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EVALUATION OF THE POSSIBILITY OF IMPROVING THE OPERATION OF A TRANSPORT COMPANY IN THE CONTEXT OF THE VEHICLE FLEET MANAGEMENT

OCENA MOŻLIWOŚCI POPRAWY FUNKCJONOWANIA PRZEDSIĘBIORSTWA KOMUNIKACYJNEGO W KONTEKŚCIE ORGANIZACJI ZARZĄDZANIA TABOREM

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Abstract: The organization of public transport greatly contributes to the proper traffic management policy of vehicles. They are an active element cooperating with the infrastructure. However, the organization of transport is not an easy task. The constantly changing demand on lines characterized by various length and intensity of use makes it difficult to decide on the choice of vehicle. Vehicles with various technical and functional parameters along with a specific frequency of running create an offer for users which is not always adapted to their needs. All the changes affecting the functioning of the rolling stock are reflected in the costs of the communication company. Analysis of the company's operations allows to identify some areas that can be optimized. The savings concern lower fuel consumption by adjusting the capacity and type of vehicle used.

Streszczenie: Organizacja transportu publicznego w dużej mierze przyczynia się do właściwej polityki zarządzania ruchem pojazdów. To one są czynnym elementem współpracującym z infrastrukturą. Jednak organizacja transportu nie jest łatwym zadaniem. Ciągle zmieniający się popyt na liniach o różnej długości i intensywności użycia utrudnia podjęcie decyzji o wyborze taboru. Pojazdy o różnych parametrach technicznych jak i użytkowych wraz z określoną częstotliwością kursowania stanowią ofertę dla użytkowników, która nie zawsze jest dostosowania do potrzeb. Wszystkie zmiany mające wpływ na funkcjonowanie taboru, mają odzwierciedlenie w kosztach przedsiębiorstwa komunikacyjnego. Analiza funkcjonowania przedsiębiorstwa pozwala zidentyfikować pewne obszary jego działania, które mogą być zoptymalizowane. Oszczędności dotyczą mniejszego zużycia paliwa poprzez dostosowanie zdolności przewozowej i rodzaju wykorzystywanego pojazdu.

Key words: public transport, optimization of transport organization
Słowa kluczowe: transport publiczny, optymalizacja organizacji przewozów

INTRODUCTION

The city is an area where thousands of people live and function. However, this functioning is possible only thanks to the well-functioning municipal logistics. It provides organization and coordination of cargo and person flows. In its system, the subsystems of individual and collective transportation play an important role. Despite the fact that most of the vehicles on the streets are individual vehicles, collective transport is the foundation of the city's transportation system. Thanks to the collective transport, the inhabitants are able to satisfy their need to reach a specific place without the necessity to possess their own vehicle.

However, the organization of transport is not an easy task. The constantly changing demand on lines characterized by various length and intensity of use makes it difficult to decide on the choice of vehicle. Vehicles with various technical and functional parameters along with a specific frequency of running create an offer for users which is not always adapted to their needs. All the changes affecting the functioning of the rolling stock are reflected in the costs of the transportation company.

The paper deals with the issues of the functioning of public transportation as well as the impact of transport organization on costs in an enterprise.

The aim of the paper is to analyze the functioning of public transportation in a transport company, and to consider the possibility of improving the functioning of the company in the context of the organization and fleet management using optimization tools.

In order to realize the aim of the paper, the analysis of literature, analytical methods and an necessary interview were used to determine the current state of managing the fleet of the transport enterprise.

1. Costs of public transport

Public transportation, being a transport system, plays a huge role in the functioning of the city, creating a kind of its skeleton. The environment with which it has direct contact, precisely the geography of the area, is an element that determines the range, concentration and efficiency. When creating a transport system, it should be connected to the already existing buildings by selecting the appropriate means of transport (Andrzej S. Grzelakowski, 2010, pp. 5-7). Transportation routes and their complexity depend mainly on the size and development of the city. In large cities, the public transport system is designed using several types of transport that interact with each other. The end result of the project is a network of transport routes that are adapted to the spatial - functional structure of the city (B. Tundys, 2008, pp. 112-120).

The public transportation system is intended primarily to serve the residents, ensuring regular travel according to the timetable. An important element is the availability, which means the possibility of use for all passengers paying for the service (J. Walker, 2011, pp. 13-14).

There are many factors affecting the functioning of the public transport system. Means of transport, energy, materials, human work create a coherent whole that meets the needs of users. Unfortunately, all of them generate costs. Getting to know the costs makes it possible to react efficiently to changes taking place in the system and make appropriate decisions. The costs for public transport were divided into:

- internal;
- costs of transport infrastructure;
- outside.

The costs of transport infrastructure are the costs of its construction and maintenance, incurred by the state and local governments. External costs are the cost of road accidents not covered by the population's fees and environmental costs - noise, pollution, etc.

