

The Method of Hierarchization of Public Transport Lines and Evaluation of Their Adaptation to the Users Needs

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Abstract Paper presents a synthetic discussion of the issues connected with public transport as an instrument of transport policies in the cities of urban agglomerations that create sustainable mobility and help achieve its goals. The theoretical investigations were supported with description of the results of empirical studies carried out by the authors. They concern the problems of using the methods of hierarchization of public transport lines and evaluation of the level of their adaptation to the customers' needs.

Keywords Public transport • Urban mobility • Transport modelling

1 Introduction

The results of theoretical investigations and empirical studies carried out by the authors in 2012–2015 in selected agglomerations of the Silesia region in the south of Poland concern the problems of creating suitable informational base for the decision-making process, where proposals of activities aimed at sustainable mobility are formulated. These decision-making processes use methods of hierarchization of public transport lines and evaluate the level of adaptation of public transport services according to the customers' needs, taking into account public transport vehicles with electric drive (buses with electric battery drive).

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2 Specific Nature of the Region

Silesia is a region in the south of Poland. On the basis of occurring in its area raw materials was formed the biggest industrial district, which plays a strategic role in the national economy as the basis of the national fuel and energy balance, developed many branches of industry, including the automotive industry.

Upper Silesia region covers 12.3 thousand km², which represents 4 % of the Poland. It is inhabited by 4.6 million people, which is over 12 % of the total population of the country. The population density is 372 people/km², and is more than three times higher than the average in Poland. Considering the built-up and urbanized area, the rate density is 3010 people/km² (Poland 2354 people/km²) [1].

Silesian Region has a specific settlement structure on the background of the country. Its characteristic feature is the large number of cities—there are 71, forming a network with a density of 58 cities/10 thousand km² [1], twice the national average.

The results of the analyzes contained in numerous works and projects carried [2, 3] out by the authors of the article, concerning the diagnosis of the current state of transport in the region, also confirm its specificity. In describing the current situation in the environment of urban transport should therefore be indicated on such phenomena as (see [4, pp. 87–88], [5–8]):

- lifestyle changes, and thus needs of mobility, which is influenced by rapidly increasing incomes of households; it is presented on Fig. 1—showing dynamics of growth of average monthly gross salary in Silesia in the decade from 2004 to 2013. This growth reached 61.6 %, and the average salary is now (2013) in Upper Silesia higher by 3.6 % than the average in Poland,

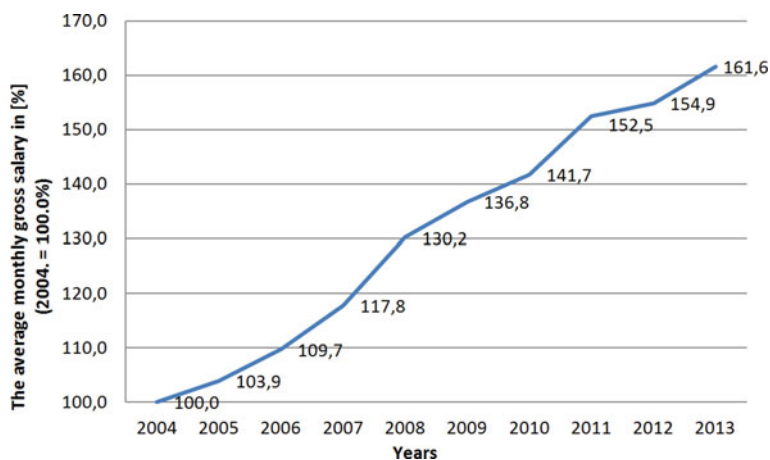


Fig. 1 Average monthly gross wages in Silesia in 2004–2013 in [%] (2004 = 100 %) (Source Own study calculations based on data from [1])

- deterioration in quality of citizens life due to the increase in traffic congestion, alarming levels of air pollution, deterioration of “acoustic climate”,
- development of suburbanization generates the distributed demand for traveling, which requires different solutions for the transport service than in the case of areas with a high concentration of demand,
- unsatisfactory effects of actions in the development of metropolitan (agglomeration) and urban development, such as: the regularity of distribution of foci of activity, application of the “tree of availability”, the harmonization of building, balancing the intensity of use and the centrifugal forces,
- underdevelopment of logistics channels causing disruption in the flow of goods in the agglomeration or cities in the region.

