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DECISION-MAKING PROBLEMS OF COLLECTIVE TRANSPORT DEVELOPMENT IN TERMS OF SUSTAINABLE URBAN MOBILITY

Abstract: *The paper presents decision problems related to the development of transport systems facing planning challenges of sustainable urban mobility. Currently, city decision-makers must deal with growing difficulties related to the organisation of public transport systems. These difficulties involve the primary need for effective and ecological public transport systems and the capacity of transport service providers. These issues require a wide spectrum of research and analysis to determine expected future economic and social benefits from the implementation of environmentally friendly infrastructure investments and increasing capacity of service providers. The paper touches on the problem of the so-called green mobility in urban areas and the main management strategies associated with its development. A general formulation of the decision model, including boundary conditions and the criteria function using a sum of revenues from making the public transport offer more attractive, were proposed and discussed.*

Keywords: urban mobility, preferences of choice, transport ecology, urban transport, green mobility, transport decision models

1. Introduction

In the era of economic globalisation and free movement all over the world, but also global warming and increasing road traffic, the care for the natural environment is becoming more and more important. This applies especially to city dwellers, where immobilizing congestion on the streets becomes normality, and the search for solutions to reduce noise and increase the safety and quality of life are decisions made by city authorities. Extensive research not only concerns the determination of future economic and social benefits from infrastructural investments on various levels but also are an indispensable element of urban area development planning.

Mobility and development of public transport systems are very important subjects of studies [see 5, 16, 20, 30, 34, 57]. Recently, much work is devoted to sustainable or more – green mobility. The authorities of many cities take up challenges in this area and encourage designing transport systems which do not pose such a big nuisance to residents as before. New solutions concern, among others, those increasing mobility, such as rapid public transport systems with exclusively designated street lanes improving the efficiency of passenger transport while reducing the number of vehicles on the road [2, 14, 17, 39].

One of the intensively developed features of mobility in the cities are road congestion management systems [15, 49], which, in the absence of financial resources and space for infrastructure, may significantly improve the capacity of transport systems. These systems manage demand for travel through innovative solutions, increasing the volume of transport and the total capacity of the system at all. Road traffic management is the part of the wider system of solutions for sustainable transport systems in urban areas and reducing the negative effects of transport on the quality of life of urban residents. City decision-makers strive to develop Sustainable Urban Mobility Plans (SUMP) covering tools for reducing uncontrolled urban development which hinders mobility, road congestion and environmental pollution [36].

All activities toward improving mobility in urban areas are associated with city-logistics which aims to organize effective freight transport in the city and reduce the nuisance associated with this transport at the same time. City-logistics is set mostly to support the economic and social development of cities and to keep the business operating safely and efficiently in close proximity of human settlements [40]. The city-logistics is not only interested in goods but also considers passengers' movement due to their daily needs since passenger and goods traffic are very mixed in urbanized areas. Transport of goods in the cities is necessary for everyday functioning [10, 14, 17]. It supplies shops and businesses as well as cultural and rest places and deals with waste management. Unfortunately, it is also one of the main factors impeding the life of city dwellers.

Good organisation of transport service for recipients located in cities allows to reduce transport work, and thus to reduce costs, increase safety and improve the quality of life of residents. The systemic approach to solve the problems listed above is important. Decisions taken should include not only passenger and freight transport but also the entire process of creating a transport chain integrating various modes of transport, starting from the origin point and ending with its destination [42].

Adaptation of transport systems to new expectations of transport users is also a consequence of increased mobility of societies, including all activities related to urban residents' movement. The problem related to literature provides many concepts of mobility, e.g. social or transport mobility [16]. In relation to society, mobility means the mobility of an individual or group of individuals associated with the change of their place in space or the social system. Then, we talk about the so-called social, spatial mobility, which includes processes of people movement (economic migration or change of residence) and processes of transition from one social group to another or within one group.

