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EVALUATION OF PARK AND RIDE FACILITIES AT COMMUNICATION CORRIDORS IN A MIDDLE-SIZED CITY

Abstract. *Rapid rise in car ownership in cities of Lithuania, particularly in capital Vilnius, has multiplied continuous traffic jams in the streets of the city and thus increased necessity of development of effective urban solutions designated for optimising transportation in urban areas and reducing negative transport effects. In order to lay down foundation for building a successful remedy Vilnius city municipality administration is planning to submit an application to receiving financial support for the implementation of the Park-and-Ride (hereinafter P&R) scheme for Vilnius within the framework of the European Union (hereinafter EU) Structural Assistance for the period 2014-2020. Multiple criteria decision-making methodology for selecting beneficial sites of P&R lots and for outlining desirable directions of development of the city of Vilnius with incorporated P&R facilities was employed in the paper. The methodology uses a set of descriptive criteria for planning the P&R scheme; expert evaluation was used for estimation of weights of significance of the chosen criteria.*

Keywords: *multiple criteria methods; P&R scheme; planning urban infrastructure; public transport.*

JEL Classification:C02; C30; D70; O18; Q01; R42; R52

1. Introduction

Urban transport system is considered to be the most substantial subsystem of an urban environment; (Gioffre et al. 2016). Sustainable and effective activities of transport system are both creating a substantial value by supplying services for city dwellers, and also serve as a prerequisite for successful development of other sectors of economics within the city. However, magnitude of available investment is a significant constraint for development of transport infrastructure and high level of automobilisation creates new big challenges for territorial planning of a city. Dealing with individual cars became one of the most complex problems related to urban transport system development (Borken-Kleefeld et al. 2015).Parking of constantly increasing number of individual cars creates impetus for extensive and intensive exploitation of urbanised areas, while the land in cities is always being scarce. P&R is a logical solution for such a problem as it allows keeping cars in separate urban areas. Consequently, such a view suggests that anthropogenic environment of urban transport system and its functioning capabilities are ought to be fully analysed in view of installing a new extensive P&R system.

In the article Authors have investigated an urbanised area of a medium-sized city, which is situated within 25 km radius from its centre with population ranging from 500 thousand to 1 million residents.

Initial ideas of using passenger cars combined together with public transport were raised in the first half of the twentieth century. Such an attitude could develop because of prevailing lobbying policy stimulating growth of quantity of passenger cars. As a consequence, infrastructure of urban transport system became saturated (Koryagin et al. 2016), which disconcerted performance of public transport, reduced communication capabilities of city dwellers (Bellido et al. 2015). Initial attempts of integrating P&R systems into cities failed. Nevertheless, scientific investigation of such systems extensively continued.

2. Literature review

The scientific literature on P&R systems reveals that even if researchers mostly have similar aims, their scientific findings and areas of investigation differ. The research could be classified into the following three groups. The first group contains research based on the ideas, concepts and territorial planning principles; the second one is based on empirical and field physical investigations; and the third one – on theoretical and mathematical models.

Analysis of the literature within the first research group brought forward the following categorisation of P&R concepts. Six concepts of systems could be distinguished: Current, Demand-led, Integrated, Hub-and-Spoke, Remote site, Link and Ride concepts (Mingardo2013). The concepts of the beneficial purpose of P&R parking lots can be distinguished: exclusive park and rides that are planned and designed specifically to service transit function for city dwellers; and a shared facility where parking is offered by shopping centres, education centres, sports venues, etc., in a very close proximity to a transit interchange point. The latter may officially or unofficially operate as a park and ride parking lot (Mock et al. 2015).

In the second research group scientists focus primarily on location of the existing P&R parking lots, on their position within the territory of the city, on occupancy of parking lots as well as on behaviour of P&R system users. As an illustration could serve the empirical research conducted by British scientists in the city of Bath. The authors derived that 29% of the city dwellers start their trips at the distance of 3.2 km from the city centre, while most of P&R parking lots are located at the distance of 2–6 km from the city centre (Clayton et al. 2014). As a consequence, P&R system infrastructure is poorly developed in the territory of the city.

A similar study revealed that in Rotherham 90% of drivers arrive to the parking lots alone. It was derived that 76.2% of drivers use these parking lots for business purposes, 15.4% for leisure activities and 8.2% for other purposes. (Mingardo2013).This P&R system is not being actively developed because the priority is given to bicycles. However Dutch uses integrated passenger car and public transport ticketing system that allows better travelling prices for the users of P&R parking lots.