Many problems are identified also in transport systems of individual agglomeration or cities. In this case should be quoted, among others (see [4, pp. 87–88], [5–8]):

- a sharp rise in individual motorization (Fig. 2) causing adverse effects in the modal split, expressed by the dominance of a passenger car; Table 1 shows the changes that occurred in the five-year period in the region of Upper Silesia,
- inadequate to the needs of quantitative and qualitative functioning of collective public transport,
- the need to implement the investment program in infrastructure and fleet to make up years of neglect and delinquency,
- the need to improve the transport offer and make it more attractive,
- ineffective activities related to the integration and balancing transport technologies, utilizing strengthening the position of public transport,
- the lack of integration of transport policy with spatial policy and selected public policies.

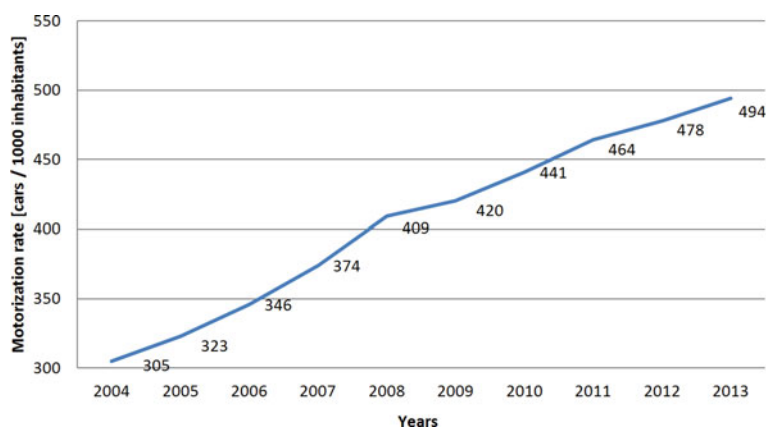


Fig. 2 Motorization rate in Silesia in 2004–2013 (*Source* Own study based on data from [4])

Table 1 Citizens activity in travels generally and non walking travels in (%) in selected agglomerations of Upper Silesia region (*Source* [6, 7])

Means of transport	The Upper Silesian Metropolis (2009)		The Bielsko-Biała agglomeration (2014)	
	Rate in (%)			
	Travels in total	Non walking travels	Travels in total	Non walking travels
Walking	28.8	–	10.1	–
Passenger car	29.3	41.2	61.6	68.5
Public transport	40.2	56.5	20.8	23.1
Other	1.7	2.3	7.5	8.4

Observed in the Silesia adverse developments in urban transport and the environment require effective actions. Due to the nature of these phenomena, a significant contribution to their overcoming, reducing the impact and elimination may have projects related to sustainability urban mobility. The current state of urban transport in cities and agglomerations of the region, especially in terms of infrastructure and fleet, requires programming and implementation of activities aimed at the modernization and expansion of these resources, and therefore the hard action [9]. However, it should be integrated into the relevant soft actions, so as to attain the horizontal objectives in the field of sustainable urban mobility. In the case where taken actions are characterized by soft actions, efforts should be made to make them having the form of integrated packages of actions.

3 Activities Leading to Changes in the Public Transport

One of the most important instruments that can be used in the process of sustainable urban mobility [10] in agglomerations and cities of the industrial region, are activities leading to changes in the public transport. It is expected at this first and foremost strengthen its role, which is reflected as the increase in the number of people benefiting from this way of movement in urban transport.

Programming the development of transport falls within the scope of transport policy and transport development strategy, documents prepared by the relevant agencies of local authorities of a particular level [11–14]. Their construction, which is a multi-step decision-making process, requires adequate information base. These are resources of knowledge concerning:

- mobility needs and transportation preferences of urban transport users,
- the functioning of the urban public transport system.

The formulation of the transport policy program or building development strategy as a decision-making process and uses the accumulated resources at the

disposal of knowledge [15–19]. From a morphological point of view it is defined sequence of steps including:

- identification of the existing system of the public transport, in the case of this project, organized by the Public Transport Authority (PTA) in the city,
- diagnosis and evaluation of the conditions of the urban public transport system,
- formulating solutions propositions being solutions of undertaken problems in terms of public transport, so—the constructing the policy agenda,
- implementation of the program of transport policy,
- monitoring and evaluation of taken actions.

Based on above point of view the multi-step decision-making process consists of the following steps:

Step 1. Identification the set of objects, which are bus lines.

Step 2. Identification the set of characteristics/variables of the objects from Step 1.

Step 3. Constructing a bus line pattern adapted to the identified needs of users of public transport.