Each person with the need for transport, whether resulting from the need to get to the workplace or moving for recreational purposes, chooses the mean of transport that meets his/her comfort, time and cost expectations (preferences). For decision-makers which organize traffic in the city, it is important to make public transport mostly preferred by inhabitants. This entails many investments and development of public transport systems tailored to the needs and expectations of residents of all social groups.

The main purpose of transport infrastructure is to ensure the safe and effective movement of people and goods while minimizing traffic costs and damage to the environment [57]. This is possible through traffic management and control [24, 58]. The traffic is forecasted and planned much earlier before the infrastructure investment. The high cost, planning effort and time necessary for infrastructure investments force forecasts of future traffic and workload on the transport network to be made for more accurate decision making. The essential element of this forecast is the information about expected and wanted modal split of transport [55]. This is important because infrastructural investments affect not only spatial distribution of travels (where and from people are travelling) but also the distribution of transport tasks (what kind of mean of transport is used) [12, 14, 47]. The expected distribution of transport tasks into types/modes of transport is usually done by models based on the utility theory. Individual utility functions taking into account different spectrums of factors assessing the usefulness of individual transport options are developed in these approaches [50, 57].

2. Planning transport in the aspect of mobility management - literature analysis

An essential aspect of research on the adaptation of passenger transport systems in cities to the needs is the proper analysis of the periodic mobility needs of its inhabitants. This implies an analysis of mobility needs requiring the appropriate transport systems to be satisfied. The mobility is perceived as a wish and ability of people to move easily to desired places in order to carry out tasks related to work, study, healthcare, shopping, sport, culture, recreation, etc. [11, 12, 54].

Thus, mobility is an inseparable part of an individual's daily life regardless of age and interests. It is necessary both for fulfilling professional duties and for organizing free time. Every day a person is mobile when he or she goes to school, work, healthcare facilities, takes care of official matters, but also meets friends, goes to restaurants, cinemas, walks or rides a bicycle recreationally. Every day everyone moves in public space using different means of transport. Thus, in order to meet the transport needs, people choose the means of transport comparing important factors including time and direct cost of travel (see [7, 8, 33, 48, 50]).

Planning sustainable urban mobility is also determined by budgetary constraints of cities prioritizing their objectives and activities. It is also influenced by EU transport and climate policy [56] to be taken into account in plans of sustainable mobility. Sustainable Urban Mobility Plan (SUMP) is a response to urban transport challenges. SUMP enables planning on the base of sustainable mobility paradigm [32, 35]. Its purpose is to develop a sustainable transport system and thus ensuring people high accessibility to their travel destinations, comfort, safety and minimum negative effects of mobility on the environment and human health [30].

As it is underlined by many researchers, models of transport tasks distribution used for mobility planning are usually local. Therefore, they differ in the type of factors considered, in distributions reflecting the influence of these factors, and in the mathematical formulation. Generally, mathematical models used to map modal split of transport tasks are classified as [1, 22, 52]: logit, multinomial logit MNL and nested logit NL.

The existing models, despite their complex forms, mostly take into account only one or two factors of choosing the type of transport (models with travel time [26], models with the price to time ratio). In addition, these models assess travel time and comfort, usually at a very general level. There is a lack of identification and analysis of arduousness of the means of transport for the environment and their impact on the behaviour of travellers.

A four-step approach to traffic modelling is used to reflect the effects of residents' communication behaviour [27, 45]. The stages of this approach include (fig. 1):

- travels generating,
- modelling of the spatial distribution of travels,
- distribution of transport tasks into available modes of transport (means of transport),
- traffic distribution over the transport network – workload on the networks of individual transport modes.

Although there are many caveats to the four-stage transport model, it remains the basic, universally recognized and used method of modelling traffic in transport systems.

The analysis in fig. 1 shows that the first stage of the method involves modelling of the travel generation, which requires identification of aggregates of traffic flow sources and destinations (the so-called communication areas). At this stage, the features of individual areas resulting from their development [25] as well as the purposes of travel are taken into account as a frame for calculation of the number of trips beginning and ending in these individual communication areas.