In an empirical investigation conducted by U.S. scientists in the city of Charlotte, North Carolina, it was shown that redevelopment of a P&R system reduces the distance covered by one person by car from 15 km to 8 km (Duncan et al. 2014).

Few examples of research based on theoretical and mathematical models can illustrate the third research group. During 2012 a survey of personnel of various institutions was conducted in Beijing.It was discovered that only 13% of respondents use P&R parking lots. The authors of the research proposed to apply the model of Decision Field Theory. The findings help to understand the level of possible sophistication of decision-making strategy of developing park and ride system (Qin et al. 2013).

Moreover Chinese and Australian researchers employed this method to construct a model which is able to save passengers' time and money. The model was practically verified in four chosen P&R parking lots in the Australian city of Perth (Chen et al. 2014).

An interesting method of using mathematical methods for choosing the optimum P&R site in a linear building and two-dimensional city was proposed (Yushimito et al. 2012). Unfortunately, the model was not yet verified in a real setting of a city.

3. Transport – Related Problems in the City of Vilnius

A rather unfavourable situation in the complicated urban development of the city of Vilnius can be found at present, when mono-functional residential, industrial and business districts have expanded separately. This made city dwellers to live far from their work. Referring to the data contained in the General Plan of

Vilnius City (2011) 36.7% of residents lived in the western part of the city, while approximately 30.5% of urban population lived in the central area of the city.

A survey of citizens was conducted within the framework of the Special plan on the *Implementation of New Transport Modes in the City of Vilnius*approved by Vilnius City Municipality in 2011(hereinafter Special Plan), which revealed dramatic change in the structure of commuting: the number of trips by car providing more comfort, independence and shorter travelling time considerably increased. Moreover a lack of quality improvement over a long period was a major reason for the constantly reducing number of public transport trips.

The current level of automobilisation in the city of Vilnius is around 569 cars per 1000 one city dweller. In comparison with other European cities it is rather high; this creates an impetus for city dwellers to use their own transport ignoring existing modes of public transport. According to the data of the period from 1980 to 2011, the relative part of trips made by car increased 4.7 times, while the relative part of the ones made by public transport decreased by 1.9 times. The average distance travelled by bus in 2011 was 4.2 km, by trolleybus – 3.25 km, and by private bus – 5 km. When comparing the average numbers during the period of 1998–2011 it is clear that the distance covered by public transport (buses and trolleybuses) remained stable, whereas the distance covered by private buses decreased. Such a shift was influenced by urban development in the peripheral areas of the city and migration of Vilnius city dwellers from the city centre to peripheral territories and by their shifting to using their private cars for everyday trips because of dissatisfaction with quality of public transport service including private buses; also deficient social and service infrastructure and distant location of workplaces from the living environment. These factors diminished the number of trips on foot and by bicycle by roughly 20%. Comparing the data of the modal split, 38.5% of the population travelled by car; 35.9% on foot and by bicycle; and 25.6% by public transport in 2011. This confirms the fact of increasing transport mobility of whole population and also shows that public transport indicators in Vilnius city greatly outnumber other cities of the EU.

It has become clear that the quality of public transport is far from satisfying dwellers of Vilnius city, and that the city demands innovative solutions to be implemented. The aims of transport system sustainability were incorporated in the adopted General Plan of the City of Vilnius. Such aims are: minimising the need for city dwellers to use motor vehicles to reach their work; enhancing operation of public transport, and granting priority versus the general traffic; promoting bio transport and trips on foot. Imposing priority of movement of public transport compared to individual vehicles helps to attract people to switch to using public transport. Alternative sound measure would be installation of parking lots or bicycle parking stations as connection facilities (terminals)that is a P&R system in urban or suburban areas.

Unfortunately, there had been no purposeful strategy of integrating a P&R system into the city of Vilnius, and such ideas and research commenced to emerge only over the last decade. Such strategic aims of sustainable transport are gradually being set out: regulatory requirements for parking lots were formulated; possibilities of using parking lots near shopping centres and other attraction venues are being analysed; requirements for allocating urban territories into zones were established; possible parking lots were outlined.

In this article both quantitative evaluation the 33 parking lots outlined in the Special plan of development of Vilnius for the period 2025–2040; and quantitative evaluation of 7 communication corridors of the city will be attempted in order to find the most perspective directions of development of the city.