Internal costs are costs incurred by enterprises organizing urban transport. These are expenditures in the form of economic outlays. According to the generic system, they are divided into: depreciation, tires, basic materials, energy, propellants, wages and other costs. Depreciation, which has a great importance in this system, means write-downs of unmortged vehicles, allowing to gather cash for the purchase of new rolling stock. In addition to depreciation, remuneration has an impact on the overall level of costs. For prudent management, driver's working hours are based on a balanced system of working time norms. Working time is adjusted to the currently prevailing demand. Drivers are billed on a monthly basis, so there is no need to pay overtime in case of work longer than 8 hours a day.

Correct settlement of public transport costs is possible using the calculation unit, in other words the appropriate cost carrier. The basic carrier is a vehicle-kilometre, meaning cost of driving one kilometre by the one vehicle. In addition, vehicles number, route lengths and vehicle-hours are used as cost carriers. A vehicle kilometre on a given line is shaped by (O. Wyszomirski, 2008, pp .129-137):

- operating speed;
- number of vehicles servicing the given line;
- number of days on which vehicles are used;
- time of running;
- vehicle use indicator.

2. Organizing the flow of people

Managing the urban transport consist of a number of aspects that have different influence on the functioning of the company. The number of running vehicles, their frequency, the type of vehicle, taking into account the fuel consumption and its capacity, all this must be taken into account, due to the line, mileage, route and constantly changing demand. An organization ensuring proper functioning requires appropriate solutions that attempt to eliminate negative aspects of transport functioning in urban areas (B. Tundys, 2013, s.122). Solutions that are able to improve transport through better organization are shown in Figure 1.

Fig. 1. Factors influencing the organization of public transport

Source: Own elaboration, based on B. Tundys, *Logistyka miejska. Teoria i praktyka*, Difin, Warszawa 2013, pp.122.

Proper organization of local passenger transport is provided by the organizer, ie the local government. The organizer's tasks were divided into three sectors:

- planning the transport development;
- organization of public transport;
- public transport management.

Planning is one of the most important things. The organizer, in accordance with the law, must undertake activities aimed at planning the sustainable development of public transport. Taking into account the expectations of users, ensuring adequate availability and diversity of means of transport.

The organization of public transport largely contributes to the proper vehicle traffic management policy. They are an active element cooperating with the infrastructure. Managing them can be divided into two layers:

- internal;
- external.

The internal layer includes dispatcher activities directly related to the movement of vehicles in space and time. Implementation of tasks in this area is carried out through the traffic services of communication enterprises. Their basic duties include: determining routes and spacing between vehicles, which can be updated both according to the needs of the city or fixed, that means a permanent distribution based on average values of passenger flows. The simplest, most frequently used system contains fixed routes and layout. Dispatcher's control in such a solution is based mainly on managing rolling stock, introducing reserve vehicles or holding them at stops.

The external layer served by the organizer of the traffic, conducts activities in the field of privileging public transport vehicles. Activities in this area concern (PublicTrans 2010, pp.119 - 120):

- impact on other vehicles involved in traffic;
- control of traffic lights;
- priority of means of transport in motion;
- organizing vehicles in space and time.

Public transport management has a very big impact on demand, i.e. the number of people wanting to use the services. The selection of rolling stock and frequency are the main determinants of whether demand will be limiting or perhaps stimulating. In addition, the number of people using the services depends on the entire transportation system, which is influenced by:

- the size of the city;
- tariff and ticket systems;
- travel length;
- distance from the city centre;
- roads condition;
- intensity of traffic.

Moreover, in addition to the above features, the density of street network is important in terms of fleet management. High density of streets combined with an area with a high number of inhabitants positively affects the amount of transport. In addition, the number of transport is dependent on the number of stops, which are also more numerous in the dense network of roads. The number of people who are professionally active influences the willingness to use transport services in the densely populated areas. When it comes to the functioning of the rolling stock, the increase of the transport speed makes the transport offer more attractive, which increases the number of people interested in it. Easy access to tickets and especially their price makes the management of the fleet having to face constant fluctuations in demand. In addition to changes resulting from the company's regulations, economic factors resulting from changes in the state play an important role in the organization of public transport. This applies mainly to changes in fuel prices or insurance of individual vehicles, the increase of which intensifies the demand for public transport services (Ł. Kosobucki, 2013, pp. 163-165).

3. Improving the functioning of public transport based on the selected enterprise

The company under consideration provides services using rolling stock consisting of 206 vehicles. This fleet is characterized by different construction parameters, different transport capacity and technical equipment. Each vehicle has a certificate entitling it to work in accordance with the requirements of the Public Transport Authority. The largest part are Mercedes - Benz Conecto G vehicles that can accommodate 124 passengers, occurring in the number of 63. Furthermore, trips are offered by Solaris Urbino 12 vehicles in the amount of 41 units, Solaris Urbino 9.8 in the amount of 33 units, Mercedes - Benz Conecto in the amount of 38 units, and 31 MAN vehicles. These vehicles are equipped with engines that reach 250 - 360 hp. The company aims to unify rolling stock, vehicles are characterized by high comfort of travel. Additional information about fuel consumption standards and the available number of places in vehicles is presented in the table No. 1.