The second stage of traffic modelling leads to a matrix of transport demand for individual transport routes (sources – destinations). Gravitational models basing on space and time distances between sources and destinations are most often used for the construction of this matrix. Parameters regarding the attractiveness of transport areas are also mapped.

The third stage is the construction of decision models for selecting the mode of transport (types of means of transport). Therefore, transport demand matrixes identified at the second stage are decomposed into matrixes for all types of transport. In the last stage of modelling, traffic flows which described inappropriate transport demand matrixes are broken down into paths (roads) in the transport network [9, 25, 57].

The analysis of the four-stage model shows that its stages, although implemented separately, intertwine with each other. There are many suggestions in the literature for the modification of this classic four-stage approach (e.g. [3, 4, 27], as well as examples of the implementation of individual stages of transport modelling (e.g. [1, 6, 25, 50, 52] with the use of IT tools. One of the quite popular tools for traffic modelling of this type is PTV VISUM used by many designers, analysts and transport researchers [13, 26, 44].

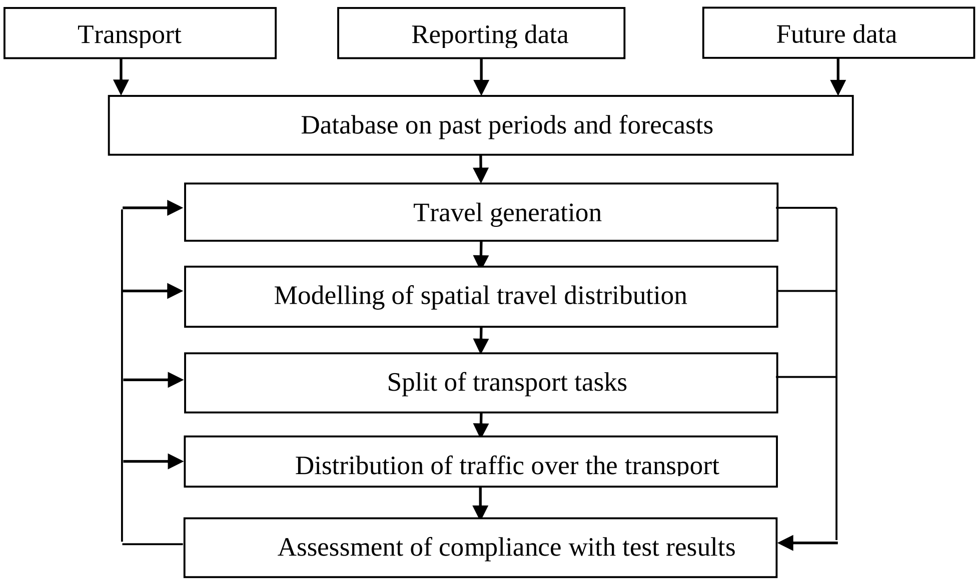

Fig. 1. The classic four-stage transport model. Source: own work on the base of [3, 26]

At all stages of working with traffic, model analyses of transport system condition and forecasts for the development of transport systems are important. In the surveys carried out to shape urban mobility, it is necessary to take into account the appropriate system and rationalisation solutions leading to the development of the proper transport policy.

Researches carried out using transport system models are applied for analyses of possible desired directions of transport system development or analyses justifying changes in organisation or traffic control. They can be used to implement ITS solutions for traffic safety management, including automatic event detection methods [21, 24, 38].

Shaping effective and safe systems is associated with additional challenges arising from different areas of social and economic life realized in a limited area. Thus, planning sustainable mobility is a consequence of the increase in the population of urban agglomerations, increase in the number of production and service plants and public institutions, expansion and compaction of road and municipal networks, etc. [9, 10]. As a result, it leads to side effects related to environmental protection (noise, air pollution, CO_2 emissions), traffic safety, access to infrastructure and traffic obstructions (e.g. congestion), etc.