4. Evaluation of Suitability of Projected Parking Lots for Their Incorporation to the P&R System

The main users of urban transport system are city dwellers, who have different mobility needs, depending on their social-demographic characteristics (age, social and property status). Such differences may have influence on the differentiated travel demand. These differences were not identified yet and therefore are excluded from the set of evaluation criteria of parking lots leaving such particularities for future investigations. Criteria of evaluation were categorised into three categories: structure of peripheral and urban territory; demand of communications; and public transport supply.

Urban transport infrastructure planners and decision-makers still have deficient experience of implementing P&R systems. Based on such managerial experience it is yet not possible to identify the most suitable location places for P&R car parking lots. However, some important quantitative indicators are known and can be derived for each particular P&R parking lot (Palevicius et al. 2016). Multiple criteria decision-making methods (MCDM) can use such indicators and serve as a good aid for decision-makers in the circumstances when many conflicting goals have to be met simultaneously and the most reasonable trade-offs must be obtained.

4.1 Setting the Set of Criteria Describing Attractiveness P&R Parking Lots

Multiple criteria decision-making tools imply a certain idea of quantitative evaluation. Based on this idea both criteria and their weights are chosen. 11 criteria were chosen within the categories outlined above keeping in mind the city of Vilnius.

Criteria were chosen based on the following considerations.

R_1 (cost of a land plot for a P&R parking lot and its construction, measure unit (hereinafter – unit) – thous.Eur; direction (hereinafter – dir.) – min). 33 alternative parking lots were chosen based on the assumption that the price of the land plot is acceptable to the municipality and investors. The price of the land plot was taken from the land evaluation map created by SC *Centre of Registers*. Costs of construction of each parking lot were calculated according to the comparative economic indices of constructing large-scale structures.

R_2 (traffic volumes on the street near the planned P&R parking lot; unit – veh/day; dir. – max). An obvious consideration confirmed in the literature was taken into consideration for choosing the criterion. The more intensive is traffic, the stronger becomes the likelihood that car drivers would opt for choosing a P&R parking lot. The numerical value of this factor was determined based on the research carried out in the latest version of the Special plan.

R_3 (the number of public transport routes in the communication corridor; unit – number of routes/ rush h; dir. - max). Density of public transport routes indicates the level of public service in the city. The higher is the density of the routes, the faster the passenger may reach the desired destination. The numerical value of this factor was derived from public transport timetables, which can be found in the website of the local transport provider ME*Susisiekimopaslaugos*.

R_4 (travel speed from the P&R parking lot to the city centre by public transport; unit – km/h; dir. - max). Low driving speed of a public transport vehicle is the main reason why car drivers may give priority to their car rather than to public transport. This factor was determined according to the arrival schedules of public transport from the planned P&R parking lot to the border of the city centre. Distances were measured by the GIS (Jakimavicius et al. 2013).

R_5 (probability of theft from the P&R parking lot; unit – points (1-3); dir. – max). According to the data of 2013, 117.2 thousand of vehicles were CASCO insured in Lithuania. This proves both that probability of theft is considerable in this country, and that car is an important asset for drivers. Level of hazard to cars, an important factor, was evaluated by a three-point system, with 3 indicating that a car parking lot is safe, 2 medium safe, 1 unsafe.

R_6 (efficiency of information system informing drivers about vacant places in the P&R parking lot; unit – points (1-2); dir. – max). Availability of such information systems optimises vehicle throughput and reduces time of searching for a vacant parking place. For evaluation of the numerical value of this factor a two-point scale was used, with 2 indicating that the system is available and 1 indicating that it is not.

R_7 (car parking price in the P&R parking lot; unit – Eur/h; dir. – min). This is an obvious criterion as the price of parking is important for car drivers.

R_8 (convenience of entering the P&R parking lot; unit – points (1-2); dir. – max).Authors discern two types of entrance to parking lots: safe and unsafe. Drivers would waste more time passing the latter drives, therefore they are less attractive. Also, to the same criterion we incorporate simultaneously entrance handling and exit time. The numerical value of this factor is expressed by a two-point scale, with 2 indicating that the entrance is safe and 1 that it is unsafe.

R_9 (width of the street near the P&R parking lot; unit – m; dir. – max). Attractiveness of a P&R parking lot depends on major technical parameters of the street (the width of the carriageway, design speed, the number of traffic lanes and other parameters). The numerical value of this factor is expressed by the width of the carriageway.

R_{10} (integrated ticketing system for the use of the P&R parking lot together with public transport; unit – Eur; dir. – max). As a driver can use an integrated ticketing system to change the transport mode to public transport, such a system would be attractive. Besides money, such an integrated ticketing system will enable the passenger to save time.