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Tab. 1. Characteristics of the company's X vehicle fleet

Brand	Fuel	Fuel consumption [l/km]	Capacity	Number of vehicles
Solaris Urbino 8,9LE	Diesel	0,26	60	33
Mercedes Conecto G	Diesel	0,54	124	63
Solaris Urbino 12	Diesel	0,46	105	41
Mercedes Conecto	Diesel	0,42	94	38
MAN NL 263	Diesel	0,44	90	31

Source: Own elaboration.

Although the company has only three brands of vehicles, the table shows that their parameters differ significantly from each other. Thanks to that it is possible to adapt the vehicles to the everyday needs of the roads. The type, number and frequency of running directly affects the organization of traffic and its importance in the life of the city. Vehicles serves both urban and suburban areas of Warsaw on a daily basis, transporting passengers to various districts. Passengers can use a total number of 47 routes organized by the carrier. It offers journeys on 35 city lines, 8 zonal lines, and 4 night lines. Routes vary in terms of both length and number of stops. The longest of them is one of the night lines consisting of 54 stops on distance of 29.2 km, the shortest urban line consists of 10 stops, including one on request, on a distance of 2.5 km. The total number of kilometres completed by the rolling stock on a weekday is 83 342,58 km. Data regarding lines is presented in the table No. 2.

Tab. 2. Characteristics of the line length and rolling stock working time

	Lines			
	City	Zonal	Night	Total
Daily mileage [vehicle-kilometres]	71 614,20	10 232,38	1 496,00	83 342,58
Daily number of vehicle-hours [vh]	3 060,0	486,0	58,5	3 604,5
Number of lines	35	8	4	47

Source: Own elaboration.

4. Analysis of the company's functioning

The functioning of transport was illustrated by the analysis of daily costs incurred by the company. The work of the financial department made it possible to use the data needed for financial analysis. The analysis is presented by the activity cost account, which takes into account all costs related to running the business. In the case of a public transport company, it is: depreciation of means of transport, employees' remuneration, consumption of materials and energy, including surcharge for oil consumption and tires, taxes and fees, social insurance and other benefits, external services and other costs. Cost calculation has been divided into three groups in terms of line types, basing on that division a separate insight into the costs of urban, zonal and night lines is possible. The costs carriers are a vehicle-kilometre and a vehicle-hour. The exact statement of activity costs is presented in the table No. 3.

Tab. 3. Daily business activity costs account in enterprise X

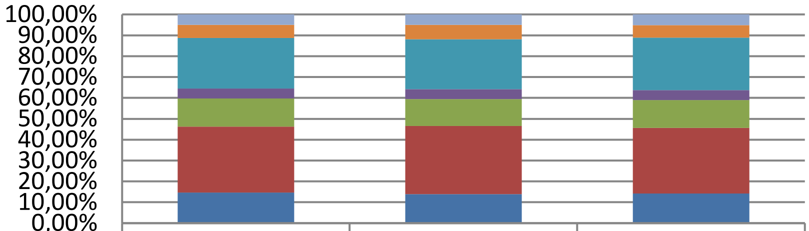
No.	**Account name**	**Routes**	

		City	Zonal	Night	Total
1	Depreciation	63 987,68	9 957,34	1 137,28	75 082,30
2	Usage of materials and energy	137 733,01	23 164,05	2508,44	163 405,51
3	Foreign Services	58 689,23	9 225,49	1 059,35	68 974,07
4	Taxes and fees	20 868,21	3 359,00	386,21	24 613,42
5	Remuneration	105 674,29	17 085,32	2 008,24	124 767,85
6	Social security and other benefits	27 619,40	4 876,57	477,26	32 973,23
7	Other costs	21 758,32	3 587,30	409,20	25 754,82
	TOTAL	436 330,14	71 255,07	7 985,98	515 571,20
	Costs carrier I:				
	Vehicle-kilometre	6,09	6,96	5,34	6,19
	Cost carrier II:				
	Vehicle-hour	142,59	146,62	136,51	143,04

Source: Own elaboration.

The daily work of a public transport company generates costs included in the table. The cost factors were calculated using the sum of individual costs and data from table No. 5. The carrier price is visible both in vehicle-kilometres and in vehicle-hours for zonal trips. The vehicle-kilometre of zonal routes is by 12.57% higher than the vehicle-kilometre price for the whole company. Fig. 2 shows the percentage share of particular costs that make up the type of transport.

Share of individual costs in total costs



	City	Zonal	Night
Other costs	4,99%	5,03%	5,12%
Social security and other benefits	6,33%	6,84%	5,98%
remuneration	24,22%	23,98%	25,15%
Taxes and fees	4,78%	4,71%	4,84%
Foreign Service	13,45%	12,95%	13,27%
Usage of materials and energy	31,57%	32,51%	31,41%
Depreciation	14,66%	13,97%	14,24%

Fig. 2. Percentage share of costs in individual types of journeys.

Source: Own elaboration

The share of costs in all groups is similar, but with small differences. The largest share of costs is attributable to the consumption of materials and energy, the composition of which mostly includes the cost of fuel, but also the costs related to the consumption of adblue and tires. The highest value from all types of journeys is 32.51% and is attributed to zonal trips. Drivers' salaries are the second largest in terms of size, and they, together with the consumption of materials and energy, account for more than half of the daily operating costs of the company. Other costs, in order, are vehicle amortization, third party services, insurance, other expenses, taxes and fees.