In many publications on planning transport in urban agglomerations, the so-called urban logistics centres supporting freight transport in cities are proposed as an indirect solution to mobility issues [40, 46, 53]. Other publications focus on the composition of the fleet of public transport vehicles optimally meeting requirements and interacting with the environment [23]. In [40] and [28], the authors present models that enable route planning for vehicles while maximizing their positive impact on the environment. Using these models helps to reduce harmful gas emissions and improve air quality in areas with high population density. In [23], the authors propose a methodology optimizing city bus fleet assignment to fixed routes according to the differences between these routes [18, 55], between types of vehicles and propulsion technologies so as to achieve the reduction of air pollution (CO_2, CO, THC, NO_x and PM). As can be seen from the research described there, it is possible to achieve a fleet assignment reducing pollution from particular pollutants without increasing emissions of other pollutants. Another important issue is considering mobility in terms of safety and its impact on the selection and management of a vehicle fleet [41].

Including public bicycle systems into urban public transport is an important activity for traffic organisation in the cities. As presented in [7, 8, 29], travel by private bicycles and those from rental systems contribute to significant savings of money and benefits for both bicycle users and the natural environment. This is from a very reduced negative impact of bicycles to the quality of life in the city (zero noise and pollution) and from better protected historical objects and flora. Many authors indicate that bicycle rental systems have increased share not only in recreational travelling but also in commuting or shopping. All this results in better use of space, both in terms of traffic and parking, and less degradation of the road network.

3. Decisive process of planning transport in the city

Modal split of transport tasks between individual types of public and private transport is primarily determined by results of the calculation of the costs done by final users of the transport system. This system operates in conditions imposed by city authorities managing local transport through administrative decisions and decisions about infrastructure investments. Therefore, optimal solutions are naturally sought for meeting transport needs in which transport costs (not only the price of the ticket) are the basic, but not the only decision criterion.

For example, in [43], the author describes the role of the city transport system and its importance for the quality of life and details this description to the issues of designing roads intersections as a part of a holistic approach to mobility planning. The author emphasizes the need for the holistic description of investment planning problems in the city due to the complexity and multidimensionality of planning and design processes.

The multidimensional approach to sustainable mobility planning is a consequence of linking urban development plans to the natural, social and economic environment. For example, in [51], authors show that urban planning also requires sustainable management of urban green areas to reduce carbon dioxide pollution. Using the example of Amazon in Brazil, they conclude that city authorities must constantly monitor the quality of urban ecosystems and provide funding for their maintenance and development. This means that sustainable transport planning should be focused on meeting transport needs without generating undesirable emissions of pollutants threatening the environment, which is in line with the general principles of sustainable transport. In addition, maintaining a harmonious relationship between transport and environment keeps a balance between the ability to serve social and economic development and possible securing of the natural environment and future quality of life.

What is more, sustainable transport planning also means ensuring the safety of people, increasing the quality of their life and involving urban communities into the decision making process associated with the layout of transport systems. As some authors show, satisfying the need for social and economic accessibility of transport with the simultaneous development of public transport is connected with recognising the preferences of all its participants.

Many decision-making methods have been developed for transport planning. An example of the classification of these methods is presented in fig. 2 [37].

Decisions Based on Master Plan

- Decision making under the Master Plan developed and fixed for a longer period has a long tradition. Such plans are characterised by the reliable development and use of a large number of source data. However, they require periodic updating because the economic, social and technological environment of transport is constantly changing.

Normative Decision Theory or Substantive Rationality

- This approach to decision making is rational and recommended by many authors. The selection is made among a range of potentially possible scenarios, taking into account the likelihood of their occurrence. In a number of cases, a mathematical expression of a problem is used.

Behavioural Decision Theory

- It is an attempt to soften the extremes in the normative approach (point 2), recognizing that decision-makers often tend to fulfil social satisfaction rather than maximize the usefulness of decisions. Although this approach is a combination of scientific research and the use of expert experience, modelling plays a slightly smaller role in this case.

