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MULTIPLE CRITERIA ASSESSMENT OF A NEW TRAM LINE DEVELOPMENT SCENARIO IN VILNIUS CITY PUBLIC TRANSPORT SYSTEM

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Abstract. This paper considers the technological development of an additional network for Vilnius City public transport. Several types of scenarios for the development of Vilnius City tram line were analysed. This paper describes the situation pertaining to Vilnius City transport system as well as the traffic parameters, which are used for a multiple attribute ranking of a tram line development in Vilnius City. The multiple attribute criteria methods have been chosen to perform the ranking of three development scenarios and to estimate the best alternative based on the traffic conditions of Vilnius City. The experts of different decision-making groups have performed the importance analysis of traffic parameters, which were chosen for the assessment of alternative scenarios for the tram line development. The transport system experts were used to determine the relative weights of indicators. Two methods – TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and SAW (Simple Additive Weighting) – were used and compared to determine the best transport development alternative based on traffic parameters. Two multi-criteria methods were applied in this research to perform the ranking of more accurate alternatives and to make the comparison of calculation results.

Keywords: public transport, transportation, multiple criteria analysis, decision support system, public transport modelling, TOPSIS, SAW.

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Introduction

The Special Plan of the Vilnius City analyses opportunities for new transport modes in the public transport system (Burinskienė *et al.* 2012). Most European cities bristle with problems related to unsustainable development of transport systems and traffic congestion. Such transportation policies as the promotion of public transport or mixed-use of transport modes and systems (ex. Park and Ride or Park and Go) require public transport to be more effective and modern (Drobne 2003; Black *et al.* 2002).

A massive increase in the level of motorisation impacts on traffic conditions and increases transportation problems. Many scientific researches analyse public transport development from the point of multi-criteria analysis of a transportation system. Changes in public transport systems and assessment of scenarios for the development of public transport could be based on economic, social and environmental principles (Joumard, Nicolas 2010; Kavaliauskas 2008). Other scientists also describe assessment of the development of a public transport system based on traffic modelling and parameters (López-Neri *et al.* 2010; Fernández 2010).

Vilnius City Municipality considers introducing the new public transport mode into the public transport system. Based exclusively on data regarding traffic conditions, this research performed a multiple criteria assessment of different scenarios pertaining to projects for the development of a new tram line. The aspects of traffic conditions and mobility are also considered by other Lithuanian scientists involved in planning and organisation of public transport as well as effective assessment of new public transport modes and development projects in Vilnius City (Ušpalytė-Vitkūnienė *et al.* 2012).

Multiple criteria methods are used for the assessment of public transport system and different public transport subsystems (Achillas *et al.* 2011). Also, they could be used in assessing different transport infrastruc-

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ture projects (Salling, Banister 2009; Polydoropoulou, Roumboutsos 2009). There is a wide range of methods based on multiple criteria utility theory: SAW – Simple Additive Weighting (Ginevičius *et al.* 2008; Sivilevičius *et al.* 2008); TOPSIS – the Technique for Order Preference by Similarity to Ideal Solution (Zavadskas *et al.* 2006); COPRAS – Complex Proportional Assessment (Zavadskas *et al.* 2007); AHP – the Analytic Hierarchy Process (Sivilevičius 2011; Wu *et al.* 2008; Maskeliūnaitė, Sivilevičius 2012; Farhan, Fwa 2009; Aghdaie *et al.* 2012).

The main aim of this work is to involve multiple criteria methods in the assessment and analysis of different transportation projects and to carry out this type of analysis for the Vilnius City transport system and the assessment of scenarios for the development of the new tram line.

1. Data on Vilnius City Transport System

The existing public transport system of Vilnius City has an intensive network operation (304 trips / capita annually) with a large travelled distance (53 km per one person per year) and high social support (the current system of discounts for different social groups); however, it is unable to compete with private cars. Results of the investigation on public transport passenger flows showed a twofold decrease in the average daily number of passengers during the period 1980–2011. Transportation mobility by public transport decreased from 87.6% in 1980 to 39.6% in 2011. Table 1 shows a detail modal split of trips in Vilnius City.

