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**Svetla STOILOVA\***, **Radina NIKOLOVA**  
Technical University of Sofia  
boulevard Kliment Ohridski 8, Sofia, Bulgaria  
*\*Corresponding author.* E-mail: [stoilova@tu-sofia.bg](mailto:stoilova@tu-sofia.bg)

## **AN APPLICATION OF AHP METHOD FOR EXAMINING THE TRANSPORT PLAN OF PASSENGER TRAINS IN BULGARIAN RAILWAY NETWORK**

**Summary.** In this study, a methodology was developed for transport plan selection of intercity trains in railway network using the method of Analytic Hierarchy Process (AHP). For studying the transport plan, the following indicators have been chosen: the transport satisfaction, average number of train stops, average distance travelled, average speed, reliability, availability of service with direct transport and transport capacity. The methodology includes determination of variant schemes of transportation; determination of the number of trains by criterion of minimum direct operating costs for transportation of each variant scheme using linear optimization model; application of AHP method to define the weights of criteria and ranking the variants schemes; and selection of an optimal transport plan according to the criterion of a minimum ratio of normalized direct operating costs to the AHP score. The methodology was experimented in Bulgarian railway network.

### **1. INTRODUCTION**

The development of a transport plan for passenger trains depends on different indicators, and it aims to satisfy the requirements of passengers and capabilities of rail operator for the organization of intercity rail transport.

The quality of the transport service for rail passenger transport is an important factor in attracting passengers. The important factors for passengers are the speed, the straightforward journey, the frequency of service, and the price of the ticket. For railway operators, it is important to determine the optimal parameters of the organization of passenger trains taking into account the operating costs. To satisfy the passengers and rail operator regarding the organization of intercity rail transport, it is necessary to explore different variant schemes of transport plan of passenger trains, which need to be assessed by quantitative and qualitative indicators. For the development of scheme for the transport of intercity trains, it is also necessary to take into account the probability of increasing or decreasing the flow of passengers, which affects the direct operating costs of rail operator. A suitable method for examination in this case is a multicriteria analysis that allows to evaluate different alternatives on both quantitative and qualitative indicators. The AHP approach is one of the more extensively used multicriteria decision-making methods.

The aim of this research is to create a methodology for optimizing the transport plan of passenger trains in railway network by applying the quantitative and qualitative indicators related to transportation and taking into account the direct operational costs. The methodology could be used as a basis for comparing different variant schemes of transportation, taking into account the change in passenger flows.

The object of the research is intercity trains in Bulgarian railway network. The methodology of the study includes determination of the indicators for examining the transport plan of intercity passenger trains; determination of variant schemes of transportation; determination of the direct operating cost for transportation of each variant scheme; application AHP method to define the weights of criteria and ranking the variants schemes; and selection an optimal transport plan according to the criterion of a minimum ratio of normalized direct operating costs to the AHP score.

The AHP method is applied in many areas of scientific research. In transport, this method is used, for example, to determine the mode of transportation, to estimate passenger satisfaction, to evaluate the transport projects, and for other purposes. In the study by Xukuo and Qiong [15], AHP method is used for the optimal decision of mode of transportation, and five factors, such as the cost, speed, security, punctuality and transportation capacity, are compared. The urban mass rail transit network in Ningbo with six preliminary schemes is investigated in the study by Junneng and Ganbin [3], applying the AHP model. A total of twenty criteria are used. In the study by Sivilevičius and Maskeliūnaite [9], research was conducted on passenger's assessment of transportation quality related to a number of criteria such as group A (criteria related to the train elements and the technical state of rails), group B (criteria related to railway trip planning and technology), group C (criteria related to the price of a trip ticket), group D (criteria related to the safety of railway trip), matching the structure and number of the questions included in the questionnaires to survey respondents (passengers) and experts (service and administration staff of the train). The AHP methodology is used to determine their weights considering the data obtained from the respondents and experts of each of three categories. The experiment comprised passengers from the train running on the international route Vilnius–Moscow. The needs of passengers of railway transportation are investigated in the study by Maskeliūnaite, Sivilevičius, and Podvezko [4] by using the AHP method. In the study by Wen H. and Lin S [13], indicators such as safety, rapidity, time and comfort are applied to analyse the qualitative factors that affect the operational efficiency of the highway passenger transport enterprises. In [5], the possibilities of applying AHP method in making decisions regarding planning and implementation of plans in traffic and ensuring the qualitative business logistics are analysed.

