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INVESTIGATION THE SCHEME OF MOVEMENT OF THE PASSENGER TRAINS WITH COMBINATION OF THEORY FOR DECISION AND LINEAR OPTIMIZATION METHOD

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Abstract:
In the study has been applied combined method of linear optimization and decision tree for determining the optimal organization of different categories passenger intercity trains. In the paper was examined the possibility of introducing the direct regional fast trains by reducing the number of stops. It was introduced a coefficient of directness of passenger flows as an indicator of selection of direct assignments of regional fast trains. Certain alternatives (variant schemes) and strategies for services of different passenger flows were determined. In research was applied an expert method to determine the probabilities for variation of passenger flows and transport demand. The model was experimented of rail line Sofia – Plovdiv– Burgas and was proposed an organization of railway passenger transport.

Keywords: *decision tree, linear optimization, trains, passenger flows, intercity, railway transport, expert*

1. Introduction

In many European countries operate intercity trains (Intercity), with reduced stops and high speed, thus they compete with alternative transport service. In Bulgaria, the rail passenger transport is served by three categories of trains - passenger, fast, and accelerated fast trains. The last category has reservation of seats and has a reduced number of stops. The number of stops of fast trains is a big. Thus are created a convenience for passengers from smaller towns, but for passengers travelling on direct long-distance the time during increases. The accelerated fast trains on certain long destinations are also not competitive on bus services, offering direct and fast trips. The important factors for passengers are the speed, the straightforward journey, the frequency of service, the price of the ticket. For railway operators, it is important to determine the optimal parameters of the organization of passenger trains - frequency, railway stations to stop the various categories of passengers trains, composition of trains, operating costs.

The objectives of this research are:

- To investigate the possibility of introducing additional category intercity trains - accelerated direct fast trains with obligatory reservation of seats ;
- To elaborate an optimal organization of the different categories of fast intercity trains with the possibility of application in various strategies of change of passengers and demand of rail transport services.

2. Schemes of organization of passenger intercity trains

In this research has been investigated the railway line Sofia - Plovdiv – Burgas. This railway direction of the railway network in Bulgaria is a part of an international railway corridor and it is characterized by significant passenger flows. In this direction there are alternative routes of the bus transport.

2.1. Coefficient of directness

To determine the stops of new category trains – direct regional fast trains in the study was introduced the following factor for directness:

- Coefficient of directness travel from station i :

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

where: P_{ij} is the passenger flows between railway stations i and j , pass. per day.

In the research was taken the following minimum values of the coefficient of directness of the station and the total passenger flow departing from the station i.

$$\lambda_{ij} \geq 0{,}25 \text{ and } \sum_{j=i+1}^{n} P_{ij} \geq 250 \text{ pass./day} \qquad (2)$$

This conditions determine a directly assignment train per day in scheme of railway passenger transport.

The passenger flows is determined by the information about ticket sales by month. In the study was used information for month with maximal number of passengers.

The station for forming a category direct fast train and train stop must perform the following conditions:

- Transport node;
- Transport center;
- Administrative center;
- Number of the city's population over 100 thousand;
- The coefficient of directness to perform the condition (2).

Figure 1 shows the coefficient of directness of passenger flows departing from Sofia Central Station to stations of the railway line Sofia-Plovdiv (by accelerate fast train and fast train). For this destination the condition (2) is satisfied only for passenger flows Sofia - Plovdiv. The coefficients of directness of passenger flows Sofia-Burgas, Plovdiv-Burgas and Plovdiv-Stara Zagora are λ=0,25. Taking into account the above conditions for the formation of a direct fast train could examine the effectiveness of the movement of direct fast trains Sofia-Plovdiv, without stopping at intermediate stations, Sofia - Burgas with stopping at stations Plovdiv and Stara Zagora.

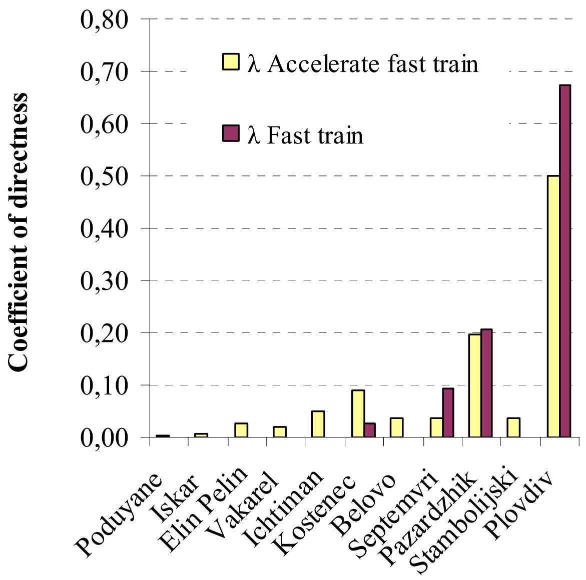


Fig.1. Coefficient of directness for station Sofia (passengers in accelerate fast trains and fast trains)

2.2. Formation of variant schemes

In the research have been examined two schemes of organization of intercity passenger trains which are shown in fig.3.