In Vilnius City, buses are the main mode of public transport. The existing public transport and the current organisation system are unable to attract more passengers. This critical situation requires a new stimulus. This stimulus could be created with the help of a new kind of comfortable public transport mode, which would reduce travel time and equipment in Vilnius City public transport system (Burinskienė *et al.* 2012). The annual increase in the number of vehicles in Vilnius City amounts to approximately 3%. Meanwhile, the number of private cars increased from 265 cars per 1000 inhabitants in 1999 to 580 in 2011. A sharp surge in motorisation levels produces numerous transportation problems. In 2008–2011, saturation was reached.

Many scientific researches analyse public transport systems from the point of modal split of passenger trips (Bhatta, Larsen 2011; Habib *et al.* 2009). The tendencies of Vilnius City modal split are demonstrated in Fig. 1.

Table 1. Modal split of trips in Vilnius City by years

Trip mode	1980	1993	2006	2011	2011/1980
On foot	44.1	38.0	34.5	35.5	0.80
By public transport	47.1	49.4	33.1	24.6	0.52
By taxi	2.9	0.1	0.4	0.7	0.2
By train	0.3	0.1	0.4	0.1	0.3
By bicycle	0.1	0.2	0.4	0.6	6.0
By car	5.5	12.2	31.2	38.5	7.0

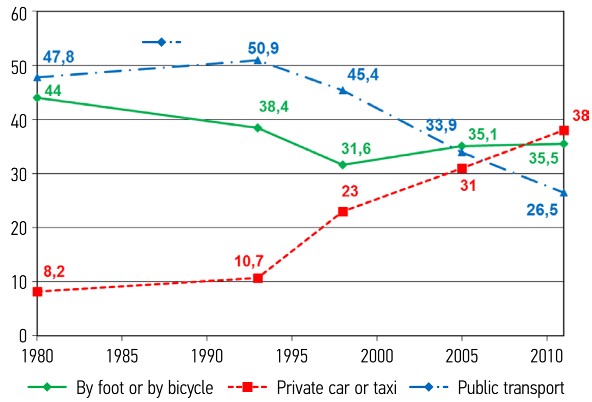

Fig. 1. Tendencies of a modal split of trips in Vilnius City

These tendencies show that the use of public transport in Vilnius City is rapidly decreasing due to growing motorisation levels and the lack of appeal of public transport.

2. Methodology

Data on traffic conditions in the transport system was obtained from modelling results of Vilnius City transport system for 2025. Modelling has been performed for different scenarios of tram line implementation. Modelling results have been taken as input data for a multiple criteria assessment of different tram development scenarios from the point of view of transport system functionality. The steps of the methodology for assessment of scenarios are presented in Fig. 2.

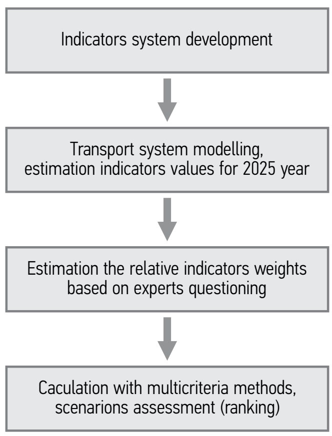

Fig. 2. Steps of scenario assessment

The steps of assessment present a modelling workflow, which consists of preparation and calculations of necessary input data based on multiple criteria methods.

2.1. Indicators

In order to perform the assessment of three different public transport development scenarios based on multiple criteria methods, it is necessary to create a system of indicators. An indicator is a quantitative or qualitative parameter that can be assessed in relation to a criterion. Also, an indicator could be measured, estimated and evaluated.

Below, all possible indicators are listed for the integration of new tram lines into the public transport system:

- travelled distance in 1 hour during the morning peak (km);
- average flow speed (km/h);
- trip duration (hour/peak hours);
- average one trip duration;
- average number of trips;
- average one trip distance (km).