A major factor in the development of the organization of the intercity trains is the operating costs for the movement of passenger trains [11, 14]. In the study by Pogarcic, Francic and Davidovic [14], an integrated optimization model is built with the aim of reducing both passenger travel costs and enterprise operating costs. Socio-economic factors also influence the choice of transport. The main requirements of passengers are in terms of transport quality which is expressed by fast and reliable transport. In Bureika et al. and Isaai et al. [1, 2], the following are defined as the main factors for choosing a mode of transport: cost, speed, security, timeliness, and transport capacity. Time is a necessary factor in processes of transportation. In the study by Wang, Yong, and Xu [12], a mixed integer program is elaborated with the objective of maximizing the served passenger volume and minimizing the total travel time for all passengers.

It can be summarized that the problem of development of a methodology for selecting a transport scheme for different categories of passenger trains by applying multi-criteria analysis and reporting both operating costs and factors that take into account passenger requirements has not been sufficiently investigated. The impact of the probable change in passenger flows on the choice of an optimal variant scheme of transportation has also not been sufficiently investigated.

## **2. METHODOLOGICAL APPROACH**

### **2.1. Indicators to assess the variant schemes**

The first phase of methodology includes determination of the indicators to assess variant schemes of transportation of intercity train. In the research, the following quantitative and qualitative indicators are applied:

• K1 – Transport satisfaction, trains/day. This factor indicates the number of trains for the variant scheme and is a measure of frequency of services.

$$K_1 = \sum_{i=1}^n N_i \quad (1)$$

where:  $N_i$  is the number of trains of itinerary  $i$  per day,  $i=1, \dots, n$ ;  $n$  is the number of itineraries for variant scheme.

• K2 – Average number of train stops. This factor indicates the frequency of services to the settlements for the variant scheme.

$$K_2 = \sum_{i=1}^n N_i \cdot n_{s,i} \quad (2)$$

where:  $n_{s,i}$  is the number of stops for train of itinerary  $i$  per day.

• K3 – Average distance travelled, km. This factor indicates the average length of itineraries for the variant scheme.

$$K_3 = \frac{\sum_{i=1}^n N_i \cdot L_i}{\sum_{i=1}^n N_i} \quad (3)$$

where:  $L_i$  is the length of itinerary for train  $i$ , km.

• K4 – Average speed, km/h. This factor indicates the speed of transport services for the variant scheme. This takes into account the time spent for traveling by passengers.

$$K_4 = \frac{\sum_{i=1}^n N_i \cdot L_i}{\sum_{i=1}^n N_i \cdot T_i} \quad (4)$$

where:  $T_i$  is the time during for train  $i$ , h.

• K5 – Reliability. In the study, the reliability is given by the average delay of trains.

$$K_5 = \frac{\sum_{i=1}^n N_i \cdot k_i}{\sum_{i=1}^n N_i} \quad (5)$$

$$k_i = \frac{N_i^d}{N_i} \quad (6)$$

where:  $k_i$  is the coefficient representing the delay of the trains from itinerary  $i$ ;  $N_i^d$  is the number of delayed trains from itinerary  $i$ , trains /day.

• K6 – Availability of service with direct transport. The direct transport means direct service by train (without intermediate stops) between large cities (over 100 thousand inhabitants). If the variant scheme offers such service:  $K_6=1$ , otherwise:  $K_6=0$ .

• K7 – Transport capacity. The transport capacity indicates the number of seats offered by the variant scheme per day.

$$K_7 = \sum_{i=1}^n N_i \cdot b_i \quad (7)$$

where:  $b_i$  is the number of seats in a train  $i$ .

The price of a trip ticket is also an important indicator for choice of transportation. This indicator is not taken into account in this study because only one mode of transport is being investigated. There is a difference in the ticket price for different categories of passenger trains. This is accounted for in the study by direct operational costs.

## 2.2. Variant schemes

The choice of optimal transport plan of intercity passenger trains is based on an assessment of pre-developed variant schemes of transportation. The variant schemes include routes in the railway network with different categories of fast trains and different composition of the trains. In the study, the categories of fast trains are as follows: direct fast trains (DFT), accelerate fast trains (AFT), and fast trains (FT). DFT are intercity express trains. In the research, they are a new category of trains with reduced stops. The AFT are intercity trains. The fast trains stop at more stations compared with the DFT and AFT. The number of wagons in trains is chosen according to the existing situation of formation of the compositions in Bulgarian rail network. By coefficient of directness, an opportunity of introduction of category DFT can be evaluated. This factor evaluates the intensity of passengers from station  $i$  to station  $j$ , which are on a railway line, compared with total passenger traffic in this line, and is defined as follow:

$$\lambda_{ij} = \frac{P_{ij}}{\sum_{j=i+1}^n P_{ij}}, \quad i = 1, \dots, n; \quad j > i; \quad j = i + 1, \dots, n, \quad (8)$$

where  $P_{ij}$  is the passenger flows between stations  $i$  and  $j$ , pass./month;  $\sum_{j=i+1}^n P_{ij}$  is the total passenger flows departing from station  $i$  for direction  $j$ , pass./month; and  $n$  is the number of stations in railway line.