Step 4. Ordering the set of characteristics/variables describing all the analyzed bus lines in the initial matrix of observation.

Step 5. Constructing a synthetic index *SILA* (Synthetic Index of the Level of Adaptation) of bus lines to the identified needs of users of public transport.

In order to determine the level of adaptation of bus lines to the identified needs of users of public transport in the area served by Public Transport Authority (PTA) in the city, were used the principles of taxonomic methods. This tool gives you the ability to describe the studied phenomenon by a single synthetic indicator instead of using many variables. Procedure in used method was as follows:

Step 1. Identification the set of objects, which are bus lines.

$$[L_1, \dots, L_i, \dots, L_n], \quad i = 1, \dots, n \quad n = 40 \quad (1)$$

Step 2. Identification the set of characteristics/variables of the objects from Step 1.

$$[x_{i1}, \dots, x_{ij}, \dots, x_{im}], \quad j = 1, \dots, m \quad m = 40 \quad (2)$$

Variables x_{ij} and their importance determined were on the basis of proposals of experts and members of the project team, based on their research experience. The examples are in Table 2.

Step 3. Constructing a bus line pattern adapted to the identified needs of users of public transport.

The bus line—variable X_0 is a vector of the form:

$$X_0 = [x_{01}, \dots, x_{0j}, \dots, x_{0m}] \quad (3)$$

Table 2 Features describing bus lines of Public Transport Authority (PTA) in the city (Rybnik)—selection of variables to synthetic measure (*Source* [6, 7, 20])

A variable name—feature describing the bus lines in Rybnik	The variable marking	The nature of variable: (N)ominants, (S)timulants, (D)estimulants	Adopted variable importance (weight)	Evaluation of reference dimension of variable
Running days of the line per week (Mon–Fri, Saturday, Sunday or holiday)	x_1	N	0.15	5.0
The time of line operation in a day of working in (h)	x_2	S	0.10	
Important traffic generators handled by the line	x_3	N	0.20	
The average number of seats in the buses used on weekdays, during periods of peak traffic attributable to 1 passenger	x_4	S	0.15	
Scheduled transportation speed of the line on a working day	x_5	S	0.15	
Average scheduled frequency of running of the line during transport peaks on working days	x_6	D	0.15	
Average scheduled frequency of running of the line during the noon (10–13) hours on Saturdays	x_7	D	0.05	
Average scheduled frequency of running of the line during the afternoon (14–17) hours on Sundays or Holidays	x_8	D	0.05	
Total	—	—	1.00	

The individual components x_{0j} will create the best dimensions [the maximum for variables with stimulant nature (S), the minimum when it comes to destimulants (D) or terminal for variables of a nominant nature (N)], which relate to the analyzed lines. These values were determined among experts and presented in Table 3.

Step 4. Ordering the set of characteristics/variables describing all the analyzed bus lines in the initial matrix of observation.

Its character is as follows:

Table 3 Pattern of a bus line adapted to the needs of public transport users in terms of the of Public Transport Authority (PTA) transport system in the city (Rybnik)

The variable name describing bus line in Rybnik—evaluation criteria of the line	Component of X_0 pattern marking	X_0 pattern of bus line	
		A reference value of the variable and its evaluation	The weighted value of the reference evaluation of variable dimension
Running days of the line per week	x_{01}	The line runs weekdays, Saturdays and Sundays or holidays (5.0)	0.75
The time of line operation in a day of working in (h)	x_{02}	>17 o'clock and after 22:30 (5.0)	0.50
Important handled traffic generators	x_{03}	Handling the area generating a large and continuous transport needs (5.0)	1.00
The average number of seats in the buses used on weekdays, during periods of peak traffic	x_{04}	≥ 3.0 (seat/lane) (5.0)	0.75
Scheduled communication speed of the line on a working day (km/h)	x_{05}	≥ 27.0 (5.0)	0.75
Average scheduled frequency of running of the line during transport peaks on working days (min)	x_{06}	≤ 30.0 (5.0)	0.75
Average scheduled frequency of running of the line during the noon (10:00–13:00) hours on Saturdays	x_{07}	≤ 45.0 (5.0)	0.25
Average scheduled frequency of running of the line during the afternoon (14.00–17.00) hours on Sundays or Holidays	x_{08}	≤ 45.0 (5.0)	0.25
Total weighted evaluation of the reference dimension of variables			5.0

$$X = \begin{bmatrix} x_{11} & \dots & x_{1m} \\ \dots & x_{ij} & \dots \\ x_{i1} & \dots & x_{nm} \end{bmatrix} \quad (4)$$

where

x_{ij} the value of the j th variable for the i th bus line in the city (Rybnik).