The above indicators were calculated using the PTV VISUM (*http://vision-traffic.ptvgroup.com*) software for traffic modelling. The present transport model of Vilnius City was used and three alternatives of tram line development were modelled. The calculated values of indicators were the main parameters of traffic conditions describing the efficiency of the transport system; besides, they were very important for assessment of scenarios for tram line development based on traffic conditions.

2.2. Results of Transport System Modelling and Scenario Development

Values for transport system indicators were obtained from the modelling results of Vilnius City transport system. Several types of development scenarios for Vilnius City public transport were modelled:

- to build a new tram line 'Santariškės –Stotis [Railway Station]';
- two tram lines, the second runs through Žalgirio Street;
- two tram lines, the second runs through Konstitucijos avenue (Table 4).

This research does not take into consideration the cost of tram line equipment. The assessment was carried out from the point of view of functionality of Vilnius City transport system. The modelling was performed for the morning peak in 2025 taking into account the following circumstances: Vilnius City transport infrastructure is developed according to the Master Plan; social data 2025 – the number of inhabitants increases to 600000 and a rough number of workplaces is 426000; car ownership 2025 – due to economic growth, the car ownership increases rapidly to 590 cars per 1000 inhabitants.

The research looks into alternatives of tram line integration into Vilnius City public transport system. Below, the alternatives that were evaluated and ranked based on SAW and TOPSIS methods are described (Zavadskas *et al.* 2001).

Alternative No. 0. Vilnius City public transport system uses the existing public transport network (buses and trolleybuses). Alternative No. 0 was analysed in order to compare the different public transport passenger flows with the equipped tram lines or without a new mode of public transport in Vilnius City. This option considers the adjustment of the public transport system according to developmental trends of the Vilnius City transport system, population and employment redistribution based on the Master Plan of the Vilnius City.

Alternative No. 1. This scenario presents the equipment of one tram line 'Santariškės–Stotis [Railway Station]'. The line runs through Kalvarijų–Vilniaus–Jogailos–Pylimo–Sodų streets (Fig. 3). The existing bus and trolleybus routes are modified in order to avoid duplication with the tram line and complete cross-serviced passenger delivery to tram line function. The main connections to bus and trolleybus routes are located in Ateities, Šiaurinė, Ozo streets, Konstitucijos avenue and A. Goštauto street. Those junctions are the main public transport connection points to/from the tram route. On the entire tram line, large passenger flows are expected.

Alternative No. 2. This alternative has two tram lines. The first tram line coincides with the previous alternative. The second tram line runs through Ukmergės–Žalgirio–Kalvarijų streets and duplicates the first tram line up to the stop 'Stotis [Railway Station]' (Fig. 3).

Alternative No. 3. This alternative is very similar to the Alternative No. 2. The second tram line starts at Ukmergės street, runs through the end of Konstitucijos avenue and continues as the second duplicated tram line running through Kalvarijų street to the Railway Station (Fig. 3). According to the modelling results of passenger traffic flows, the third alternative is more rational and functional than the Alternative No. 2. The passenger traffic flows at the end of the tram line are higher as well as in the entire tram route.

The second tram line has the greatest passenger flow at Ukmergės street stop in Šeškinė. The tram line carries approximately 76% of passengers (5370 passengers using that section). The first tram line takes a lot of passengers going in this direction. At the stops Žaliasis Tiltas [Green Bridge] and Baltupiai, the passenger flow amounts to approximately 500 passengers per hour using other public transport routes.

The transfer of tram lines, buses and trolleybuses on Laisvės avenue becomes very important. Also, the transfer is very important at Gedimino stop, where the total number of passenger flow reaches 5000 passengers per hour.

Passenger traffic flows for all alternatives are presented in Table 2.