R_{11} (building density provided in the General Plan of Vilnius City; unit – %; dir. – max). Building density is an index which defines the efficiency of using the territory designated for the parking lot and influences the number of cars to be parked cars on that parking lot.

4.2 Estimation of Weights of Criteria of P&R Parking Lot Criteria by the AHP Method

It is a separate problem of quantifying opinions of experts, of creating a reliable link between psychology and the scale in the real numbers (Morselli 2015). To determine significance of criteria used, expressed in weights, the method of pairwise comparison developed by T. Saaty, the Analytic Hierarchy Process (hereinafter AHP), was applied (Saaty 1980; Kou et al. 2016). The method is based on the use of pairwise comparison matrix $P=|p_{ij}|$ (i, j=1,2...,m), where m is the number of compared criteria. In our case m=11.

For the comparison of these criteria 10 experts performing in the stages of preparation, evaluation and organisation of projects on urban and road transport systems and territorial planning were invited to participate in this research. Experts were chosen according to their qualification and practical working experience (more than 10 years). 8 experts participated all the way through the research. Compatibility of their standpoints has been verified utilising methods presented in the following parts of this article.

Each expert filled in a pairwise comparison matrix-questionnaire (comparison of criteria R_1, R_2..., R_{11} is observed). After concordance degree of estimates by each expert was determined by consistency index *C.I.* and concordance ratio *C.R.*(Saaty 1980). For example, the consistency index of the matrix of the 1st expert is *C.I.* = 0.077, and consistency ratio appears to be *C.R.* = 0.054 < 0.1. This means that the estimates of the 1-st expert can be considered as consistent. Estimates of the remaining experts appeared to be consistent as well.

The means of weights of criteria within the group of the experts appeared to be as follows: R_1 – 0.089; R_2 – 0.098; R_3 – 0.157; R_4 – 0.148; R_5 – 0.072; R_6 – 0.068; R_7 – 0.11; R_8 – 0.064; R_9 – 0.045; R_{10} – 0.095; R_{11} – 0.053.

Expert evaluation is a procedure that allows harmonising standpoints of different experts. Reliability of the results becomes much higher by comprising evaluation of weights made by a group of experts. Resulting weights are found by taking the average of weights. Consistency of the results within groups can be found by calculating concordance coefficient *W* (Kendall et al. 1990), which uses ranks of criteria by importance.

Concordance coefficient appeared to be $W = 0.520$. Significance of the concordance coefficient and the consistency of evaluating made within groups are verified by test statistics, which uses χ^2 random distribution with degrees of freedom $v = m - 1$ (Kendall et al. 1990):

$$\chi^2 = W\ r\ (m-1) = \frac{12S}{rm\,(m+1)}. \tag{1}$$

χ^2appeared to be $\chi^2 = 41.61$, while its critical value $\chi^2_{\alpha,\, v}$ obtained from the table of chi-square distribution with $v = m - 1 = 10$ degrees of freedom and significance level $\alpha = 0.05$ is $\chi^2_{\alpha,\, v} = 18.31$. Hence, the hypothesis that claims that estimations of the experts are inconsistent (41.61 >> 18.31) can be rejected.

4.3 Multiple Criteria Evaluation of P&R Parking Lots by the SAW, TOPSIS and COPRAS Methods

Seeking to comprehensively comprise factors influencing each P&R system for evaluation of their attractiveness in development of transport system of the city of Vilnius, multiple criteria evaluation methodology was employed. 33 perspective parking lots listed in the Special Plan were evaluated (Palevicius et al. 2016). Parking lots attributed to the P&R system were categorised to peripheral zone (Group I), middle zone (Group II) and central parking zone (Group III), as it was decided by Vilnius City Municipality in 2012.

Using multiple criteria evaluation methodology normalised values of criteria were comprised into a single evaluation criterion of a method together with weights of criteria obtained in the previous section. Chosen methods require indication of each criterion as a maximising or minimising (described in 4.1. chapter).

Authors chose three MCDM methods SAW, TOPSIS, and COPRAS in order to smoothen disturbance effects of normalisation as well as effects of particularities of each method (Podvezko et al. 2014; Podvezko et al. 2010). The SAW method is the most obvious method, which explicitly reveals the idea of MCDM methods: to comprise normalised values of criteria into a cumulative criterion of evaluation. The TOPSIS method uses a distinctive idea of comparing Euclidean distances in the *m*-dimensional space between an evaluated alternative, and hypothetical worst and best alternatives. The COPRAS method is popular among researchers not only in its country of origin Lithuania, but also worldwide (Zavadskas et al. 2016).

