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Iwona RYBICKA*, Paweł DROŹDZIEL
Lublin University of Technology, Faculty of Mechanical Engineering
Nadbystrzycka 36, 20-618 Lublin, Poland
Ondrej STOPKA, Vladimír ĽUPTÁK
Institute of Technology and Business in Ceske Budejovice, Faculty of Technology,
Department of Transport and Logistics
Okružní 10, 37001 České Budějovice, Czech Republic
**Corresponding author*. E-mail: i.rybicka@pollub.pl

METHODOLOGY TO PROPOSE A REGIONAL TRANSPORT ORGANIZATION WITHIN SPECIFIC INTEGRATED TRANSPORT SYSTEM: A CASE STUDY

Summary. The paper is focused on the proposal regarding the regional transport organization within Integrated Transport System in a given territory using the selected multi-criteria analysis methods. Introductory parts of this research study include basic information related to this topic as well as description of the current state of the public passenger transport operation, specifically the Integrated Transport System, on a particular territory. Subsequent part of the paper consists of specification of all the data and methods used and applied to obtain the final outcomes. The most important part of the paper highlights all the acquired results and proposed recommendations that need to be established to achieve the more appropriate regional transport organization in the examined territory.

1. INTRODUCTION

Transport as such has become a part of everyday life. Nowadays, people can use various/ several types of transport. These include, for example, car, bus, trolley bus, train, metro, or other means of transport. The quality of the offered connections applies also to the services provided by the transport sector. The main task of transport sector is to satisfy the customers´ requirements for quality, flexibility, fastness and safety in transportation of people and goods. The quality is seen differently from the perspective of transport service user and transport service provider or operator, and also from the perspective of the whole society [1-3].

2. INTEGRATED TRANSPORT SYSTEM – TÁBOR REGION

The Integrated Transport System (ITS) in the Tábor region, particularly its first stage, was created in 2013. It includes the Tábor - Sezimovo Ústí - Planá nad Lužnicí agglomeration, where the passengers can choose a means of transport. However, the passengers must buy a season public transport ticket, which is sold for a limited period of time (from 15 to 365 days). Since January 1, 2004, all public transport bus lines, two České Dráhy (Czech Railways) railway lines (namely the 220 line in the Tábor – Sezimovo Ústí – Planá nad Lužnicí and the 202 line in the Tábor – Horky u Tábora – Slapy sections) and 22 bus lines operated with COMETT PLUS have been integrated into the ITS. The last České dráhy section integrated in the system after the extension of the public transport route running through Nasavrky and Svrabov – Hejlov has been (since 1 September 2011) a part of the České Dráhy railway line no. 201 in the Tábor – Nasavrky section. Táborsko region integrated transport is thus the first integrated transport system in the South Bohemian region. In total 7.5 mil. passengers are transported per year within the ITS, but only a limited number of people have used the offered choice of means of transport. However, the interest in maintaining the existing integrated transport system still persists. Almost 70 % of persons transported are holders of season public transport ticket, so they are able to take advantages of the ITS [4-10].

3. ANALYSIS OF CURRENT STATE OF THE RESEARCH PROBLEM

The Comett Plus, public transport division ensures the public transport services in Tábor, Planá nad Lužnicí and Sezimovo Ústí. In this area, it operates in total 14 routes of the bus public transport, which is ensured by 31 buses during the rush hour. The whole network includes five main routes. The overall length of the network is 65 km and the length of all routes is more than 270 km (both directions). On working days, more than 640 buses are dispatched [4, 9, 11].

- The first direction is served by the bus lines 10, 11, 12, 13, 14, 16, 17 and 50. Those ensure the passenger transport from Klokoty, Pražské sídliště and Nemocnice bus stops via Sídliště nad Lužnicí, Sezimovo Ústí and Planá nad Lužnicí.
- The second direction is served by the bus lines 20 and 21, ensuring the passenger transport from Košín, Radimovice u Tábora, Náchod, via Blanické předměstí to Čekanice and Stoklasná Lhota.
- The bus lines 30 and 31 ensure the passenger transport from Zárybničná Lhota and Měšice via Čelkovice, Horky and Větrovy to Radimovice u Želče, Slapy and Dražičky.
- The bus line 40 ensures passenger transport from the Autobusové nádraží (Bus station) to Záluží and Hlinice.

The fifth route (bus lines 60 and 61) ensures the passenger transport from Maredův vrch via Staré město to Čelkovice and Lužnické údolí. The last route is served only by low-floor midibuses. This is because of the Staré město narrow streets where a standard bus would not manoeuvre.