The daily operating cost of the enterprise is PLN 515,541.20, while the percentage of individual types of trips in total daily costs is shown in drawing No. 3.

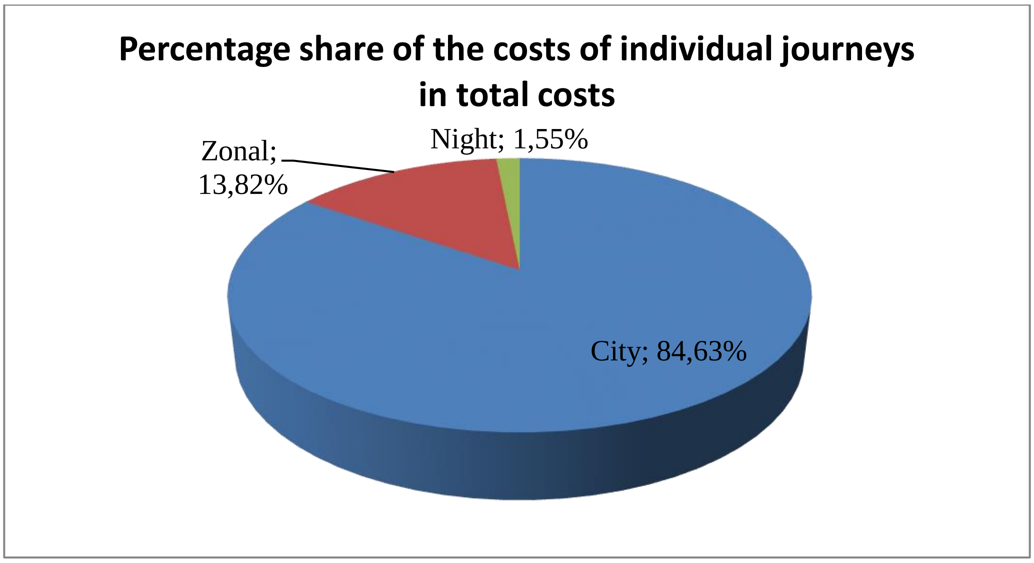


Fig. 3. The percentage share of the costs of individual journeys in the total costs of the enterprise on a daily basis
Source: Own elaboration.

The analysis of the above data indicates a bad organization of zonal trips, due to the largest cost, which may result from several reasons. Although the overall cost of zonal trips is less than 14% of daily total costs, the value of the vehicle-kilometre is much higher than the other values. Moreover, the share of material and energy consumption costs is also the highest, accounting for almost 1/3 of the cost of travel. The share of fuel costs in the costs of materials and energy consumption is about 91%. The highest costs in this area may indicate poor management of rolling stock, inappropriate choice of vehicles for the line and poorly selected frequency of running. Due to the above data, the analysis of the functioning of zonal trips will be carried out in the next step and optimization will be carried out in its area..

4.1. Analysis of zonal trips

Zone crossings, also serving the second zone, are an offer for people living in the suburbs of the city. Company X has in its offer 8 lines connecting the city with the suburbs. These routes are varied in terms of length and frequency of running. The number of vehicles necessary to service all lines in terms of the frequency of running is 27. The number of available vehicles for the implementation for zonal trips according to the requirements of the organizer is 37. Detailed information about the routes and the vehicles assigned to them is presented in the table No. 4.

Tab. 4. Current state of support for zone lines

Line	Daily mileage [v-k]	Number of required vehicles	Vehicle				
			Solaris 8,9	Mercedes C	Solaris 12	Mercedes C G	MAN
A	1632	5				5	
B	1250,8	2			2		
C	1474	4			1	3	
D	1357,78	3		1		2	
E	1962,4	5				5	
F	663	4		1		3	
G	956	2					
H	936,4	2			2		
Number of available vehicles			6	4	6	18	

Source: Own elaboration.

The table shows that, in sequence:

- Line A is operated by 5 Mercedes - Benz Conecto G vehicles;
- Line B is operated by 2 Solaris 12 vehicles;
- Line C is operated by 1 Solaris 12 vehicle and 3 vehicles Mercedes - Benz;
- Line D is operated by one Mercedes - Benz Conecto;
- Line E is operated by 5 Mercedes - Benz Conecto G vehicles;
- Line F is operated by 1 Solaris 12 and 2 Mercedes-Benz vehicles;
- The G line is operated by 2 MAN vehicles;
- Line H is operated by 2 Solaris 12 vehicles.

In addition, the table shows that the longest route is route E, which is 1962.4 km long and is served by five Mercedes - Benz Conecto G vehicles. The shortest route is 663 km and it is implemented in 1/4 by Mercedes - Benz Conecto vehicles and in ¾ Mercedes - Benz Conecto G vehicles. In the case of route being serviced with different types of vehicles, the number of kilometres travelled by each of them is proportional to their part used in the operation of the given line. The number of buses needed is a result of the frequency requirements. The number of available vehicles is limited due to the requirements of their technical equipment imposed by the organizer for transport.