4.3.1 Evaluation of P&R Parking Lots by the SAW Method

The SAW (Simple Additive Weighting) method is one of the simplest and most widely used methods.

We used the classic normalisation of criteria, such that the sum of normalised values makes up unity (Podvezko et al. 2015).

Sum S_j represents the cumulative criterion of the method (Ginevicius et al. 2012):

$$S_j = \sum_{i=1}^{m} \omega_i \tilde{r}_{ij}, \qquad (2)$$

where ω_i is the weight of the *i*-th criterion (i=1,2, … , *m*), $\tilde{r}_{ij}$ is the normalised value of the *i*-the criterion of the *j*-the evaluated P&R parking lot. The larger is the value of the criterion S_j, the more attractive P&R parking lot is deemed to be.

Results of evaluation by the SAW method are presented in Table 1.

4.3.2 Evaluation of P&R Parking Lots by the TOPSIS Method

This decision-making method uses proximity to the ideal point (Ginevicius et al. 2012). According to this method, the closer is the alternative to the best hypothetic artificial reference alternative, and the further it is from the worst hypothetic artificial reference alternative, the better is considered the evaluated alternative. This method is widely used in engineering sciences (Rasiulis et al. 2016), transportation systems (Mardani et al. 2015), etc.

Normalisation formula for the TOPSIS method is the following:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^2}} \quad (i = 1,\ 2\ldots,\ m;\ j = 1,\ 2\ldots,\ n), \qquad (3)$$

where $\tilde{r}_{ij}$ is the normalized value of the *i*-th criterion of the *j*-th object.

The best V^* and the worst V^- hypothetic reference alternatives were calculated as well as distances of each considered alternative to such alternatives D_j^- and D_j*.

The cumulative criterion C_j^* of the TOPSIS method is calculated by the formula

$$C_j^* = \frac{D_j^-}{D_j^* + D_j^-} \quad (j = 1,\ ...,\ n)\ ^{(0 \le C_j^* \le 1)}, \qquad (4)$$

The better is the alternative the higher is the corresponding value of the criterion C_j^*.

Results of evaluation by the TOPSIS method are presented in Table 1.

4.3.3 Evaluation of P&R Parking Lots by the COPRAS Method

COPRAS method was created in 1994 by scholars Zavadskas and Kaklauskas from Vilnius Gediminas Technical University (Stefano et al. 2015). This method is widely used in scientific articles (Stefano et al. 2015).

Multiple criteria assessment by the COPRAS method is carried out in four stages. At stage I normalised non-dimensional values of criteria (as found in Table 4) are calculated.

At stage II, normalised values are multiplied by weights:

$$d_{ij} = \tilde{r}_{ij}\omega_i, (i = 1,\ 2\ldots, m;\ j = 1, 2\ldots, n). \qquad (5)$$

where $\tilde{r}_{ij}$ are normalised values of criteria; ω_i are weights found by the AHP method.

At stage III, sums S_{-j} of minimising weighted normalised values of criteria; and S_{+j} maximising ones for the j-th alternative are calculated by the following formulae:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}; \qquad S_{-j} = \sum_{i=1}^{m} d_{-ij}, \qquad (6)$$

At stage IV, the value of the cumulative criterion Q_j of the method based on found values S_{-j} and S_{+j} is calculated by the following formula:

$$Q_j = S_{+j} + \frac{\sum_{j=1}^{n} S_{-j}}{S_{-j} \sum_{j=1}^{n} \frac{1}{S_{-j}}} \quad j = 1, 2..., n. \qquad (7)$$

Results of evaluation by the COPRAS method are presented in Table 1.

The findings of the multiple criteria evaluation are presented in average ranks of each P&R parking.

Parking zones in the city are marked in colours. Red denotes the central zone, yellow – the middle zone, green – the peripheral zone.

Evaluation of attractiveness of P&R parking lots helps to assign priorities for building such parking lots. Nevertheless, the idea of P&R implies development of aggregate communication corridors stretched within the city of Vilnius. Such a corridor can function only in case if a net of parking lots is functioning. In the subsequent chapter attractiveness of such corridors will be evaluated in order to assign priorities for directions of development of Vilnius. Such evaluation would allow to assign priorities for completing the most perspective corridors in the first place together with P&R parking lots within such corridors.