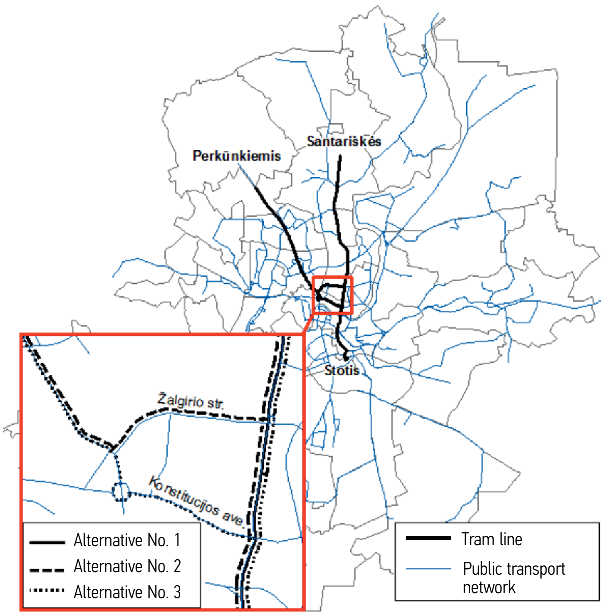

Fig. 3. Illustration of alternatives

Table 2. Passenger flows at stops of tram line route

Alternative	Passenger flows in a peak hour (passengers/hour) in the stops of the route Total (incoming/outgoing)					
	Santariškės	Perkūnkiemis	Ukmergės–Žalgirio	Konstitucijos–Kalvarijų	Vilniaus–Gedimino	Stotis [Railway Station]
No. 1	1288 (881/407)	no station	no station	6521 (5031/1490)	6651 (5060/1591)	3567 (1952/1615)
No. 2	1288 (881/407)	587 (484/103)	3937 (3255/682)	8141 (6191/1950)	7666 (5589/2077)	4309 (2401/1908)
No. 3	1288 (881/407)	687 (562/125)	5391 (4769/622)	9575 (7384/2191)	8569 (6377/2192)	4678 (2747/1931)

2.3. Assessment of Indicator Importance

The importance of each indicator was estimated through interviews with 25 experts of transportation system.

Table 3 shows the results of expert interviews. The lowest value means that the indicator is the most important; meanwhile, the highest value means that the indicator is the least important (Zavadskas *et al.* 2001).

Table 3. Results (ranks) of expert interviews

Experts	Indicators					
	*R*1	*R*2	*R*3	*R*4	*R*5	*R*6
*E*1	1	2	3	4	5	6
*E*2	2	1	3	4	5	6
*E*3	1	2	4	3	6	5
*E*4	1	3	2	4	5	6
*E*5	1	2	3	4	6	5
*E*6	3	2	1	4	6	5
*E*7	1	2	3	4	6	5
*E*8	1	3	2	4	5	6
*E*9	2	1	4	3	6	5
*E*10	1	2	3	4	6	5
*E*11	2	1	3	4	6	5
*E*12	1	2	4	3	5	6
*E*13	2	5	3	4	6	1
*E*14	1	5	4	3	6	2
*E*15	1	4	3	2	6	5
*E*16	2	1	3	4	6	5
*E*17	1	2	3	6	4	5
*E*18	2	1	3	4	6	5
*E*19	1	2	5	4	6	3
*E*20	4	3	2	1	6	5
*E*21	1	2	3	4	6	5
*E*22	1	3	2	4	6	5
*E*23	1	2	3	4	6	5
*E*24	2	1	3	6	4	5
*E*25	1	2	3	4	5	6
t_{sum}	37	56	75	95	140	122
t_{avg}	1.48	2.24	3	3.8	5.6	4.88

The total sum of all expert interview results for all indicators:

$t_{sum,T} = 525.$

The total average of all expert interview results for all indicators:

$t_{avg,T} = 21.$

Table 4 presents the transport system modelling for several types of alternatives for the development of Vilnius City public transport. Alternatives have been described in Chapter 2.2.