The element that is the most important factor in the cost of materials and energy is fuel consumption. The number of fuel burned by all vehicles servicing the total route is presented in the table No. 5.

Tab. 5. The amount of fuel burned on a given total route

	Vehicle				
Line	Solaris 8,9	Mercedes C	Solaris 12	Mercedes C G	MAN
A	424,32	685,44	750,72	881,28	718,08
B	325,21	525,34	575,37	675,43	550,35
C	383,24	619,08	678,04	795,96	648,56
D	353,02	570,27	624,58	733,20	597,42
E	510,22	824,21	902,70	1 059,70	863,46
F	172,38	278,46	304,98	358,02	291,72
G	248,56	401,52	439,76	516,24	420,64
H	243,46	393,29	430,74	505,66	412,02

Source: Own elaboration.

With the use of the current state of operation of zone lines and table no. 6 it is possible to calculate the daily number of used litres of fuel for zonal trips, which amounts to 5151.23 litres. In case of route serviced with one brand of vehicles the value from table No. 6 is taken into account, the service with more types of buses forces to use the average weighted combustion and the number of kilometres driven by a given vehicle. In addition to burning, it is also important to meet the expectations of passengers and to adapt vehicles to the number of people who want to use transport services. The maximum number of passengers per hour during periods of increased traffic and the carrying capacity of vehicles are shown in Fig. 12.

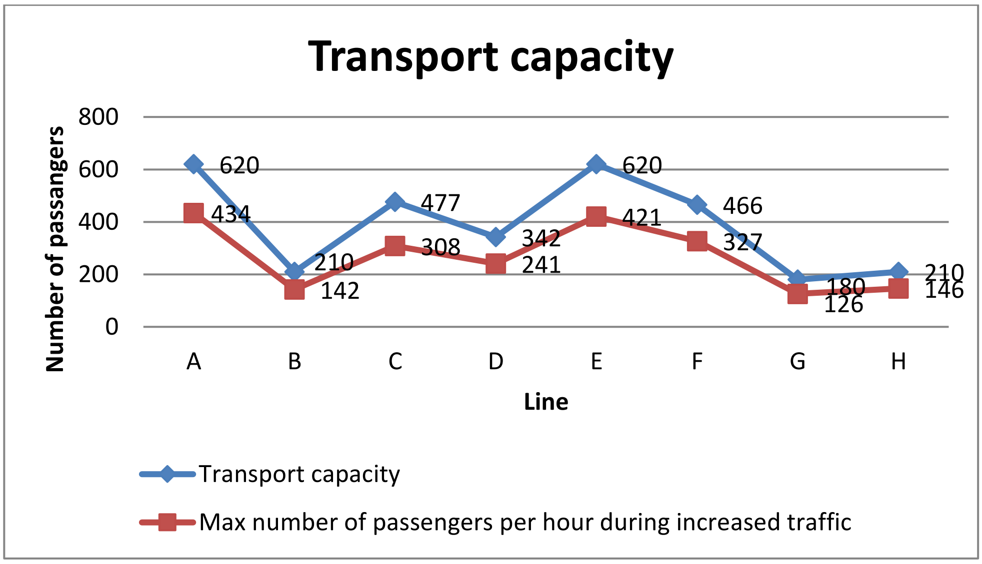


Fig. 12. Transport capacity chart

Source: Own elaboration.

After analyzing the chart, it is obvious that the demand for transport services is met. The maximum number of people at peak hours is clearly lower than the capacity of the given means of transport. In addition, on all lines, the maximum number of people using public transport during peak hours does not exceed 70.5% of transport capacity, which may indicate an inappropriate allocation of transport means to the line. It is also connected with the servicing the routes by vehicles with the highest combustion and the largest number of places. After analyzing the above data, a re-allocation of buses to the line will be carried out in order to optimize the amount of fuel burned in order to minimize costs.

5. Optimization

The aim of the optimization is the new allocation of vehicles to the lines, in a way that minimizes the amount of fuel burned, while maintaining the transport capacity. The Solver in an Excel spreadsheet will be a tool used to solve the problem. It will help to find the optimal solution, the objective function in the model will be the sum of the products of the number of vehicle types and the number of litters of fuel consumed on a given route by a given vehicle. To support the line by more than one vehicle type, combustion on each line in the objective function is divided by the number of vehicles per line. This division makes it possible to check the fuel consumption of one vehicle passing the part of the route, which is presented in the table No. 6.

Tab. 6. The amount of fuel burned by one vehicle

	Vehicle				
Line	Solaris 8,9	Mercedes C	Solaris 12	Mercedes C G	MAN
A	84,86	137,09	150,14	176,26	143,62
B	162,60	262,67	287,68	337,72	275,18
C	95,81	154,77	169,51	198,99	162,14
D	117,67	190,09	208,19	244,40	199,14
E	102,04	164,84	180,54	211,94	172,69
F	43,10	69,62	76,25	89,51	72,93
G	124,28	200,76	219,88	258,12	210,32
H	121,73	196,64	215,37	252,83	206,01

Source: Own elaboration.