5. Evaluation of Attractiveness of Communication Corridors of the City of Vilnius

Not all 33 parking lots, which are presented in the Special Plan must be built and more obviously, not simultaneously. Nevertheless, a rational plan of developing of the city for solving transport problems has to be developed. As this paper concentrates on the solution of the P&R problem, Authors take into account that P&R system cannot function without a proper technical infrastructure. Such technical infrastructure implies functioning of several P&R parking lots in each communication corridor.

Table 1.Results of quantitative evaluation of P&R parking lots

City zone	Parking No	SAW		COPRAS		TOPSIS		Sum of ranks in the zone	Priority in the zone
		S_j	Rank in the zone	Q_j	Rank in the zone	V^*	Rank in the zone		
Peripheral zone, Group I	1	0.0822	3	0.0799	3	0.3992	6	12	3
	2	0.0714	9	0.0734	8	0.5838	2	19	6–9
	3	0.0867	2	0.0887	1	0.6942	1	4	1
	4	0.0736	7	0.0755	7	0.5726	3	17	5
	5	0.0531	13	0.0550	13	0.1839	14	40	13–14
	6	0.0573	12	0.0592	12	0.2147	13	37	12
	7	0.0756	6	0.0777	5	0.5230	4	15	4
	8	0.0809	4	0.0829	2	0.4042	5	11	2
	9	0.0640	10	0.0661	10	0.2986	10	30	10
	10	0.0725	8	0.0789	4	0.3784	7	19	6–9
	11	0.0778	5	0.0756	6	0.3764	8	19	6–9
	12	0.0595	11	0.0614	11	0.2581	11	33	11
	13	0.0520	14	0.0540	14	0.2377	12	40	13–14
	14	0.0923	1	0.0709	9	0.3117	9	19	6–9
Middle zone, Group II	15	0.0898	3	0.0855	3	0.4762	6	12	3–4
	16	0.0688	10	0.0702	11	0.3333	12	33	11
	17	0.0824	5	0.0838	5	0.5429	3	13	5
	18	0.0812	6	0.0846	4	0.6218	1	11	2
	19	0.0752	7	0.0766	7	0.3906	9	23	8–9
	20	0.0623	12	0.0635	12	0.2425	13	37	12–13
	21	0.0923	1	0.0880	1	0.5448	2	4	1
	22	0.0609	13	0.0623	13	0.3381	11	37	12–13
	23	0.0725	8	0.0738	8	0.5305	4	20	7
	24	0.0837	4	0.0794	6	0.4407	7	17	6
	25	0.0724	9	0.0732	9	0.4945	5	23	8–9
	26	0.0672	11	0.0720	10	0.3413	10	3	10
	27	0.0904	2	0.0861	2	0.4121	8	12	3–4

Centre zone, Group III	28	0.1831	3	0.1822	2	0.6231	1	6	1–3
	29	0.1367	6	0.1372	6	0.3056	6	18	6
	30	0.1489	5	0.1562	4	0.3675	5	14	5
	31	0.1845	2	0.1918	1	0.4445	3	6	1–3
	32	0.1943	1	0.1783	3	0.4719	2	6	1–3
	33	0.1515	4	0.1533	5	0.4038	4	13	4

Authors conducted evaluation of already projected 7 communication corridors in order to help decision-makers to assign priorities for their development. This evaluation is based on several quantitative criteria. First, averages of the cumulative criteria obtained in the previous chapter, were used. Such cumulative criteria were normalised as is described below. Second, Authors assumed that parking lots in the first zone are more important than the ones in the second or, even more, in the third zone. This assumption items from the efficiency concept of P&R parking lots. The larger is the relative distance covered by a passenger by public transport, the more efficient is the P&R system. Third, the distance l to the parking lot from the primary road of the communication corridor (they are named exactly as their primary roads with the exception, the adjacent parking lot to the airport) also has to be taken into account, and minimised for convenience of passengers. Quantitative data for each corridor is presented in Table 2. A scheme of distances and zones considered is shown in (Palevicius et al. 2016).

From eight to just a single parking lots are found within each communication corridor. Parking lots distributed among communication corridors are shown in Fig. 1. Authors chose the attempted aggregate P&R area in the communication corridor to be 60 000 m^2 as such area is readily available in 5 communication corridors out of 8 and is reasonably large to satisfy the needs of the city of Vilnius. In 3 communication corridors available areas will appear to be redundant, while in other 3 communication corridors there will be a deficiency of such dedicated space.