This article deals only with the first from the above mentioned directions, that is, transportation from Planá nad Lužnicí via Sezimovo Ústí, Sídliště nad Lužnicí, bus station and Klokoty. The bus lines in this direction are the most frequently used ones compared with the remaining routes. This route includes both the frequently used lines and the less frequently used or even useless lines because of the conformity of the routes with only slight differences. For this reason, on four bus lines (11, 13, 16, and 17) will be assessed, as those are capable of operating other less needed lines. The chosen lines operate the whole town, not only some of its parts as for example lines no. 12 and 40, or are identical to line 14 (that does not go to the bus station). Conversely the line number 10 is the most popular and the most frequently used by the passengers [4, 8, 11, 12].

4. DATA, METHODS AND RESULTS

The article focuses on the multiple criteria evaluation of alternatives. These methods deal with the optimal selection of alternative from several sets of alternatives. In addition to the selection of the optimal or the best alternative, preferential arrangement is also carried out. Based on the nature of the individual criteria, we can distinguish maximizing and minimizing criteria. All criteria must be of the same nature; therefore, they are always converted into maximizing character [13-15].

The most appropriate method for determining the weight is the Fuller´s Triangle Method, or the Fuller´s triangle, which is considered very clear by the authors. As the most suitable evaluation method, TOPSIS was chosen.

4.1. Evaluation from the carrier´s perspective

From carrier´s perspective, the evaluation criteria regarding mostly the occupancy of the means of transport are rush hours or the off-peak traffic hours. Based on this, the carriers adjust the number of means of transport needed. There is thus an increase in the number of means of transport (buses) in the rush hour and subsequently a reduction [14-17].

Evaluation criteria from carrier´s perspective are as follows [14, 18]:

- (Bus or other means of transport) occupancy during the morning rush hour,
- occupancy during the afternoon rush hour,
- occupancy during the morning off-peak time,
- occupancy during the afternoon off-peak time,
- number of vehicles.

4.1.1. Fuller´s triangle method – the carrier´s perspective

It is a method also known as a method of pairwise comparison. Its basic principle consists in comparing two criteria and subsequently choosing the one we think is the most important. To make the record using the Fuller´s triangle as clear as possible, K-1 must always have two lines. The first line contains each comparison with the first criterion, in the second line, the second criterion is compared with the remaining criteria except with the one in the first line. This is repeated until all possible comparisons are carried out, i.e., each row contains one less element than the row above it [14, 15, 19].

Selected criteria:

K1 – occupancy during the morning rush hour (7:00 - 7:45),

K2 - occupancy during the afternoon rush hour (14:30 - 15:30),

K3 - occupancy during the morning off-peak time (11:00 - 12:00),

K4 - occupancy during the afternoon off-peak time (19:30 - 20:30),

K5 – number of vehicles.

In the selected criteria, two values of bus occupancy in the rush hours and off-peak times were chosen twice. Off-peak time is the time when passenger transport is less heavy compared with the rush hour when the number of passengers is higher. The statistics show that the morning rush hour is between 7:00 and 7:45, when most passengers go to work or school. The afternoon rush hour is between 14:30 and 15:30, when passengers usually return back home. Conversely, the off-peak time is between 11:00 – 12:00 and 19:30 – 20:30, when less passengers use public transport.

Fuller´s triangle is made up of two lines in which each pair of criteria occurs only once. In each pair, the number of that criterion, which is more important, is circled or otherwise marked. For normalized weight of the K_j criterion calculation, an equation is applied, see [14].

The criterion that is considered to be more important than another criterion is circled in case of all pairs. The next step of this method is to add up more important, circled criteria, which will be counted in the individual lines and eventually divided according to their total number (the total number of circled criteria).

Thus, for each criterion, it must be counted of how many times it is marked as preferred before another criterion. To determine the weight of criteria, each criterion is divided by the number of all comparisons.

There are also certain disadvantages of the Fuller's Method. The disadvantage is that if we compare each criterion with another one, the least preferred one gets a zero value. In this case, it happens that there is no need to count with this last criterion. However, the aforementioned criterion may not be insignificant. To avoid such situation, we must increase each preference by 1. A criterion with the zero will subsequently have the value of 1.