The objective function in the above problem takes the form of a formula (J. Oziomek, A. Rogowski, 2016, pp. 44-45):

$$\sum_{i=1}^{5}\sum_{j=1}^{8} c_{ij} \cdot x_{ij} \rightarrow min \qquad (1)$$

where:

c_{ij} – variable which determines the part of the fuel burnt by i - vehicle on j – route

x_{ij} – variable determining the number of i - vehicles and on the j - route, $x_{ij} \in \mathrm{C}$

The exact objective function takes the value with the respective assumptions (2):

$$\begin{aligned} FC = {} & 84{,}86x_{11} + 137{,}09x_{21} + 150{,}14x_{31} + 176{,}26x_{41} + 143{,}62x_{51} + 162{,}60x_{12} \\ & + 262{,}67x_{22} + 287{,}68x_{32} + 337{,}72x_{42} + 275{,}18x_{52} + 95{,}81x_{13} \\ & + 154{,}77x_{23} + 169{,}51x_{33} + 198{,}99x_{43} + 162{,}14x_{53} + 117{,}67x_{14} \\ & + 190{,}09x_{24} + 208{,}19x_{34} + 244{,}4x_{44} + 199{,}14x_{54} + 102{,}04x_{15} \\ & + 164{,}84x_{25} + 180{,}54x_{35} + 211{,}94x_{45} + 172{,}69x_{55} + 43{,}1x_{16} + 69{,}62x_{26} \\ & + 76{,}25x_{36} + 89{,}51x_{46} + 72{,}93x_{56} + 124{,}28x_{17} + 200{,}76x_{27} + 219{,}88x_{37} \\ & + 258{,}12x_{47} + 210{,}32x_{57} + 121{,}73x_{18} + 196{,}64x_{28} + 215{,}37x_{38} \\ & + 252{,}83x_{48} + 206{,}01x_{58} \rightarrow \mathrm{min} \qquad (2) \end{aligned}$$

The assumptions for optimization result mainly from the number of available vehicles for the implementation of zonal trips, the number of vehicles needed to maintain the frequency of running and meeting required capacity. The conditions resulting from the number of vehicles available are described by inequalities (3 - 7):

$$\sum_{j=1}^{8} x_{1j} \leq 6 \qquad (3)$$

$$\sum_{j=1}^{8} x_{2j} \leq 4 \qquad (4)$$

$$\sum_{j=1}^{8} x_{3j} \leq 6 \qquad (5)$$

$$\sum_{j=1}^{8} x_{4j} \leq 18 \qquad (6)$$

$$\sum_{j=1}^{8} x_{5j} \leq 3 \qquad (7)$$

The conditions resulting from the number of vehicles needed to maintain the running frequency are described by equations (8-15):

$$\sum_{i=1}^{5} x_{i1} = 5 \tag{8}$$

$$\sum_{i=1}^{5} x_{i2} = 2 \tag{9}$$

$$\sum_{i=1}^{5} x_{i3} = 4 \tag{10}$$

$$\sum_{i=1}^{5} x_{i4} = 3 \tag{11}$$

$$\sum_{i=1}^{5} x_{i5} = 5 \tag{12}$$

$$\sum_{i=1}^{5} x_{i6} = 4 \tag{13}$$

$$\sum_{i=1}^{5} x_{i7} = 2 \tag{14}$$

$$\sum_{i=1}^{5} x_{i8} = 2 \tag{15}$$

where:

$$j = \begin{cases} 1 \; dla \; linii \; A \\ 2 \; dla \; linii \; B \\ 3 \; dla \; linii \; C \\ 4 \; dla \; linii \; D \\ 5 \; dla \; linii \; E \\ 6 \; dla \; linii \; F \\ 7 \; dla \; linii \; G \\ 8 \; dla \; linii \; H \end{cases}$$

The conditions of fulfilling the transport capacity on each line are shown by inequalities (16 - 23), the values from the right side of the equation are presented in Chart No. 3:

$$\sum_{\substack{i=1 \\ n=1}}^{5} x_{i1} \cdot k_n > 434 \tag{16}$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i2} \cdot k_n > 142 \quad (17)$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i3} \cdot k_n > 308 \quad (18)$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i4} \cdot k_n > 241 \quad (19)$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i5} \cdot k_n > 421 \quad (20$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i6} \cdot k_n > 327 \quad (21)$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i7} \cdot k_n > 126 \quad (22)$$

$$\sum_{\substack{i=1\\n=1}}^{5} x_{i8} \cdot k_n > 146 \quad (23)$$

where:

k_n – capacity of vehicle; n – type/brand of vehicle, n = 1,2,3,4,5;

$$n = \begin{cases} 1\ for\ vehicle\ Solaris\ 8{,}9\ LE \\ 2\ for\ vehicle\ Mercedes - Benz\ Contecto \\ 3\ for\ vehicle\ Solaris\ 12 \\ 4\ for\ vehicle\ Mercedes - Benz\ Contecto\ G \\ 5\ for\ vehicle\ \ MAN\ NL\ 263 \end{cases}$$

In addition, an integerity condition was imposed on the cells that are changed. All conditions have been established in order to achieve the desired effect, which will be minimizing fuel consumption in zonal trips. All assumptions are presented in the table No. 7.