Naturally, P&R parking lots to be included into evaluation were chosen based on rankings of attractiveness obtained in the previous chapter. Thus 11 parking lots with lower rankings outside the set area of 60 000 m^2 were considered as redundant and were not included into the evaluation. The remaining 22 parking lots lie in all three zones of the city were included into evaluation. Distribution of available parking space within each communication corridor is the following. “A1” would contain 76 485 m^2 of the parking space; “5212” – 76 485 m^2; “A2” – 56 430 m^2; “A14” – 76 485 m^2; “102” – 61 916 m^2; “103” – 28 732 m^2; “A3” – 28 732 m^2; “Airport” 25 495 m^2.

Table 2.Quantitative data for each communication corridor

Corridor	Parking No.	L, m	l_{ij}, m	area, m^2	$\tilde{S}_j$	$\tilde{Q}_j$	$\tilde{V}^*_j$
A1	8	13 300	8 300	25 495	0.876	0.935	0.128
	7	11 200	6 200	25 495	0.819	0.876	0.166
	10	9 400	5 000	25 495	0.785	0.890	0.120
	9	7 500	300	25 495	–	–	–
	19	4 100	300	10 926	–	–	–
	20	3 500	600	10 926	–	–	–
5212	5	7 100	300	25 495	0.575	0.620	0.058
	6	6 100	100	25 495	0.621	0.667	0.068
	21	4 800	500	25 495	1.000	1.000	1.000
	18	6 000	1 200	25 495	–	–	–
	29	3 000	100	10 926	–	–	–
	31	2 100	100	10 926	–	–	–
A2	26	7 300	700	10 926	0.728	0.818	0.626
	25	7 000	300	10 926	0.784	0.832	0.908
	16	5 700	500	10 926	0.745	0.798	0.612
	27	3 500	300	10 926	0.979	0.978	0.756
	17	3 400	300	10 926	0.893	0.952	0.997
A14	14	10 100	2 100	25 495	1.000	0.799	0.099
	13	10 500	4 300	25 495	0.563	0.609	0.076
	4	7 000	100	25 495	0.797	0.850	1.000
	24	6 000	500	10 926	–	–	–
	15	4 700	500	10 926	–	–	–
	22	4 500	800	10 926	–	–	–
	33	1 400	100	3 237	–	–	–
	32	1 300	100	3 237	–	–	–
102	2	6 500	300	25 495	0.774	0.828	0.186
	3	5 900	100	25 495	0.939	1.000	0.221
	23	3 600	300	10 926	0.785	0.839	0.974
103	12	4 600	100	25 495	0.645	0.692	0.082
	30	1 200	100	3 237	0.813	0.857	0.590
A3	11	4 600	2 000	25 495	0.843	0.852	0.120
	28	2 200	100	3 237	1.000	1.000	1.000
Air-port	1	6 500	100	25 495	0.891	0.901	0.127

For correctness cumulative criteria of all three methods SAW, COPRAS and TOPSIS were normalised within each zone, first to make their sum within each zone of the three to be equal to unity and then dividing each cumulative criterion within the zone by its maximal value. Authors denote such normalised cumulative criteria as $\tilde{S}_j$, $\tilde{Q}_j$ and $\widetilde{D}_j$. Only values of considered parking lots are presented in Table 2, while for redundant lots we put dashes.

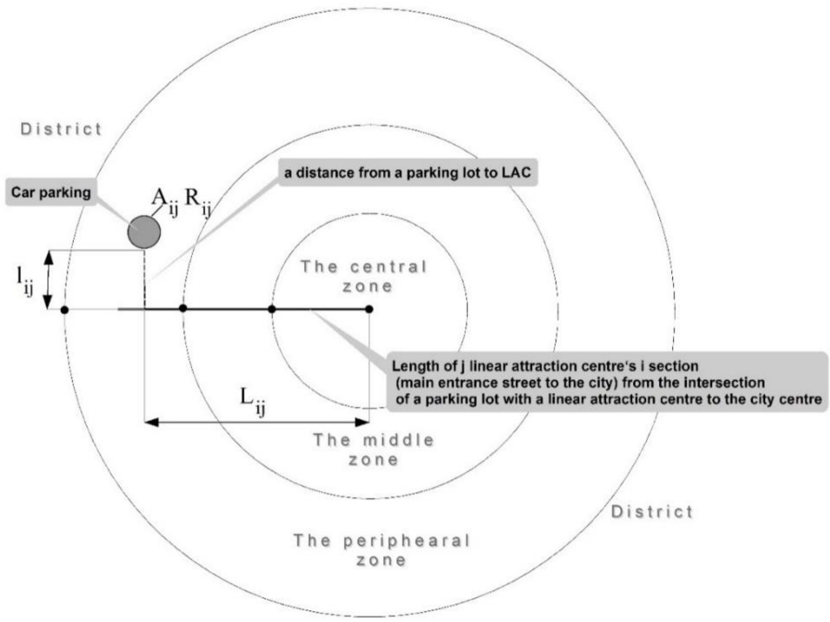

Figure 1. Scheme of distances and zones considered in the model of evaluation of communication corridors