In the study, it is accepted that direct fast train can be studied in the organization of transport, if the following condition is met:

$$\lambda_{ij} \geq 0.25 \quad (9)$$

This value has passenger flows between major administrative centres, which are served by railway transport in Bulgaria.

### 2.3. Evaluation of the variant schemes by applying AHP method

The decision approach in the second phase of methodology involves multicriteria analysis. The Analytic hierarchy process (AHP), developed by Saaty, is one of the multiple-criteria decision-making methods. In the study, the variant schemes are evaluated by criteria given in 3.1. The AHP method is used to assess the weights of the criteria and to prioritize the variant schemes according to the maximum AHP score.

The AHP method is based on the following principles: structure of the model, development of the ratings for each decision alternative for each criterion and synthesis of the priorities.

The first step is to make pairwise comparisons between each criterion using Saaty's scale, [6 - 8, 10]. Tab.1 presents the Saaty's scale.

Table 1

Pairwise Comparison Scale

Intensely of importance	Definition
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for intermediate comparison

The result of the pairwise comparison on  $n$  criteria can be summarized in an  $(n, n)$  evaluation matrix in which every element  $a_{ij}$  ( $i, j = 1, \dots, n$ ) is the quotient of weights of the criteria. The element  $X_i$ s are assigned from Table 1.

The matrix elements have the following relationships:

$$a_{ii} = 1; \quad a_{ij} \neq 0; \quad a_{ji} = 1/a_{ij} \quad (10)$$

The second step in the AHP procedure is to normalize the matrix. The relative weights are given by the normalized right eigenvector ( $W = \{w_1, \dots, w_n\}^T$ ) associated with the largest eigenvalue ( $\lambda_{\max}$ ) of the square matrix  $A$  providing the weighting values for all decision elements. The largest eigenvalue ( $\lambda_{\max}$ ) can be calculated by using the following equation:

$$AW = \lambda_{\max} \cdot W \quad (11)$$

$$\lambda_{\max} = \sum_{i=1}^n \left[ \left( \sum_{j=1}^n a_{ij} \right) W_i \right] \quad (12)$$

The third step calculates the consistency ratio and checks its value.

The consistency ratio is found with the following formula:

$$CR = \frac{CI}{RI} \leq 0,1 \tag{13}$$

where  $CI$  is the consistency index and  $RI$  is a random index. The random matrix is given by Saaty [8]. Its values are shown in Table 2.

Table 2

Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The consistency index is as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{14}$$

The largest eigenvalue  $\lambda_{\max}$  is the maximum eigenvalue of the priority matrix, and  $n$  is the number of elements in the matrix. Generally, if the  $CR$  is less than 0.10, the consistency of the decision maker is considered satisfactory. However, if  $CR$  exceeds 0.10, some revisions of judgements may be required. To control the results of the methods, the consistency ratio ( $CR$ ) is used to estimate directly the consistency of pairwise comparisons.

#### 2.4. Evaluation of the variant schemes by criterion minimum operational costs

In the third phase of the methodology, to determine the number of trains for each variant scheme, a linear optimization model by criterion of minimum direct operational transport costs is applied.

The objective function is as follows:

$$R_g = \sum_{i_1=1}^{I_1} r_i^{o,d,FT} l_i x_i^{FT} + \sum_{i_2=I_1+1}^{I_2} r_i^{o,d,AFT} l_i x_i^{AFT} + \sum_{i_3=I_2+1}^{I_3} r_i^{o,d,DFT} l_i x_i^{DFT}, BGN / day \rightarrow \min \tag{15}$$

where  $i_1 = 1, \dots, I_1$  is the number of itineraries of fast trains;  $i_2 = I_1 + 1, \dots, I_2$  is the number of itineraries of accelerate fast trains;  $i_3 = I_2 + 1, \dots, I_3$  is the number of itineraries of direct fast trains;  $r_i^{o,d}$  is the direct operational costs for train itinerary  $i$ , BGN/km; BGN (Bulgarian Lev) is the currency of Bulgaria;  $l_i$  is the length of itinerary of train  $i$ , km;  $x_i$  is the number of trains of itinerary  $i$ ;  $i = 1, \dots, I_3$  is the number of itinerary of passenger trains of investigated categories; and  $g$  is the number of variant scheme,  $g = 1, \dots, G$ .

The objective function (15) defines the optimal plan that provides the realization of the necessary passenger transportation with minimal direct operational costs.