- Scheme 1: The service has two categories intercity trains – direct accelerate fast trains and fast trains.
- Scheme 2. The service has three categories intercity trains – direct accelerate fast trains, accelerate fast trains and fast trains.

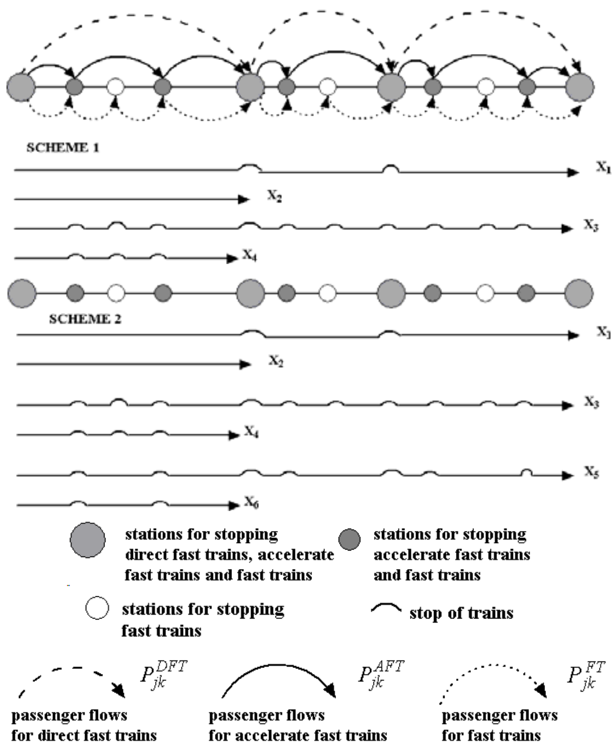


Fig.2. Schemes for organization of passenger intercity trains

For both schemes have been examined variants of service with different compositions of the number of cars on the passenger train.

Transport variants are: a_1 - transport scheme 1 in which the trains are composed with 3 cars; a_2 - transport scheme 1 in which trains are composed with 4 cars; a_3 - transport scheme 1 in which trains are composed with 3 cars for the route Sofia-Plovdiv and with 4 cars for the route Sofia-Burgas; a_4 - transport scheme 2 in which the trains are composed with 3 cars; a_5 - transport scheme 2 in which trains are composed with 4 cars; a_6 - transport scheme 2 in which trains are composed with 3 cars for the route Sofia-Plovdiv and composed with 4 carriages for the route Sofia-Burgas.

3. Optimization the organization of movement of passenger trains

In this study have been examined two approaches to optimize the organization of passenger trains:

- First approach (state of certainty)- Development of variant schemes and selection of optimal organization using the method of linear optimization. When the situation of transportation and the size of passenger flows are known the system for decision-making is in a state of certainty. In these cases, the optimization of railway passenger transport could be solved by the methods of linear, dynamic optimization, or other mathematical methods, [1,5].
- Second approach (state of uncertainty) - combined method by applying the theory for decision and linear optimization.

The contemporary development of passenger transport offers competitive transport modes, in which the passenger can select the best option for him to travel. Therefore, in many cases when have to be developed a strategy for service with passenger transport on a railway direction the decisions should be taken in the state of uncertainty, i.e. its have a probabilistic nature. In these cases, an appropriate method of providing an optimal organization of passenger transport is the method of decision tree. Decision analysis can be used to determine an optimal strategy when a decision maker is faced with several decision alternatives and an uncertain or risk-filled pattern of future events.

3.1. First approach

In the first approach the studied system is considered in a state of certainty..

When the situation of transportation and the size of passenger flows are known the system for decision-making is in a state of certainty. In these cases, the optimization of railway passenger transport can be solved by the methods of linear, dynamic optimization, or other mathematical methods, [1,5].

To determine the optimal organization of transportation is necessary to develop variant schemes for organization by categories trains which to be compare by criterion minimum transport costs. For each variant scheme is applied individually linear optimization model to minimize the total transport cost.