Group Decision Making

- This approach involves the work of a broader group of experts. Their opinions and proposals are subjected to analysis and an attempt to incorporate them into the solution being prepared. In order to improve work, a steering committee consisting of fewer people is generally set up. Mathematical modelling is applied through the input of individual experts.

Adaptive Decision Making

- This approach assumes the interaction between several groups of experts or pressure (interest) groups. The final solution is usually developed as a result of negotiations and compromise on individual sub-decisions. This approach is particularly applicable when the problem involves many hard-to-define aspects that are difficult to clearly identify using the theories mentioned above.

Mixed-mode Decision-making Strategies

- For global strategies, a mixed approach can be used. It includes, in particular, analysis, persuasion, bargaining on a number of levels, especially in view of the multitude of (often different) goals that can be achieved.

Fig. 2. Systematics of solving decision-making problems in transport system planning. Source: Own work on the base of [37]

The taxonomy presented in the figure clarifies that in many cases, decision making should be supported by construction and analysis of mathematical models to explore alternative variants meeting the goals of transport planning. The results obtained through mathematical modelling allow for the selection of the most reasonable variants fulfilling modelling criteria the best. The main goal of the process of planning development of sustainable transport systems in urban agglomerations is to set not only parameters for the newly designed network taking into account users' preferences but also the availability of the means of transport for all participants of transport process regardless of age or trip destination. To a lesser extent, it may also apply to the existing transport systems.

As can be seen from the above, planning and implementing a strategy for sustainable urban development is associated with the development of urban public transport. It is necessary to introduce innovative solutions in this field to make it better prepared for the challenges of modern cities and their societies. This applies especially to the strict planning zones, e.g. in central city districts, where the pedestrian and bicycle traffic is high. This implies a wide spectrum of activities aimed at limiting the role of passenger cars in the city centres. As it was presented in points 1 and 2, the improvement of quality and competitiveness of public transport can be accomplished by introducing ITS systems, developing a network of safe bicycle routes and pedestrian zones in the city.

The problem is then in shaping public urban transport systems so that as many residents as possible would like to use it. It is important to recognise the preferences of transport users and, on the other hand, introduce the system of incentives for switching their own cars to public transport. This implies the construction of decision models of a complex structure.

4. Decision model for planning sustainable mobility in cities

4.1. Assumptions of the model

It is assumed that the problem lies in planning sustainable mobility in urban agglomerations using mathematical methods. This requires a formal traffic model embracing expectations of transport service buyers expressed by their preferences, as well as the conditions resulting from the pursuit of sustainable mobility. It can be assumed that travellers' preferences determine the workload on the transport network for its fixed shape and agreed transport offers. The requirement for sustainable transport is taken into account when making decisions affecting the capacity of the transport system. The flexibility of transport demand and availability of transport offers must be considered together. For the purposes of designing sustainable urban mobility, it is proposed to include a scenario approach combined with four-stage traffic modelling.

Taking the above into account, it is assumed that the future transport network of a given urban area is known and considered in various development scenarios, as well as current and future transport offers assumed by different scenarios. Both private and collective (public) means of transport are considered. In addition, functional dependencies mapping spatially and temporally aggregated transport needs of the residents of a given area are known, as well as their preferences for travel and transport offer.

It is assumed that the structure of the urban transport network is mapped by graph $\boldsymbol{GM}=\langle \boldsymbol{PO}, \boldsymbol{PT}\rangle$, where $\boldsymbol{PO} = \{1,2,\ldots,i,\ldots,j,\ldots.op\}$ is a set of passenger stops, i.e. nodal points for getting on and off the public transport vehicles, while $\boldsymbol{PT} = \{(i,j): i,j \in \boldsymbol{PO}; i \neq j\}$ is a set of transport connections (routes connecting stops).