Tab. 7. Requirements for optimization

Line	Vehicle					Required transport capacity [p/h]	Required number of vehicles
	Solaris 8,9	Mercedes C	Solaris 12	Solaris C G	Man		
A	x11	x21	x31	x41	x51	434	5
B	x12	x22	x32	x42	x52	142	2
C	x13	x23	x33	x43	x53	308	4
D	x14	x24	x34	x44	x54	241	3
E	x15	x25	x35	x45	x55	421	5
F	x16	x26	x36	x46	x56	327	4
G	x17	x27	x37	x47	x57	126	2
H	x18	x28	x38	x48	x58	146	2
Number of available vehicles	6	4	6	18	3		
Vehicle capacity	60	94	105	124	90		

Source: Own elaboration.

The Solver addition after the optimization, in places with the x sign, will introduce the appropriate numbers that minimize the objective function. After optimizing process by Solver, the visible effects are presented in the table No. 8.

Tab. 8. Change of rolling stock after Solver optimization

Before optimization					
Line	Vehicle				
	Solaris 8,9	Mercedes C	Solaris 12	Mercedes C G	MAN
A				5	
B			2		
C			1	3	
D		1		2	
E				5	
F		1		3	
G					2
H			2		
After optimization					
Line	Vehicle				
	Solaris 8,9	Mercedes C	Solaris 12	Mercedes C G	MAN
A			1	4	
B	1	1			
C	1		3		
D	1	1			1
E	1		2		2
F				4	
G	1	1			
H	1	1			

Source: Own elaboration.

The lower part of the table 8 shows the new assignment of vehicles to the lines. A noticeable change is visible, and above all a smaller share of Mercedes-Benz Conecto G vehicles for Solaris 8.9 LE vehicles. In the initial state, 5 lines were operated by the same type of vehicle, after optimization only F-line is served by one type of vehicles, while the other ones are operated by buses of different brands. The new assignment provides greater share of service by vehicles with lower fuel consumption but also lower capacity. Furthermore, it can be seen that the conditions regarding the available and needed number of vehicles have been preserved. The results of maintaining the required transport capacity are shown in Figure No. 13.

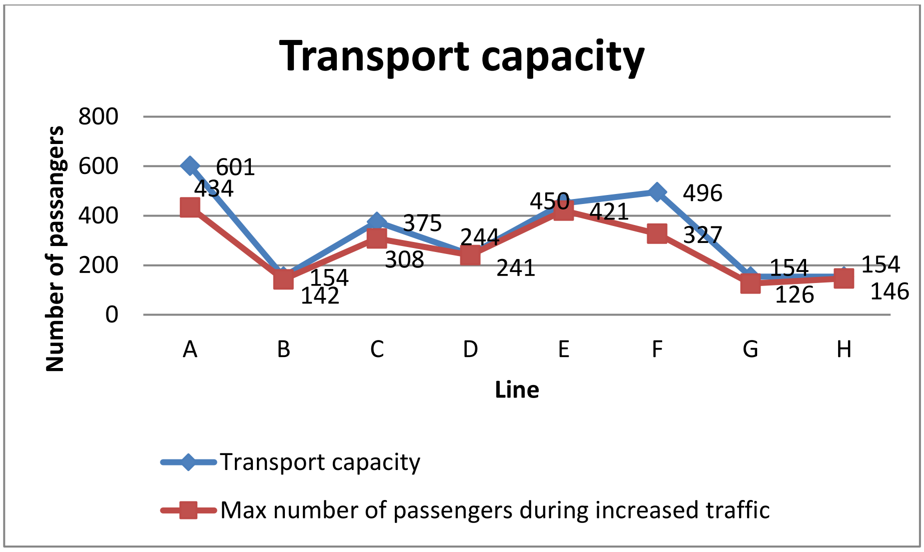


Fig. 13. Transport capacity chart after optimization
Source: Own elaboration

The figure No. 13 shows the noticeable capacity change in relation to the situation before optimization. Although in the current situation the lines are operated by vehicles with lower transport capacity all f them are able to handle demand during hours of increased traffic.

The change in fuel consumption on each line is shown in table No. 9.

Tab. 9. Fuel consumption on a given line

Line	Average fuel consumption before optimization [l/km]	Average fuel consumption after optimization [l/km]	Difference[l/km]
A	0,54	0,52	0,02
B	0,46	0,34	0,12
C	0,52	0,41	0,12
D	0,50	0,37	0,13
E	0,54	0,41	0,13
F	0,51	0,54	-0,03
G	0,44	0,34	0,10
H	0,46	0,34	0,12

Source: Own elaboration.

Optimization on almost all lines has significantly reduced average fuel consumption, except for the F line, where has increased the number of vehicles with a higher standard of combustion.

The objective function after optimization has been set to 4201.63, which is equivalent to the total amount of fuel burned in zonal lines. This value is 18.4% lower than the value of fuel consumption before optimization. The comparison of values is presented in the table No. 10.