The restrictive conditions are as follows:

$$\sum_{i_1=1}^{I_1} L_{ijk}^{FT} \cdot a_i^{FT} \cdot \alpha_i^{FT} \cdot x_i^{FT} \geq P_{jk}^{FT} \tag{16}$$

$$\sum_{i_2=I_1+1}^{I_2} L_{ijk}^{AFT} \cdot a_i^{AFT} \cdot \alpha_i^{AFT} \cdot x_i^{AFT} \geq P_{jk}^{AFT} \tag{17}$$

$$\sum_{i_3=I_2+1}^{I_3} L_{ijk}^{DFT} \cdot a_i^{DFT} \cdot \alpha_i^{DFT} \cdot x_i^{DFT} \geq P_{jk}^{DFT} \tag{18}$$

where  $a_i$  is the number of seats in a train by itinerary  $i$ ;  $\alpha_i$  is passenger trains capacity utilization coefficient for train itinerary  $i$ ;  $\alpha_i \leq 1$ ;  $P_{jk}$  is the passenger flows from station  $j$  to station  $k$ , pass./day;  $j = 1, \dots, J$  is the number of station where the passenger flows start; and  $k = 1, \dots, K$  is the number

of station where the passenger flows finish. In the general case  $j = k$ ; when  $\kappa > j$  - it is assumed even direction, and when  $\kappa < j$  - odd direction.  $L_{ijk}$  is the coefficient that takes into account the possibility of passenger train  $i$  to serve the itinerary of passenger flow  $P_{jk}$ ;  $L_{ijk}=1$ , where it is possible trains  $i$ -th itinerary to serve passenger;  $L_{ijk}=0$ , otherwise; AFT – accelerate fast train.

The number of trains must be a positive and an integer:

$$x_{i_1}^{FT} \geq 0; x_{i_2}^{AFT} \geq 0; x_{i_3}^{DFT} \geq 0 \quad , \quad (19)$$

$$x_{i_1}^{FT}; x_{i_2}^{AFT}; x_{i_3}^{DFT} - \text{integer} \quad . \quad (20)$$

The total number of passenger trains must not exceed the maximum train capacity of the railroad.

$$\sum_{i_1=1}^{I_1} L_{i_1jk}^{FT} \cdot x_{i_1}^{FT} + \sum_{i_2=I_1+1}^{I_2} L_{i_2jk}^{AFT} \cdot x_{i_2}^{AFT} + \sum_{i_3=I_2+1}^{I_3} L_{i_3jk}^{DFT} \cdot x_{i_3}^{DFT} < N_{jk}^{max}, \quad (21)$$

where  $N_{jk}^{max}$  is the capacity for section between stations  $j$  and  $k$  for railroad, trains/day.

For some of the itineraries serving major administrative and business centres, additional restrictions on the frequency of transport links can be set:

$$x_{i_1}^{FT} \geq M_{i_1}; x_{i_2}^{AFT} \geq M_{i_2}; x_{i_3}^{DFT} \geq M_{i_3}; \quad (22)$$

where  $M_{i_1}$ ,  $M_{i_2}$  and  $M_{i_3}$  are the minimum number of fast, accelerate fast, and direct fast trains to meet the transport needs of passengers between major administrative and business centres, trains / day.

## 2.5. Method for selecting the optimal transport plan

The final phase of the methodology includes a scheme selection. The optimal scheme is selected by criterion, minimum value of ratio  $r_g$  of the normalized costs (received from direct operating costs), and the scores corresponding to the AHP priority.

$$r_g = \frac{c_g}{a_g} \rightarrow \min \quad , \quad (23)$$

where  $c_g$  is the normalized costs for variant scheme  $g$ ;  $a_g$  is the AHP score for variant scheme  $g$ ; and  $g=1, \dots, G$  is the number of variant schemes.

The minimal value of this ratio presents the optimal scheme.

The normalized costs present the proportion of direct operational costs for each of the variant schemes.

$$c_g = \frac{R_g}{\sum_{g=1}^G R_g}, \quad (24)$$

where  $R_g$  is the direct operating costs for scheme  $g$ , BGN/day.

This approach to choosing the optimal transport plan allows to evaluate the variant schemes according to criterion of minimum direct operating costs and complex criterion of the predefined indicators - the maximum AHP score. This allows to reduce subjectivism when making a decision, i. e., a combination of an expert and optimization method is made, taking into account of economic and technological factors in choosing a transport plan.