The n index describes a group of transport service buyers, while the set of all service buyers was defined as $\boldsymbol{N} = \{n: n = \mathbf{1},\ldots,\mathrm{N}\}$. It is also assumed that the buyer of the transport service may change the type of transport at the intermediate (interchange) node during the journey. Each group of transport services buyers has their clearly defined expectations for the service, e.g. comfort, fare, transit time, etc. Therefore, it is assumed that a vector of quality features significantly affecting the choice of transport offer (mean of transport) is known. By marking individual quality features with q, the set for each group of service buyers will be: $\boldsymbol{Q}^n = \{q^n: q^n = \mathbf{1},\ldots,\boldsymbol{M}\}$, where $n \in \boldsymbol{N}$.

Since the fulfilment of transport needs can be done by various types of public transport (means of transport, e.g. tram, bus, metro, taxi, suburban railway, bicycle, etc.), a set of types of transport $\boldsymbol{RTZ}$ is defined. $\boldsymbol{RTZ} = \{1, ..., rtz, rtz^*, \ldots, \mathrm{RTZ}\}$, where rtz is a type of public transport for which $rtz \neq rtz^*$, and RTZ is a number of all types of public transport available in the area. Qualitative features of rtz-th mean of transport competing under the offer rtz^* were determined. The set of qualitative features competing under the rtz^* offer is defined as follows:

$$\forall rtz \in \boldsymbol{RTZ} \qquad \boldsymbol{QF}_{rtz} = \{q1_{rtz}^{q^n}\colon\ q1_{rtz}^{q^n} \in R^+ \wedge\ rtz \in \boldsymbol{RTZ}\backslash rtz^* \wedge q^n \in \boldsymbol{Q}^n\}$$

The variety of transport needs reported under individual transport subsystems means that they must be considered individually in the model. Thus, separate groups n, $n \in \boldsymbol{N}$ can be served by particular types of transport: $n(rtz)$.

Each rtz-th type of transport was characterised by a vector of technical, technological, ecological and economic parameters:

$$\mathrm{vc(rtz)} = [\mathrm{QF_{rtz}}, \mathrm{rn_{rtz}}, \mathrm{poj_{rtz}}, \mathrm{c_{rtz}}], \quad rtz \in \boldsymbol{RTZ}$$

where:

$\boldsymbol{QF}_{\boldsymbol{rtz}}$ – set of qualitative features of rtz-th type of transport,
$rn_{\boldsymbol{rtz}}$ – type of engine of rtz-th type of transport,
$poj_{\boldsymbol{rtz}}$ – capacity of rtz-th type of transport,
$c_{\boldsymbol{rtz}}$ – unit cost of transport by rtz-th type of transport.

Exemplary structure of the urban transport network, including bus, tram and metro systems, is presented in fig. 3. ($i \equiv$ D – Destination, $i \equiv$ IP – intermediate point, $i \equiv$ ST –

source of travel / origin point). There may be more than one mean of transport working between two stops located in the transport network.

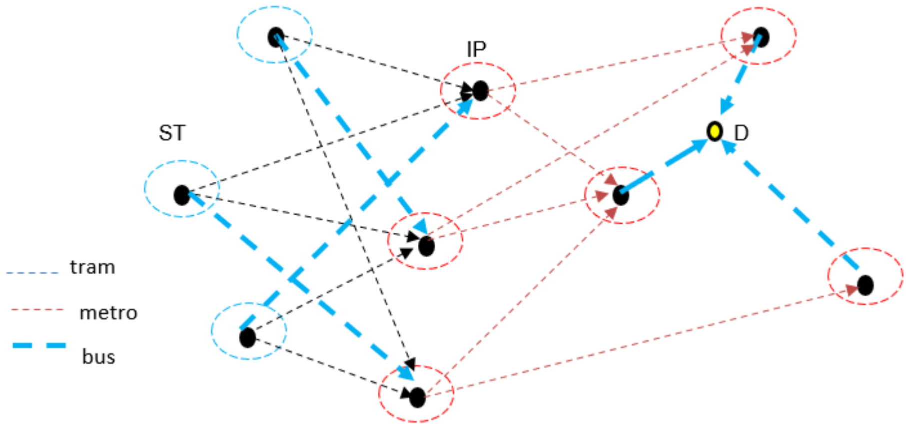

Fig. 3. The structure of the urban public transport network

4.2. Formal decision-making problem of choosing transport offer

The decision-making problem can be formulated as follows. For defined:

- PO, PT, $E^{rzt,ab}$, N, RTZ, Q^n, QF_{rtz}
- rn(rtz), $\boldsymbol{RN}(rtz^*)$ – set of types of engines in a given type of the mean of transport,
- poj(rtz) – capacity of rtz-th type of transport,
- c(rtz) – unit cost of transport by rtz-th type of transport
- and other

the vector of values of quality features of the transport offer for rtz^*-the mean of transport must be determined:

$$\mathbf{QF}_{rtz^*} = \left[q1_{rtz^*}^{q^n}\colon\ q1_{rtz^*}^{q^n} \in R^+\right]\quad q^n \in \boldsymbol{Q}^n$$

The decision variable is interpreted as the volume of the stream of service buyers (e.g. passengers) of n-th type moved between interchange points (i,j) by a given type of transport mean rtz^* using engine of $rn(rtz^*)$ type – the value of the feature will become known in the moment of choosing the given means of transport by the buyers of the service):

$$\mathbf{X} = \left[x_{rtz^*,n,(i,j),rn(rtz^*)}\left(q1_{rtz^*}^{q^n}\right)\colon\ \ x_{rtz^*,n,(i,j),rn(rtz^*)}\left(q1_{rtz^*}^{q^n}\right) \in\ R^+;\ q^n \in \boldsymbol{Q}^n;\ (i,j) \in \boldsymbol{PT}, n \in \boldsymbol{N}, rn(rtz^*) \in \boldsymbol{RN}(rtz^*);\ rtz^* \in \boldsymbol{STZ}\right]$$

The constraint on the capacity of the mean of transport is as follows:

$$\forall\, rtz^* \in \boldsymbol{STZ}; \quad q^n \in \boldsymbol{Q}^n;\ (i,j) \in \boldsymbol{PT}, n \in \boldsymbol{N}, rn(rtz^*) \in \boldsymbol{RN}(rtz^*)$$
$$x_{rtz^*,n,(i,j),rn(rtz^*)}\left(q1_{rtz^*}^{q^n}\right) \le poj(rtz^*)$$

Criteria function $F(\mathbf{X})$ corresponding to the revenue from the realisation of transport services takes the form of:

$$F(\mathbf{X}) = \sum_{stz*\in\boldsymbol{STZ}} \sum_{q^n\in\boldsymbol{Q}^n} \sum_{n\in\boldsymbol{N}} \sum_{(i,j)\in\boldsymbol{PT}} \sum_{rn(rtz^*)\in\boldsymbol{RN}(rtz^*)} \Bigg(c(\,rtz^*)\left(x_{rtz^*,n,(i,j),rn(rtz^*)}\left(q1_{rtz^*}^{q^n}\right)\right) - k_{rtz^*,q^n}\left(q1_{rtz^*}^{q^n}\right)\cdot x_{rtz^*,n,(i,j),rn(rtz^*)}\left(q1_{rtz^*}^{q^n}\right)\Bigg) \longrightarrow max$$

In the function F(**X**), the value $c(rtz)^*$ is the unit revenue from the transport services realised under the offer number rtz^* while k_{rtz^*,q^n} is an average cost of transport services under offer rtz^*.

Values of the elements of vector $\mathbf{QF}_{rtz^*}$ of the quality characteristics of transport offer (mean of transport) number rtz^* and a matrix of transport needs **X** of buyers of the *n*-th group is sought under defined conditions of flows in the network, i.e. non-negativity, additivity and traffic flow behaviour, as well as satisfying demanded transport needs of all groups of buyers.