In order to evaluate communication corridors Authors propose the following quantitative criterion $CC_{k,SAW}$based on the obtained evaluation of parking lots by the SAW method, which comprises outlined above criteria in accordance with desired directions, maximising or minimising.

$$CC_{k,SAW} = \sum_{j \in J_k} \frac{A_j \tilde{S}_j L_j}{l_j}, \quad (8)$$

where k is the number of the evaluated communication corridor; J_k is the set of indices for all parking lots to be included to the communication corridors; A_i is the area of the i-th parking lot; $\tilde{S}_i$ is the value of the normalised cumulative criterion of the SAW method for the i-th parking lot; L_i is the distance from the parking lot to the city centre; l_i is the distance to the parking lot from the primary road of the communication corridor.

Formulae for criteria for other two methods COPRAS and TOPSIS are similar and contain $\widetilde{D}_j$, and $\tilde{Q}_j$ instead of $\tilde{S}_j$.

Values of obtained cumulative criteria$CC_{k,SAW}$; $CC_{k,COPRAS}$ and $CC_{k,TOPSIS}$ are presented in Table 3 together with ranks obtained by each named method, cumulative rank and the final rank by all the three methods.

Table 3. Results of quantitative evaluation of communication corridors

Corri -dor, k	$CC_{k,SAW}$	$CC_{k,COPRAS}$	$CC_{k,TOPSIS}$	**Rank (SAW)**	**Rank (COP RAS)**	**Rank (TOP SIS)**	**Cum. rank**	**The final rank**
A1	111 179	121 161	18 665	8	8	8	24	8
5212	1 557 344	1 656 855	386 121	3	2	4	9	3
A2	611 168	647 287	598 803	6	6	2	14	5
A14	1 580 772	1 652 053	1 801 498	2	3	1	6	2
102	1 943 239	2 071 269	561 984	1	1	3	5	1
103	787 600	845 117	119 100	5	5	6	16	6
A3	120 641	121 192	78 228	7	7	7	21	7
Airpor t	1 475 837	1 492 765	210 226	4	4	5	13	4

6. Conclusions

1. The issues concerning the transport system in contemporary cities are popular among many researchers. Increasing level of automobilisation, extension of transport routes in cities as well as a relatively small amount of investment into development of transport infrastructure require implementation of new tools for sustainable development of cities. Globally, also including Europe and Lithuania in particular, the following trends towards developing the urban transport infrastructure have been crystallised: minimisation of use of motor transport and maximisation of use of bio-transport; public transport; and trips on foot.
2. Pursuing implementation of urban sustainable development it is indispensable to strengthen priorities over public transport by attributing parking lots to the use of public transport. Majority of researchers assume that a large number of private cars in possession of city dwellers is one the most complicated problems of an urban transport system to tackle.
3. Passenger traffic is one of the most significant indicators describing public transport. Practice shows that despite the fact that the quantitative indicators of Vilnius public transport are behind the ones of many similar-sized cities in the EU, conditions to improve public services have changed inconsiderably. Vilnius appears to be the city where installing a new system of P&R parking lots is vital aiming to encourage city dwellers to use public transport.
4. Seeking to prioritize P&R parking lots introduced in the Special Plan, Authors proposed a specific criteria-based evaluation methodology, which is based on 11

quantitative criteria. The multiple criteria decision-making methodology and specially SAW, COPRAS and TOPSIS methods, dealing with many mutually exclusive quantitative criteria, were applied to gauge attractiveness of already projected 33 parking lots in the city of Vilnius.

4. Not all 33 parking lots must be built and more obviously, not simultaneously, because P&R system cannot function without a proper technical infrastructure. Therefore the idea of P&R implies development of aggregate communication corridors stretched within a city.

5. Attractiveness of communication corridors projected in the General Plan of Vilnius city was evaluated taking into account parking lots to be incorporated in such corridors. A quantitative criterion was proposed. Results of the evaluation could be used to assign priorities for completing the most perspective corridors in the first place together with P&R parking lots within such corridors.

6. The findings obtained suggest that at the first stage of the implementationofthe Special PlanP&R parking lots should be built in the communication corridor along the route 102. The next option by attractiveness is communication corridor "A14".

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