## 3. APPLICATION. CASE STUDY FOR BULGARIAN RAILWAY NETWORK

The complex methodology is applied for railway network of Bulgaria. In the research, schemes of organization of intercity passenger trains according to train categories and number of wagons are

examined. In the research, the category of DFT is investigated in transport plan if the condition (9) is met. This condition determines also the stops of DFT. The condition (9) is met for passenger flows between the following stations: Sofia – Plovdiv (0.37); Sofia – Stara Zagora (0.31); Sofia – Mezdra (0.43); Sofia – Pleven (0.34); Stara Zagora – Bourgas (0.45); Plovdiv – Bourgas (0.31), Pleven – Varna (0.25); and Gorna Oryahovitsa – Varna (0.49). Based on the coefficient of directness, the following routes of direct fast trains are defined: Sofia – Plovdiv (without intermediate stops); Sofia – Plovdiv – Bourgas (stops at stations Plovdiv and Stara Zagora); and Sofia – Gorna Oryahovitsa – Varna (stops at stations Mezdra, Pleven and Gorna Oryahovitsa). Fig. 1 presents the train itineraries in Bulgaria's railway network, with the solid lines denoting DFT (from  $x_1$  to  $x_3$ ), thin lines denoting AFT (from  $x_4$  to  $x_{10}$ ), and dashed lines denoting FT (from  $x_{11}$  to  $x_{27}$ ).

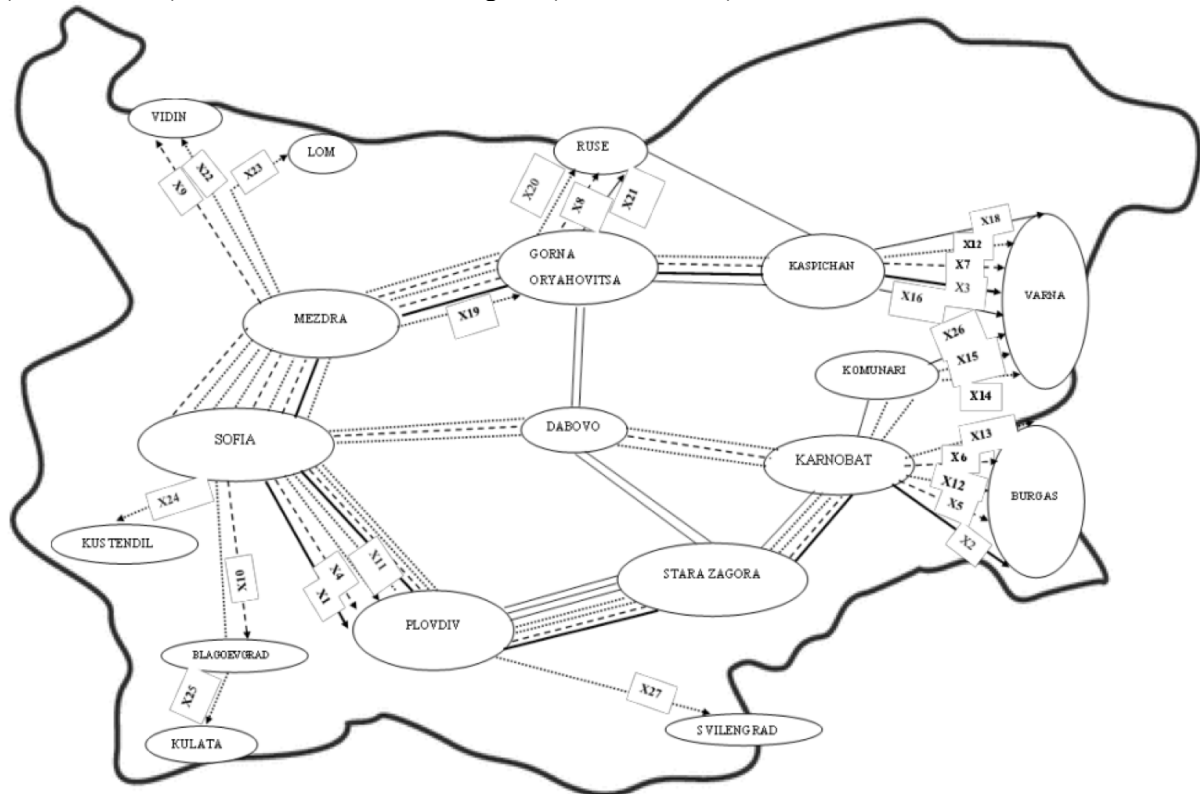


Fig. 1. Scheme of train itineraries

In the research, nine schemes of organization of intercity passenger trains have been examined:

- Scheme 1, Scheme 2, and Scheme 3: service with three categories of intercity trains: (DFT – 3 itineraries, AFT – 7 itineraries and FT – 17 itineraries. The total number of itineraries is 27.
- Scheme 4, Scheme 5, and Scheme 6: service with two categories of intercity trains: DFT – 3 itineraries, and FT – 17 itineraries. The total number of itineraries is 20.
- Scheme 7, Scheme 8, and Scheme 9: service with two categories of intercity trains: AFT – 7 itineraries and FT – 17 itineraries. The total number of itineraries is 24.