In addition, acceptable values of the quality parameters of supplier's transport offer rtz^* should be set as well as acceptable differences between quality characteristics of a given transport offer and the quality expectations of service buyers. Assuming that the validity matrix of quality features for individual service buyers will take the following form:

$$\Psi = \left[\psi_{n,\,q^n}\colon\ \psi_{n,\,q^n} \in R^+\right]\ n \in \boldsymbol{N}, \qquad q^n \in \boldsymbol{Q}^n$$

Then, the constraint on the permissible differences between the quality parameters of a given transport offer and the quality expectations of service buyers can be described by the inequality:

$$\forall\, q^n \in \boldsymbol{Q}^n, \qquad \forall n \in \boldsymbol{N}, \qquad \forall rtz^* \in \boldsymbol{STZ} \quad |q1_{rtz^*}^{q^n} - \psi_{n,\,q^n}| \le \mu$$

while the permissible values of the quality features of the transport offer by rtz^*-th mode of transport, $rtz^* \in \boldsymbol{STZ}$ ($q1_{rtz^*,q^n}^{max}$ – the maximal value of the feature):

$$\forall\, q^n \in \boldsymbol{Q}^n \quad q1_{rtz^*}^{q^n} \ge 0 \wedge q1_{rtz^*}^{q^n} \le q1_{rtz^*,q^n}^{max}$$

The proposed model uses a few key issues. The first is the formulation of analytical relationships describing the impact of qualitative features on demand for transport in individual transport relations. The second one is the relationships binding travellers’ expectations and features of available transport offers with the probability of travelling using individual transport offers. Nevertheless, it is worth noting that the proposed approach allows us to consider problems of traffic distribution jointly and shaping transport offers for all scenarios of development of sustainable urban mobility. If one of the quality features of a given offer becomes zero, it will mean the legitimacy of resignation from transport offer (actual or hypothetical).

5. Conclusions

Planning sustainable urban mobility requires a modern approach to the design of public transport systems. In the era of intensive activities aimed at reducing degradation of the natural environment, increasing safety and quality of life of residents in highly urbanized areas, a systematic approach to planning and development of transport systems together with spatial development of urban areas is fundamental. Modern system solutions combining space and transport planning are aimed at greater use of alternative ecological forms of transport, e.g. using bicycles as a means of transport.

Sustainable mobility means shaping city transportation in a way that ensures equal accessibility for all social groups living and working in each area and proper form of users' communication behaviours. This behaviour, regardless of the purpose and length of travel, should in total create individual motorisation, not degrade public transport and non-motorised transport (on foot and by bicycle), and should maintain harmony with its surroundings. Sustainable transport is conducive to improving the city's image and spatial order, creating a good quality public space, and reducing diversity in the development and quality of life of individual city areas [6].

Modern system solutions combining space and transport planning are aimed at greater use of means of transport that are environmentally friendly, e.g. bicycles, electric buses, trams, etc. As mentioned today, city authorities are undertaking various activities to develop sustainable transport systems and reduce the negative impact of transport on the quality of life of urban residents. As a result, Sustainable Urban Mobility Plans are already developed in many cities. Plans are aimed at developing tools helping to reduce uncontrolled urban development, road congestion and environmental pollution. Decision-makers are focused on the organisation of public transport in a way, ensuring that the major part of the population uses it regularly instead of private transport. This entails the implementation of many investments and the development of public transport systems adapted to the needs and expectations of residents.

Sustainable Urban Mobility Plans are a drive to increase the efficiency of the transport system and improve the attractiveness of the urban environment. They cover not only the city within the administrative boundaries but also the work and study commutation areas. This means that planning for sustainable urban mobility is a strategic approach to urban development. It aims to provide residents with free movement, access, communication, trade and networking in a way that does not disturb social, environmental and economic well-being.

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