urban areas constitute merely 18.54% and 14.67%. The individual dependences are presented in Fig. 1.

![Fig. 1. Structure of travels in the urban area analyzed: $HP$ - walking travels, $HN$ - non-walking travels](image)

*Source: based on [14]*

Continuing an analysis of the results obtained, it can be observed that in the case of travels realized from Monday to Friday, those travels whose purpose is home 45.27% and work 21.50% constitute the greatest share in relation to all the travels in the urban area analyzed. In the case of travels realized on Saturdays and Sundays, those travels whose purpose is home constitute 45.61%, those travels whose purpose is leisure activities constitute 20.83%, and those travels whose purpose is shopping centres constitute 8.2%. An accurate percentage distribution taking into account the purposes of travels divided into travels realized from Monday to Friday and on Saturdays and Sundays is presented in Fig. 2.
In accordance with the assumption accepted, means of transport are used in non-walking travels in individual and integrated manners. By analyzing the results of research carried out, it can be observed that 93.85% of travels realized from Monday to Friday are travels done with single means of transport, and only 6.15% of travels are integrated travels in the urban area analyzed. Moreover, 54.96% of travels are travels realized with individual means of transport, 1.03% of travels are travels realized with group means of transport and 44.01% of travels are travels realized with collective means of transport. Also in the case of travels realized on Saturdays and Sundays, travels with single means of transport (94.77%) constitute a vast majority, and only 5.23% of travels are those travels where means of transport are used in an integrated manner (Fig. 3). Travels realized with individual means of transport constitute 66.76% of these travels, travels realized with group means of transport constitute 1.15%, and travels realized with collective means of transport constitute 32.09% (Fig. 4).

**Fig. 2.** Share of travel purposes in travels realized from Monday to Friday and on Saturdays and Sundays

*Source: based on [14]*

**Fig. 3.** Use of means of transport in travels in the urban area analyzed:


*Source: based on [14]*
With reference to the life cycle of urban areas, hourly ranges, in which travelers start and finish travels in these areas, are essential. The results of research carried out for travels from Monday to Friday demonstrate that the most of travels (as many as 13.46%) are commenced in the hourly range from 7:01 to 8:00, and 13.23% of travels are started in the hourly range from 9:01 to 11:00, and only 4.7% of travels in the hourly range from 12:01 to 13:00. In the afternoon hours, the greatest number of travels (as many as 10.69%) are started in the hourly range from 15:01 to 16:00 and only 7.7% of travels in the hourly range from 16:01 to 17:00. The hourly range from 18:01 to 20:00, when 6.19% of travels start, is worth noticing. An accurate distribution of travels in the individual hourly ranges from Monday to Friday is presented in Fig. 5.
In the case of travels realized on Saturdays and Sundays, 19.55% of travels start in the hourly range from 9:01 to 11:00 and 8.58% of travels start in the hourly range from 11:01 to 12:00. In the afternoon and in the evening hours, 7.28% of travels start in the hourly range from 15:01 to 16:00, 7.21% of travels in the hourly range from 17:01 to 18:00, and almost 8.91% of travels start in the hourly range from 18:01 to 20:00. The individual distribution of travels in connection with the hourly ranges defined for travels realized on Saturdays and Sundays is presented in Fig. 5.

4. CONCLUSIONS

Formation of travels in the mobility system in urban areas is a complex process that takes into account those parameters that refer to the aspects of transport policy connected with mobility management. The activities presented in the article focused on a formal description of travels and the presentation of research results in the selected urban area. A correlation of these activities is suitable because it allows one to comprehensively present the problem of mobility in urban areas.

The research results presented in the paper demonstrate the domination of non-walking travels in urban areas, where travels, both from Monday to Friday and on Saturdays and Sundays, realized with individual means of transport are predominant. The scanty share at the level of 0.73% (Monday-Friday) and 0.1% (Saturday-Sunday) of multi-modal travels in the urban area analyzed is alarming.

The parameters of travels defined in the paper are used in the research conducted by the author oriented onto an analysis and further formation of mobility in urban areas in the aspect of sustainable development.

Abstract

This article covers issues connected with travel modeling in a mobility system in urban areas. In such a complex spatial and structural system that an urban area is, a travel was presented as a combination of the source and purpose of the travel. A proposal was put forward to analyze the travel with reference to essential parameters in the aspect of the new culture of mobility in urban areas. The parameters detailed were defined in the paper, and also on their basis, questionnaire surveys were conducted with travelers in the urban area that was selected for this purpose. Partial results of these investigations are presented in this article.

Keywords: urban areas, travel, walking travels, non-walking travels, system mobility in urban areas.

Modelowanie podróży w systemie mobilności na obszarach miejskich

Streszczenie

W artykule odniesiono się do problematyki związanej z modelowanie podróży w systemie mobilności na obszarach miejskich. W tak złożonym układzie przestrzenno-strukturalnym jakim jest obszar miejski wyszczególniono podróż jako połączenie źródła i celu podróży. Zaproponowano analizować podróż w odniesieniu do parametrów istotnych w aspekcie nowej kultury mobilności na obszarach miejskich. Wyszczególnione parametry zdefiniowano w pracy a także na ich podstawie przeprowadzono badania ankietowe wśród podróżnych na wytypowanym do tego celu obszarze miejskim. Częściowe wyniki tych badań przedstawiono w artykule.

Słowa kluczowe: obszar miejski, podróż, podróż piesza, podróż niepiesza, system mobilności na obszarach miejskich.

LITERATURE