Then was constructed the observation matrix taking into account the results of the evaluation. The method of evaluation uses comparison for each assessed line the

value criterion of the constructed X_0 pattern of bus line tailored to the needs of residents, which was shown in Table 3. In situation, where:

- criterion value of the line is more advantageous than the reference value, take rating of 5,
- value criterion for the line is close to the reference value or its equivalent, this assessment should be 3 or 4,
- value criterion for the line is unfavorable in relation to the reference value, take a rating of 1 or 2.

It is convenient to use the matrix taking into account the results of the assessment of the line, because it has the character of the standardized matrix, and thus released from various titers of characteristics of the tested bus lines. Table 4 shows the character of this matrix for several selected examples of bus lines in Rybnik.

Step 5. Constructing a synthetic index *SILA* (Synthetic Index of the Level of Adaptation) of bus lines to the identified needs of users of public transport.

Firstly was calculated the synthetic measurement (*SM*) of the line adjustment, which is constructed as a linear combination of the values of the proposed evaluation variables. Hence:

$$SM = \sum_{i=1}^m x_{ij} \quad m = 1, 2, \dots, 8 \quad (5)$$

While the value of synthetic index of the level of adaptation (*SILA*) was calculated using the formula:

$$SILA_i = \frac{MS_i}{\sum_{j=1}^m x_{oj}} = \frac{MS_i}{MS_0} \quad (6)$$

where

$MS_0 = \sum_{j=1}^m x_{oj}$ synthetic measure of the level of adaptation X_0 pattern for MPT bus lines in Rybnik to the identified needs of users of public transport.

Table 4 Observation and assessment of individual variables which characterize these lines

No. of bus line in Rybnik city	The value of the variable (features) describing a given bus line taking into account its evaluation							
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
1	0.75	0.50	1.00	0.75	0.45	0.30	0.10	0.05
2	0.15	0.20	1.00	0.60	0.30	0.30	0.10	0.05
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
26	0.75	0.50	1.00	0.60	0.30	0.75	0.25	0.15
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
51	0.75	0.30	0.80	0.15	0.30	0.60	0.10	0.05
52	0.75	0.50	0.60	0.60	0.75	0.75	0.05	0.05

Table 5 Dimensions of (SM) and ($SILA_i$) for example selected bus lines in Rybnik

No. of bus line in Rybnik city	Dimensions	
	SM	$SILA_i$
1	3.90	0.78
2	2.70	0.54
$\vdots$	$\vdots$	$\vdots$
26	4.30	0.86
$\vdots$	$\vdots$	$\vdots$
51	3.05	0.61
52	4.05	0.81

Normalized values $SILA_i$ belong to the interval (0, 1). The closer the unity, the bus line better suited to your needs. Table 5 shows the results of synthetic measurement and synthetic line adjustment factor for example selected line.

4 Conclusions

Analysis of the obtained results can be noted that the maximum value of assessing the degree of adjustment of Public Transport Authority (PTA) bus lines in Rybnik city according to established criteria to the needs of users is 5.00 (pattern of bus line). 75 % of this value (synthetic measure equal to 3.75) has reached 12 bus lines, including 6 of the 7 main lines (lines no. 3, 26, 29, 48, 48 and 52) and 2 of 9 basic lines (lines 28 and 45).

The results allowed for variant defining and analysis of the operation of the bus lines. From the point of view of the balancing of urban mobility, the most useful was the variant maximizing the level of functional alignment the line system to the needs of public transport users. This variant presents a wide range of activities corresponding to the principles of sustainable mobility. The most important ones include:

- distinction of bus lines with strategic importance for Public Transport Authority (PTA) as the organizer of transport (main lines) and lines which task is to ensure a high level of accessibility to areas which are currently with the lowest attractiveness of transport (leading lines),
- extension of the working day for certain bus lines,
- increasing the frequency of courses on selected lines,
- the introduction of new connections—mainly direct, especially between districts with high demographic potential and movable,
- increasing the immediacy of routes lines serving the connection of selected districts to the city center,
- introduction to transportation on selected lines of modern fleet,
- increasing the availability of urban public transport in the individual districts of the city (reduction of areas “excluded” of the public transport).

Implementation of these measures should contribute to improving the attractiveness of the Public Transport Authority (PTA) transport system, and consequently, to increase the number of journeys undertaken by collective public transport in the Rybnik agglomeration.

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