The number of wagons in train composition for schemes 1, 4 and 7 is 4 wagons and for schemes 2, 5 and 8 is 3 wagons. The number of wagons for scheme 3 is 3 wagons for DFT and 4 wagons for AFT and FT; the number of wagons for scheme 6 is 3 wagons for DFT and 4 wagons for FT; and the number of wagons for scheme 9 is 3 wagons for AFT and 4 wagons for FT.

A group assessment by experts was used to conduct the assessment of the criteria and application of the AHP method. For this purpose, a group of 7 experts from "BDZ - Passenger Transport" Ltd and from Technical University of Sofia was formed, who, with discussion, have determined the scores using Saaty's scale. The Super-Decision software was used to conduct the study. Tab.3 shows the results of the group evaluation of the experts for the criteria as well as the determined weights. On comparison of the criteria based on the determined weights, average speed has the greatest weight

(0.26), followed by availability of service with direct transport (0.24), transport satisfaction (0.17) and reliability (0.13). The value of CR shows that the consistency of the decision makers is considered satisfactory. The condition (13) is met.

Table 3

Prioritization matrix

Prioritization matrix	K1	K2	K3	K4	K5	K6	K7	Weight
K1: Transport satisfaction	1	1	5	1	2	1	1	0.171
K2: Average number of train stops	1	1	2	1/5	1/2	1/5	1	0.076
K3: Average distance travelled	1/5	1/2	1	1/5	1/3	1/5	1/2	0.039
K4: Average speed	1	5	5	1	2	2	2	0.260
K5: Reliability	1/2	2	3	1/2	1	1/2	3	0.130
K6: Availability of service with direct transport	1	5	5	1/2	2	1	5	0.240
K7: Transport capacity	1	1	2	1/2	1/3	1/5	1	0.084
CR=0.063<0.1								

Using Saaty's scale, the prioritization matrices were compiled for each of the criteria, comparing variant schemes. To assess the impact of passenger flows on the stability of the transport plan selection, the proposed methodology was applied when changing the passenger flows from minus 15% to plus 15% with the step 5%. The number of trains in each variant scheme and each change in passenger flows is determined by linear optimization model given in 2.3. The train's capacity utilization coefficient is 80%.

Fig. 2 shows the AHP scores for prioritizing the variant schemes without changing the passenger flows. The optimal variant scheme is scheme 3 by criterion maximum AHP score.

Tab. 4 presents the normalized costs, the AHP scores, and the value of ratio of normalized costs/AHP scores of all variant schemes when changing the passenger flows. The results presented in Tab.4 show the following:

- According to minimum direct operating cost, the optimal variant scheme is different for the change in passenger flow. For example, when the passenger flows is reduced from -15%, the optimal variant scheme is 7, which includes two train categories (AFT and FT) with a train composition of 4 wagons; when the passenger flows is reduced from -10% to 0%, the optimal variant scheme is 7; when the passenger flows increase from 5% to 15%, the optimal variant scheme is 1, including three train categories (DFT, AFT and FT) with train composition of 4 wagons; and when the passenger flows increase from 20% to 30%, the optimal variant scheme is 7.
- According to maximum AHP score, the optimal variant scheme when changing the passenger flows is the same – scheme 3 (DFT – 3 wagons; AFT – 4 wagons; and FT – 4 wagons).
- The optimal variant scheme using ratio of normalized costs/AHP scores for each change in passenger flows is also Scheme 3.

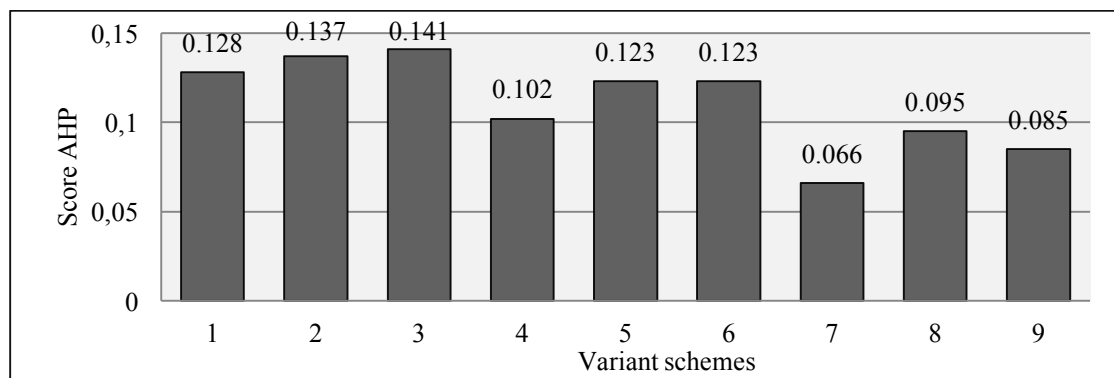


Fig. 2. Results for prioritization of variant schemes



Table 4

Normalized costs, AHP scores  
and ratio normalized costs/AHP scores for all variant schemes