Below, the calculations of the importance of indicators are presented:

1) Calculation of the importance of subjective indicators (weight):

$$q_i = \frac{\underline{q}_i}{\sum_{i=1}^{n} \underline{q}_i}, \tag{1}$$

where: q_i – the importance of the i-th indicator; $\underline{q}_i$ – the expert score of the i-th indicator; $\sum_{i=1}^{n} \underline{q}_i$ – the sum of expert evaluation scores for the i-th indicator.

The weights could also be estimated based on a more sensitive methodology.

2) Calculation of indicator set of sum-square:

$$S = \sum_{i=1}^{n} \left(\sum_{j=1}^{l} r_{ij} - \frac{1}{n} \cdot \sum_{i=1}^{n} \sum_{j=1}^{l} r_{ij} \right)^2 = 7701.5, \tag{2}$$

where: S – results of indicator valuation deviation of sum-square; r_{ij} – experts j valuating rank for the i-th indicator; l – number of experts; n – number of indicators in indicator set.

3) Estimation of the coefficient of concordance (Kendall, Gibbons 1990):

$$W = \frac{12 \cdot S}{l^2 \cdot \left(n^3 - n\right)} = 0.704. \tag{3}$$

4) Calculation of the actual chi-square (χ^2):

$$\chi^2 = \frac{12 \cdot S}{l \cdot n \cdot \left(n+1\right)} = 88.02. \tag{4}$$

Table 4. Modelling results of Vilnius City transport system

No	Indicator	Present values	Alternatives			Function
			No. 1	No. 2	No. 3	
*R*1	Travelled distance per 1 hour during the morning peak (km)	872545	740735	720605	710022	min
*R*2	Average flow speed (km/h)	35.24	37.82	45.56	46.87	max
*R*3	Trip duration (hour/peak hours)	25274	19619	11504	12860	min
*R*4	Average one trip duration (min.)	21.06	19.18	15.14	15.42	min
*R*5	Average number of trips	72017	61382	50012	49601	min
*R*6	Average one trip distance (km)	12.12	12.07	12.01	11.89	min

Table 5. Results of the importance of subjective indicators (weights)

$\underline{q}_i = 1 - g_i$	$g_i = \frac{t_{avg,i}}{\sum_{i=1}^{n} t_{avg,i}}$	Importance/weights (q_i)
$\underline{q}_1 = 0.930$	$g_1 = 0.070$	$q_1 = 0.186$
$\underline{q}_2 = 0.893$	$g_2 = 0.107$	$q_2 = 0.179$
$\underline{q}_3 = 0.857$	$g_3 = 0.143$	$q_3 = 0.171$
$\underline{q}_4 = 0.819$	$g_4 = 0.181$	$q_4 = 0.164$
$\underline{q}_5 = 0.733$	$g_5 = 0.267$	$q_5 = 0.147$
$\underline{q}_6 = 0.768$	$g_6 = 0.232$	$q_6 = 0.154$

Expert interview validation:

- $W > 0$, $W = 0.704 > 0$;
- $\chi^2 > \chi^2_{TABLE}$, $88.02 > 15.09$ ($\chi^2_{TABLE} = 15.09$, when the variance is $v = n-1 = 6-1 = 5$ and significance level $\alpha = 0.01$).

Validation results show that expert interview results presented in Table 3 are compatible.

2.4. Scenario Assessment Approaches

The methods SAW and TOPSIS were used for ranking public transport development scenarios and evaluating the alternatives of tram line development projects.

2.4.1. The SAW Method

The indicators and their values of importance were used as input data for calculations (Tables 4 and 5).

Indicator matrix is normalised according to the following conditions:

If indicator is minimized: $$\underline{X}_{ij} = \frac{X_j^{\min}}{X_{ij}}, \quad (5)$$

where: X_{ij} – the value of the i-th indicator for the j-th alternative; X_j^{min} – the smallest i-th indicator value for all the alternatives compared; $\underline{X}_{ij}$ – denotes the converted values. Thus, the smallest indicator value $X_{ij} = X_j^{\min}$ acquires the largest value equal to unity.