Compilation of the Fuller´s triangle and weights determination for all the criteria is indicated in following Table 1 (value - 1-5; 1 - excellent; 5 - insufficient) [14, 15, 19]:

Table 1

Fuller´s triangle compilation. Source: authors

Fuller´s triangle	Criteria	Preference	Preference + 1	Weight
K1 K1 K1 K1 K2 K3 K4 K5	K1	3	4	0.27
K2 K2 K2 K3 K4 K5	K2	4	5	**0.33**
K3 K3 K4 K5	K3	1	2	0.13
K4	K4	0	1	0.07
K5	K5	2	3	0.20
Total	-	**10**	**15**	**1**

4.1.2. TOPSIS method – the carrier´s perspective

The TOPSIS method is one of the methods where the evaluation of options is performed by comparison with ideal variants. To express the distance between variants, different units are used. The TOPSIS method is based on the classical Euclidean metric space.

TOPSIS is an English acronym for Technique for Order Preference by Similarity to Ideal Solution. It is based on selecting the alternative which is the closes to the ideal alternative and farthest from the basal alternative. For the TOPSIS method, the maximization character is expected, therefore the individual minimizing criteria are converted into the maximizing [19-23].

As for step 1, an evaluation matrix consisting of *m* variants and *n* criteria, with the intersection of each variant and criteria given as x_{ij}, is created. Thus, we have a matrix $(x_{ij})_{m \times n}$.

Evaluation from carrier´s perspective and its summary into the tables before and after conversion is indicated in Table 2 and 3.

Table 2

Evaluation from carrier´s perspective. Source: authors

Evaluation from carrier´s perspective					
Line	Ø Bus occupancy – morning rush hour (7:00 – 7:45)	Ø Bus occupancy – afternoon rush hour (14:30 – 15:30)	Ø Bus occupancy – forenoon off-peak hour (11:00 – 12:00)	Ø Bus occupancy – evening off-peak hour (19:30 – 20:30)	Number of vehicles
11	38.47	43.44	19.29	20.24	4
13	45.20	39.45	24.96	18.41	4
16	42.31	29.63	25.39	18.60	2
17	38.57	35.11	24.39	15.32	3
x	max	max	max	max	min

Transfer of the criteria to the same type is not difficult as each minimization criterion can be easily converted to the maximization criterion [20, 22], shown as follows:

- First case – the scale is given by the nature of the issue (in our case, four vehicles). Thus, we take the maximum value that can be achieved, and subtract from it the values of individual criterion.
- Second case – the scale is not given. In this case, we find the variant with the highest (worst) value and subtract from it the value of the criterion. This step can be presented as protection against the worst variant.

Thus, in our case it is necessary to perform a modification in the Table 2 for K5 criterion, i.e. number of vehicles. In this criterion, the highest value is 4, so the transformation replaces the original criteria value of y_{i4} by the value of $4 - y_{i4}$.

Table 3

Conversion of the criteria into maximizing character. Source: authors

Evaluation from carrier´s perspective					
Line	Ø Bus occupancy – morning rush hour (7:00 – 7:45)	Ø Bus occupancy – afternoon rush hour (14:30 – 15:30)	Ø Bus occupancy – forenoon off-peak hour (11:00 – 12:00)	Ø Bus occupancy – evening off-peak hour (19:30 – 20:30)	Number of vehicles
11	38.47	43.44	19.29	20.24	0
13	45.20	39.45	24.96	18.41	0
16	42.31	29.63	25.39	18.60	2
17	38.57	35.11	24.39	15.32	1
Weights	0.27	0.33	0.13	0.07	0.2

Calculation of normalized criteria matrix

Model solution of line 11 during the morning rush hour (see Eq. 1).

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} = \frac{38.47}{\sqrt{38.47^2+45.2^2+42.31^2+38.57^2}} = \mathbf{0.466} \quad (1)$$

where y_{ij} - bus occupancy, number of vehicles, i - 1, 2,…, m, j - 1, 2,…, n.

All the normalized values are listed in following Table 4.

Table 4

Table of normalized values (r_{ij}). Source: authors

Normalized values				
0.466	0.583	0.408	0.555	0.000
0.548	0.529	0.528	0.505	0.000
0.513	0.398	0.537	0.510	0.894
0.468	0.471	0.516	0.420	0.447

The values in each column will be multiplied by weights that belong to a specific column (see Eq. 2):

$$z_{ij} = w_j \cdot r_{ij} \quad (2)$$

where w_j – weight, r_{ij} - normalized criterion

Multiplication of values by weights is summarized in Table 5.