Tab. 10. Comparison of the number of liters of fuel consumption

	Zonal lines		
	Before optimization	After optimization	Difference
The amount of fuel per day [l]	5151,23	4201,63	949,6
Average fuel consumption [l/km]	0,5	0,41	0,09

Source: Own elaboration.

The change of vehicles servicing particular lines significantly influenced the minimization of fuel consumption, the results are presented in the table above. The daily amount of liters of fuel saved is less than 950. Assuming a fuel price of 4.2 PLN, the amount for minimizing its consumption reaches approx. PLN 3,986 per day. Taking into account the above assumption and costs of fuel consumption, the price of vehicle-kilometer after optimization is presented in the table No. 11.

Tab. 11. Comparison of fuel consumption costs and vehicle-kilometres

	Before	After
Consumption of materials and energy [PLN]	23 164,05	19 178,05
Price of vehicle-kilometre [PLN / v-k]	6,96	6,54

Source: Own elaboration.

The table shows that the optimization has significantly reduced the daily costs of materials and energy. The assumed fuel price makes it possible to determine the level of savings thanks to which the price of the vehicle-kilometer is reduced by PLN 0.42.

SUMMARY

The aim of the paper was realized, an analysis of the functioning of public transport was carried out and using the analytical tools, the possibilities of improving the functioning of the company in the context of transport organization and fleet management were assessed.

The organization of transport is inherently associated with costs, where the largest amount of them is spent on the consumption of materials and energy. Analysis of the selected company showed that zonal trips, dealing with the transport of people on lines connecting more than one zone, were the weakest point in the organization of transport. The cost of vehicle-kilometer calculated for zonal routes was 12.57% higher than the cost of vehicle-kilometer on all lines. In addition, the share of costs of materials and energy consumption in this group was also the largest and amounted to 32.51% of all costs related to zonal trips. After more detailed analysis of zonal trips, a large share of vehicles with high fuel consumption and large capacity in terms of the number of people is noticeable. The characteristics of demand fulfillment shows that even at rush hour the filling of vehicles did not exceed 3/4 of the transport capacity.

The optimization using the Excel spreadsheet and the Solver add-in resulted in the expected effect. There has been a big change in the use of rolling stock on individual lines. The number of used vehicles with less capacity and fuel consumption has increased. Almost on every line, except for the F line, there was a decrease in fuel consumption. Despite the change in the size of vehicles, required transport capacity has been preserved. The daily number of saved liters of fuel is nearly 949.6, where the savings on this account at a fuel price of PLN 4.2 / l reach PLN 3,986. This allows to reduce the price of vehicle-kilometer in this zone by PLN 0.42.

Many factors influence the functioning of urban transport, the type of rolling stock and its capacity, frequency of running, demand etc. A very important element are the parameters of the vehicle, among others, fuel consumption, which largely influences the total costs, and the size and capacity of the bus affect the transport capability. This means that the choice of vehicles should be optimized both in terms of transport capacity to meet the transport needs of users and in terms of minimizing the costs of combustion, what has a positive impact on the company's finances. The requirements set by the organizer on the given routes and the adaptation of the vehicle's driving capabilities to the planned route are also important. Most costs are due to fuel consumption, which is why changes in its area are cost-effective. The changes introduced after optimization can contribute to large savings.. However, it should be remembered that due to various factors determining the functioning of transport, it should be constantly monitored and changes adapted to urban needs. The constantly changing demand due to the conditions of city life, the intensity of traffic, events on the road make it difficult to make decisions about the selection of elements of public transport and its functioning.

LITERATURE:

1. PublicTrans 2010, „Zintegrowany transport publiczny w obsłudze miast i regionów" V Konferencja Naukowo – Techniczna organizowana w ramach XXIV KTP, Instytut Technologi Eksploatacji, Radom 2010
2. Tundys B., *Logistyka miejska. Koncepcje, systemy, rozwiązania*, Difin, Warszawa 2008
3. Stużyńska E., *Funkcjonowanie transportu miejskiego*, Wyższa Szkoła Logistyki, Poznań 2009
4. Tundys B., *Logistyka miejska*, Difin, Warszawa 2008
5. Tundys B., *Logistyka miejska. Teoria i praktyka*, Difin, Warszawa 2013
6. Walker J., *Human Transit. How clearer thinking about public transport can enrich our communities and our lives*, IslandPress, Washington 2011
7. Wyszomirski O., *Transport miejski. Ekonomika i organizacja*, Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk 2008

8. Grzelakowski A., *System transportowy jako przedmiot regulacji. Aspekty metodologiczne*, Prace Wydziału Nawigacyjnego Akademii Morskiej w Gdyni, nr 24/2010.

9. Kosobucki Ł., *Popyt na przewozy jako determinanta wielkości taboru obsługującego autobusowe linie komunikacyjne*, Studia Ekonomiczne. Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, nr. 143/2013

10. Oziomek J., A. Rogowski, *Zagadnienia synchronizacji linii komunikacyjnych w transporcie publicznym*, Logistyka nr 1-2/2016