If indicator is maximised: $$\underline{X}_{ij} = \frac{X_{ij}}{X_j^{\max}}, \quad (6)$$

where: X_j^{max} – the largest value of the i-th indicator.

A normalised matrix for each indicator of the current public transport development scenario is multiplied by its importance (Table 6). The multiplied indicators are summed up at each row (alternative). The largest value means the highest rank of a public transport development scenario (Zavadskas *et al.* 2001).

Table 6 shows the normalised indicator matrix calculated according to the formulas (5 and 6).

Table 6. Normalised indicator matrix for the SAW calculation

	Normalized indicators for the SAW method					
Alternative	*R*1	*R*2	*R*3	*R*4	*R*5	*R*6
No. 1	0.959	0.807	0.586	0.789	0.808	0.985
No. 2	0.985	0.972	1.000	1.000	0.992	0.990
No. 3	1.000	1.000	0.895	0.982	1.000	1.000

2.4.2. The TOPSIS Method:

1) Indicator matrix is normalised by the following formula:

$$X_{ij} = \frac{\underline{X}_{ij}}{\sqrt{\sum_{j=1}^{n} \underline{X}_{ij}^2}}, \text{ for } i = 1, \ldots, m; j = 1, \ldots, n, \quad (7)$$

where: X_{ij} – the normalised j-th indicator of the i-th alternative; $\underline{X}_{ij}$ – the concrete value of the j-th indicator of the i-th alternative; m – the number of alternatives and n – the number of indicators.

2) Indicator matrix is multiplied by the matrix of importance values:

$$P^* = [X] \cdot [q]. \quad (8)$$

3) The normalised matrix is used for determination of the best alternative L_j^+ and the worst alternative L_j^-. Calculation of deviation of an alternative from the ideal positive alternative is based on:

$$L_j^+ = \sqrt{\sum_{i=1}^{n} \left(f_{ij} - f_j^+ \right)^2}, \quad (9)$$

where: L_j^+ – the best alternative of the j-th indicator; f_{ij} – the normalised concrete value of the j-th indicator of the i-th alternative; f_j^+ – the largest value of the normalised j-th indicator (ideal positive alternative); n – the number of indicators.

4) Calculation of deviation of an alternative from the negative alternative:

$$L_j^- = \sqrt{\sum_{i=1}^{n} \left(f_{ij} - f_j^- \right)^2}, \qquad (10)$$

where: L_j^- – the worst alternative of the j-th indicator; f_j^- – the smallest value of the normalized j-th indicator (ideal negative alternative).

If the indicator is minimised, it is necessary to take the minimal value from each row. If the indicator is maximised, the maximal value is taken from each row.

5) Calculation of deviation of the proportional alternative from the ideal alternative K_{BIT}:

$$K_{BIT} = \frac{L_j^+}{L_j^+ + L_j^-}; \qquad (11)$$

According to the analysed indicators, the best alternative scenario for the development of Vilnius City public transport system is the one with the highest K_{BIT} value.

According to the (7) formula, the indicator matrix was normalised (Table 7).

Table 7. Normalised indicator matrix for the TOPSIS calculation

	Normalised indicators for the TOPSIS method					
Alternative	*R*1	*R*2	*R*3	*R*4	*R*5	*R*6
No. 1	0.591	0.501	0.751	0.664	0.657	0.581
No. 2	0.575	0.603	0.440	0.524	0.535	0.578
No. 3	0.566	0.621	0.492	0.534	0.531	0.573