		Variant Scheme								
		1	2	3	4	5	6	7	8	9
-15%	$a_g$	0.145	0.135	0.145	0.109	0.122	0.103	0.072	0.095	0.074
	$c_g$	0.1142	0.106	0.113	0.110	0.116	0.111	0.104	0.114	0.109
	$r_g$	0.788	0.787	0.778	1.016	0.957	1.080	1.445	1.207	1.475
-10%	$a_g$	0.142	0.125	0.142	0.108	0.118	0.119	0.069	0.093	0.084
	$c_g$	0.1098	0.1152	0.108	0.106	0.1198	0.110	0.104	0.115	0.109
	$r_g$	0.773	0.921	0.764	0.985	1.015	0.930	1.514	1.245	1.302
-5%	$a_g$	0.129	0.139	0.142	0.103	0.124	0.124	0.067	0.094	0.078
	$c_g$	0.1083	0.124	0.110	0.106	0.119	0.110	0.099	0.115	0.105
	$r_g$	0.839	0.892	0.779	1.037	0.961	0.894	1.478	1.232	1.353
0%	$a_g$	0.128	0.137	0.141	0.102	0.123	0.123	0.066	0.095	0.085
	$c_g$	0.1073	0.122	0.109	0.105	0.1235	0.109	0.099	0.114	0.106
	$r_g$	0.838	0.897	0.777	1.038	1.004	0.893	1.514	1.208	1.251
5%	$a_g$	0.119	0.136	0.131	0.097	0.119	0.118	0.079	0.094	0.107
	$c_g$	0.1040	0.123	0.106	0.106	0.119	0.1064	0.105	0.1191	0.110
	$r_g$	0.874	0.906	0.811	1.094	1.005	0.902	1.329	1.267	1.030
10%	$a_g$	0.111	0.145	0.139	0.101	0.113	0.103	0.076	0.102	0.11
	$c_g$	0.100	0.124	0.105	0.110	0.121	0.1106	0.101	0.1192	0.107
	$r_g$	0.901	0.860	0.756	1.092	1.076	1.074	1.329	1.169	0.976
15%	$a_g$	0.105	0.147	0.141	0.092	0.12	0.109	0.077	0.103	0.106
	$c_g$	0.1005	0.124	0.105	0.108	0.126	0.112	0.101	0.116	0.103
	$r_g$	0.958	0.845	0.748	1.175	1.056	1.034	1.319	1.135	0.980
20%	$a_g$	0.125	0.149	0.148	0.096	0.119	0.102	0.079	0.097	0.085
	$c_g$	0.108	0.118	0.112	0.108	0.120	0.109	0.104	0.111	0.106
	$r_g$	0.867	0.794	0.763	1.135	1.010	1.077	1.317	1.148	1.248
25%	$a_g$	0.124	0.135	0.138	0.108	0.125	0.114	0.062	0.094	0.100
	$c_g$	0.112	0.114	0.113	0.108	0.115	0.109	0.105	0.111	0.108
	$r_g$	0.91	0.849	0.825	1.004	0.923	0.959	1.700	1.187	1.087
30%	$a_g$	0.125	0.132	0.134	0.106	0.124	0.112	0.078	0.087	0.102
	$c_g$	0.112	0.114	0.1136	0.108	0.115	0.109	0.105	0.113	0.108
	$r_g$	0.900	0.867	0.848	1.021	0.929	0.975	1.349	1.300	1.064

$a_g$  - Score AHP Method;  $c_g$  - Normalized costs;  $r_g$  - ratio Normalized costs / Score AHP Method

To assess the stability of the obtained solution, a sensitivity analysis of the weight of the criteria was conducted. Tab. 5 shows sensitivity analysis of criteria. Criteria K2, K3, K4, K6 and K7 have

high degree of stability. Small degree of stability has criteria K1 (from 0% to 20.20%) and K5 (from 0% to 58.1%).