Table 5

Multiplication of values by weights. Source: authors

Multiplication of values by weights				
0.126	0.192	0.053	0.039	0
0.148	0.175	0.069	0.035	0
0.139	0.131	0.070	0.036	0.179
0.126	0.155	0.067	0.029	0.089

Creation of ideal and basal alternative (H-ideal, D-basal)

$h_j = \max_i z_{ij}; j = 1,2,\dots,n$

$d_j = \min_i z_{ij}; j = 1,2,\dots,n$

h_j ={0.148; 0.192; 0.070; 0.039; 0.179}

d_j ={0.126; 0,.31; 0.053; 0.029; 0}

Calculation of distance from ideal alternative (Eq. 3):

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(z_{ij} - h_j)^2}\,; i = 1,2,\dots,m \quad (3)$$

Calculation of distance from basal alternative (Eq. 4):

$$d_i^- = \sqrt{\sum_{j=1}^{n}(z_{ij} - d_j)^2}\,; i = 1,2,\dots,m \quad (4)$$

Calculation of alternatives distance from basal alternative (Eq. 5):

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-}\,; i = 1,2,\dots,m \quad (5)$$

Table 6

Summary of the obtained results. Source: authors

Calculation of distance from ideal alternative			
d_{11}^+	d_{13}^+	d_{16}^+	d_{17}^+
0.181	0.180	0.062	0.100
Calculation of distance from basal alternative			
d_{11}^-	d_{13}^-	d_{16}^-	d_{17}^-
0.062	0.052	0.180	0.093
Indicator of alternatives distance from basal alternative			
c_{11}	c_{13}	c_{16}	c_{17}
0.255	0.224	0.744	0.482

The individual results are arranged into the Table 7.

Table 7

Final evaluation of variants from carrier´s perspective. Source: authors

Final evaluation of variants	
Line 11	3rd place
Line 13	4th place
Line 16	1st place
Line 17	2nd place

4.2. Evaluation from the passenger´s perspective

The passenger has different requirements and needs for evaluation of urban public transport lines. It can be assumed that passengers are more interested in overall "comfort", i.e. all activities and facts associated with travelling by the means of public transport to the intended destination. Since there are many criteria, only a few must be selected. From the passenger's perspective, the following main criteria have been chosen [22-25]:

- the average line interval,
- the time of transportation,
- comfort, and
- the distance to the destination.

4.2.1. Fuller´s triangle method – the passenger´s perspective

Precise procedure – see chapter 4.1.1.

The criteria chosen by the authors – value - 1-5; 1 - excellent; 5 – insufficient: (see Table 8):

K1 – Ø Line interval (min.)
K2 – Time of transportation (min.)
K3 – Comfort of passengers (min.)
K4 – Distance of the (bus) stop to the destination (min.)

Table 8

Fuller´s triangle compilation. Source: authors

Fuller´s Triangle	Criterion	Preference	Preference + 1	Weight
K1 K1 K1 K2 K3 K4	K1	3	4	**0.40**
K2 K2 K3 K4	K2	1	2	0.20
K3	K3	0	1	0.10
K4	K4	2	3	0.30
Total	**-**	**6**	**10**	**1**

4.2.2. TOPSIS method – the passenger´s perspective

Tables 9 and 10 below include the criteria described above and, using the above-mentioned procedures to obtain the data, tables have been created, which also include the data obtained from the questionnaire survey. Together with the weights calculated using the Fuller's Triangle, this is the basis for the TOPSIS method [14, 22, 24, 26].

Table 9

Evaluation from passenger´s perspective. Source: authors

Line	Ø Interval	Time of transportation	Comfort	Ø Distance to the destination
11	38.47	43.44	19.29	20.24
13	45.20	39.45	24.96	18.41
16	42.31	29.63	25.39	18.60
17	38.57	35.11	24.39	15.32
X	min	min	min	min

Table 10

Conversion of the criteria into maximizing character. Source: authors

Line	Ø Interval	Time of transportation	Comfort	Ø Distance to the destination
11	43.64	4	0	3
13	37.55	4	0.70	27
16	0	4	0.50	0
17	39.61	0	0.10	3
Weights	0.40	0.20	0.10	0.30

When converting from minimization to maximization, first of all, it is necessary to find the highest number in the column of that criterion, and deduct the other values that are in the column of given criteria from this number [21, 24, 27, 28].

Calculation of normalized criteria matrix (Eq. 6):

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} = \frac{43.67}{\sqrt{43.67^2+37.55^2+0^2+39.61^2}} = \mathbf{0.625} \qquad (6)$$

All the normalized values are listed in following Table 11.