This matrix (Table 7) was multiplied by the matrix of importance values q:

$$P^* = \begin{bmatrix} 0.591 & 0.501 & 0.751 & 0.664 & 0.657 & 0.581 \\ 0.575 & 0.603 & 0.440 & 0.524 & 0.535 & 0.578 \\ 0.566 & 0.621 & 0.492 & 0.534 & 0.531 & 0.573 \end{bmatrix} \times$$

$$\begin{bmatrix} 0.186 & 0.179 & 0.171 & 0.164 & 0.147 & 0.154 \end{bmatrix} =$$

$$\begin{bmatrix} 0.110 & 0.090 & 0.128 & 0.109 & 0.097 & 0.090 \\ 0.107 & 0.108 & 0.075 & 0.086 & 0.079 & 0.089 \\ 0.105 & 0.111 & 0.084 & 0.088 & 0.078 & 0.088 \end{bmatrix}.$$

The normalised matrix is used for calculating the ideal positive f_j^+ and negative f_j^- alternatives:

$$f_j^+ = \left\{ 0.110\ 0.111\ 0.128\ 0.109\ 0.097\ 0.090 \right\};$$

$$f_j^- = \left\{ 0.105\ 0.090\ 0.075\ 0.086\ 0.078\ 0.088 \right\}.$$

Calculation results according to the formulas (9, 10) for deviation of all alternatives from the negative and positive alternatives are presented in Table 8.

$$K_{BIT,\text{No. 1}} = \frac{0.021}{0.021 + 0.061} = 0.259;$$

$$K_{BIT,\text{No. 2}} = \frac{0.061}{0.061 + 0.018} = 0.769;$$

Table 8. Calculation results for deviation of TOPSIS alternatives

	Alternative		
	No. 1	No. 2	No. 3
L^+	0.021	0.061	0.053
L^-	0.061	0.018	0.023

$$K_{BIT,\text{No. 3}} = \frac{0.053}{0.053 + 0.023} = 0.695.$$

The best alternative of tram line development in Vilnius City public transport system is the one with the highest K_{BIT} value.

3. Calculation Results and Discussion

The multi-criteria methods showed the same results as ranking of the tram line development scenarios (alternatives).

The most attractive alternative is Alternative No. 2; based on the multiple criteria calculation methods, the second place can be awarded to the Alternative No. 3, and Alternative No. 1 seems to be the least appealing.

The multiple criteria research of scenarios for the development of a tram service in the Vilnius City public transport system showed that the best solution from the point of functionality of the transport system is to have two tram lines (Alternative No. 2): the first – 'Santariškės–Stotis [Railway Station]' and the second – through Žalgirio street. Two multiple criteria methods showed the same ranking of public transport development alternatives.

Based on modelling results of the Vilnius City transport system the Alternative No. 2 has the best results in decreasing the total trip duration by approximately 54%, i.e. from 25274 to 11504 hours during the peak period; also, this alternative has the best modelling results for the average one trip duration, which decreases by approximately 28%. The Alternative No. 3 (two tram lines with the second one running through Konstitucijos avenue) has the best modelling results for the average flow speed, which increases by 33% up to 46.87 km/h and this alternative has the least travelled distance per 1 hour in the morning peak hours amounting to 710022 km.

The assessment of tram line development scenario in Vilnius City shows that the Alternative No. 3 has a high ranking as well and the ranking results are almost the same as for the Alternative No. 2. The main advantage of the Alternative No. 2 over the Alternative No. 3 is that Konstitucijos avenue has well-developed public transport routes that provide perfect connection of Ukmergės and Kalvarijų streets. In this case, the tram line is not as necessary in the mentioned section as on Žalgirio street.

Conclusion

1. The analysis of scenarios for the development of Vilnius City public transport system demonstrated that the multiple criteria methods are suitable for the as-

sessment of developmental projects related to the public transport system. The multiple criteria methods could be successfully used in the strategic planning of the Vilnius City public transport system to select the best alternative.
2. The multiple criteria methods are flexible and could be successfully adopted for the validation of public transport system modelling results and the reasoning of transport system development scenarios. Also, the integration of multiple criteria methods into the transport system modelling could be successfully applied for investigating transportation problems in other cities.
3. The future research of scenarios for the development of Vilnius City public transport system could not only take into account the indicators presenting the traffic condition data but also involve the indicators from the economic, social and environmental groups that would carry out a more complete assessment.

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