Table 5

## Sensitivity analysis of criteria

Criterion	K1	K2	K3	K4	K5	K6	K7
Degree of stability of weight	17.10%	7.60%	3.90%	26%	13%	24%	8.40%
From	0%	4.30%	0%	0%	0%	0%	0%
To	20.20%	100%	78.70%	85.80%	58.1%	91.50%	100%

The optimal variant scheme of the methodology offers an increase in the transport service with trains, reducing the direct operating costs with the amount of 5734 BGN/day compared with the existing situation. The proposed number of trains is 74 trains/day versus 73 trains/day in the existing situation. The results of this study demonstrate the effectiveness of organization of direct fast trains over long distances with fewer stops for directions Sofia-Plovdiv-Burgas and Sofia-Gorna Oryahovitsa-Varna. DFT are Sofia-Plovdiv (156 km – 1 pair/day; without intermediate stops), Sofia-Plovdiv-Burgas (450 km – 1 pair/day; two intermediate stops) and Sofia-Gorna Oryahovitsa-Varna (543 km – 2 pairs/day; three intermediate stops). The proposed transport plan is different in terms of categories, composition and itineraries compared with the current situation.

Fig. 3 presents a comparison of the number of pairs of trains for values of passenger trains capacity utilization coefficient  $\alpha=80\%$  and  $\alpha=90\%$  and increase of the passenger flow.

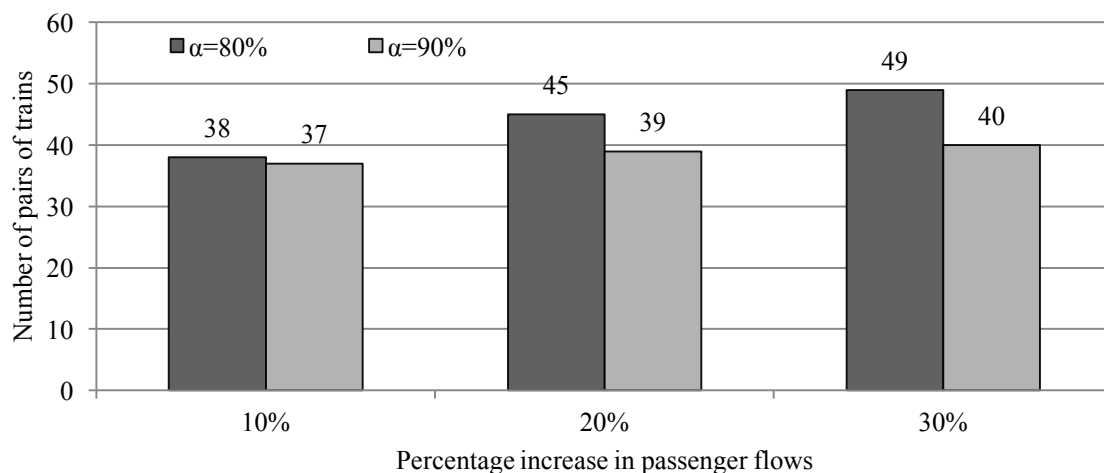


Fig. 3. Number of trains when changing passenger flows

The number of intercity trains in the current situation in Bulgarian railway network is 81. This number of train corresponds to the available rolling stock. From Fig.3, it can be seen that when the passenger flows increase more than 20%, the number of trains for values of passenger trains capacity utilization coefficient 80% significantly exceeds the number of trains for which rolling stock can be provided. Determination of the number of intercity trains for values of passenger trains capacity utilization coefficient 90% when the passenger flows increase more than 20% indicates that the number of pairs of trains can be reduced.

The results show the following:

- According to the parameters of the methodology, when the passenger flow increases from 20% to 30%, the rolling stock will be insufficient.
- Increased passenger flow from 20% to 30% can be carried with existing rolling stock but with reduced frequency.

#### 4. CONCLUSIONS

The study has shown the following results:

1. The main importance for transport plan selection has the criteria average speed (0.26), availability of service with direct transport (0.24), transport satisfaction (0.17) and reliability (0.13).
2. To improve the organization of railway passenger transport in Bulgaria, it is appropriate to introduce service with direct fast trains over long distances with fewer stops for directions Sofia-Plovdiv-Burgas and Sofia–Gorna Oryahovitsa–Varna.
3. An original complex methodology for selection of transport plan of intercity passenger transport has been elaborated taking into account the variation of passenger flows. As a criterion for selecting the optimal transport plan, the ratio of the normalized costs to the scores corresponding to the AHP priority has been applied.
4. Using the main passenger flows (without percentage change) in complex methodology allows determining the number and itineraries of trains for daily service. The amending of passenger flows can be used in determining the extraordinary, seasonal and calendar additional trains. The change in passenger flow can also be used in operational management.
5. The proposed methodology can be applied for both railway line and railway network. It also could be used to determine the transport plan of other categories passenger trains such as suburban trains or international passenger trains.

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