Table 11

Table of normalized values (r_{ij}). Source: authors

Normalized values			
0.625	0.577	0	0.110
0.537	0.577	0.808	0.988
0	0.577	0.577	0
0.567	0	0.115	0.110

Every column is gradually multiplied by the weights, which belong to a specific column (see Eq. 2). Identically to Table 5, multiplication of values by weights is summarized in Table 12.

Table 12

Multiplication of values by weights. Source: authors

Multiplication of values by weights			
0.250	0.115	0	0.033
0.215	0.115	0.081	0.296
0	0.115	0.058	0
0.227	0	0.012	0.033

Creation of ideal and basal variants (H-ideal, D-basal):

$h_j = \max_i z_{ij}; j = 1,2,\ldots,n$

$d_j = \min_i z_{ij}; j = 1,2,\ldots,n$

h_j ={0.250; 0.115; 0.081; 0.296}

d_j ={0; 0; 0; 0}

Table 13

Summary of the obtained results. Source: authors

Calculation of distance to the ideal variant			
	d_{13}^{+}	d_{16}^{+}	d_{17}^{+}
0.275	0.035	0.388	0.296
Calculation of distance to the basal variant			
d_{11}^{-}	d_{13}^{-}	d_{16}^{-}	d_{17}^{-}
0.277	0.392	0.129	0.230
Indicator of distance between the variants and the basal variant			
c_{11}	c_{13}	c_{16}	c_{17}
0.502	0.918	0.25	0.437

Subsequently, the results obtained from the perspective of the passengers are evaluated (see Table 14). The individual results are sorted from the highest to the smallest, with the highest number being recorded as the 1st place.

Table 14

Final evaluation of variants from passenger´s perspective
Source: authors

Line No. 11	2nd position
Line No. 13	1st position
Line No. 16	4th position
Line No. 17	3rd position

The results obtained by the TOPSIS method clearly prove that both the carrier and the passenger prefer different lines.

The passenger prefers line No. 13 the most, line No. 11 is the second and lines No. 17 and 16 are on the third and fourth place on the passenger's preference scale. The individual stops of line No. 13 had the shortest average distance from the potential destination. Another reason why this line was considered the winner was comfort. On all comfort issues, line No. 13 was considered to be the cleanest, most comfortable and least noisy. The reason why line No. 16 was considered to be the worst is due to its longest average interval, whereas the average interval was the highest in terms of weight.

From the carrier's perspective, however, the most preferred line was No. 16, which was considered the worst for the passengers. As has already been said, passengers and carriers have different priorities. Line No. 16 was chosen by the carrier as the most appropriate because the number of vehicles in use was smaller. This fact was crucial. The weight assigned to the criterion concerning the number of vehicles may be distorted owing to the lack of knowledge of traffic. In contrast, line No. 13, which is the most popular among the passengers, was considered the worst [21, 22].

5. PROPOSAL

Although Tábor is a smaller town, it provides an extensive range of bus lines. Therefore, an optimization of the number of existing lines in direction 1 is proposed, with the intention of termination of most lines. Only lines 10 and 13 will remain.

Line 10 is currently the busiest and most popular line from the passenger's perspective. There is an important factor which is that it connects the largest housing estate in Tábor with the rest of the town and terminates at the entrance of Tábor Hospital, unlike the other lines of direction 1. Therefore, this line will remain.

Currently, line 10 is considered a main transportation line. The proposal intends to convert the main transportation line No. 10 to line No. 13. Lines No. 11, 12, 14, 16, 17 and 50 will be terminated, whereas line No. 10 will become an additional line. Line No. 13 is the longest line and passes through the vast majority of stops of terminated lines. My proposition is to terminate these lines because of the lack of clarity for the passengers who are not residents of Tábor or do not regularly use these lines.

6. CONCLUSION

The method, which has been used, found out that the passengers preferred line No. 13 the most, which, however, was not most appropriate for the carrier. This fact was a stimulus to propose a reinforcement of this line and removal of the remaining lines with only one additional line No. 10 remaining, without revocation. Therefore, the proposal is to design a new solution for Line No. 13, which will become the main transport line, so that the accumulation and complementation of diverse bus lines can be avoided.

Proposed methodology in regard to the transport organization within Integrated Transport System applying the selected multi-criteria analysis methods has high potential for its utilization within other regional territories even with connection to, for example, railway, water or air passenger transport.

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