Figure 2 shows an example of passenger flows for different categories intercity passenger trains.

$$R_k = \sum_{i_1=1}^{I_1} r_i^{o,FT}.l_i x_i^{FT} + \sum_{i_1=1}^{I_1} r_i^{f,FT}.x_i^{FT} + \sum_{i_2=I_1+1}^{I_2} r_i^{o,AFT}.l_i x_i^{AFT} + \sum_{i_2=I_1+1}^{I_2} r_i^{f,AFT}.x_i^{AFT} + \sum_{i_3=I_2+1}^{I_3} r_i^{o,DFT}.l_i x_i^{DFT} + \sum_{i_3=I_2+1}^{I_3} r_i^{f,DFT}.x_i^{DFT} \to \min, \quad \text{lv./day} \qquad (3)$$

where: FT is fast train, AFT is accelerate fast train, DFT is direct fast train; $i_1 = 1,\ldots,I_1$ is the number of assignments of fast trains; $i_2 = I_1 + 1,\ldots,I_2$ is the number of assignments of accelerate fast trains; $i_3 = I_2 + 1,\ldots,I_3$ is the number of assignments of direct fast trains; r_i^o is the operational costs for train destination i, lv./km; r_i^f is the infrastructure costs for rail infrastructure, l_i is the length of destination of train i, km; x_i is the number of trains of destination i, $i = 1,\ldots I_3$ is the number of assignment of passenger trains of investigated categories, k is the number of variant scheme.

The objective function (3) defines the optimal plan that provides the realization of the necessary passenger transportation with minimal transportation costs.

The restrictive conditions are:

$$\sum_{i_1=1}^{I_1} L_{ijk}^{FT}.a_i^{FT}.\alpha_i^{FT}.x_i^{FT} \geq P_{jk}^{FT} \qquad (4)$$

$$\sum_{i_2=I_1+1}^{I_2} L_{ijk}^{AFT}.a_i^{AFT}.\alpha_i^{AFT}.x_i^{AFT} \geq P_{jk}^{AFT} \qquad (5)$$

$$\sum_{i_3=I_2+1}^{I_3} L_{ijk}^{DFT}.a_i^{DFT}.\alpha_i^{DFT}.x_i^{DFT} \geq P_{jk}^{DFT} \qquad (6)$$

where: a_i is the number of seats in a train by assignment i; α_i is the coefficient of utilization of seats in a train assignment i; $\alpha_i \leq 1$; P_{jk} is the passenger flows from station j to station k, pass. per day; $j = 1,\ldots,J$ is the number of station where the passenger flows start; $k = 1,\ldots,K$ is the number of station where the passenger flows finish. In the general case $j = k$, it is assumed when к > j - even direction; when к < j - odd direction. L_{ijk} is the coefficient that takes into account the possibility of passenger train i to serve the assignment of passenger flow P_{jk}; L_{ijk} =1, where it is possible trains i - th assignment to serve passenger; L_{ijk} =0, otherwise.

Fig.3 shows a comparison of transport costs for the variant schemes determined by the linear optimization model. The both schemes 1 and 2, with a composition of 3 wagons are similar results. An optimal scheme is the second in which moving direct fast trains, accelerate fast trains and fast trains . All trains are composition of 3 wagons. In Figure 4 is shown optimal organization that is compared with the current organization of the intercity fast trains to direction Sofia-Plovdiv-Burgas.

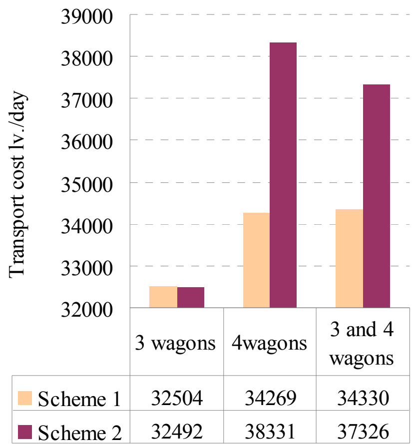


Fig.3. Comparison of transport cost for variant schemes

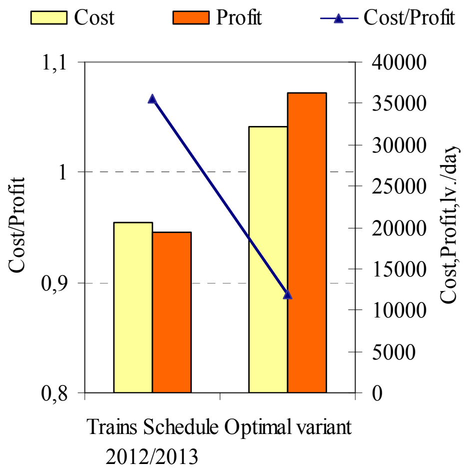


Fig.4. Comparison of cost and profit

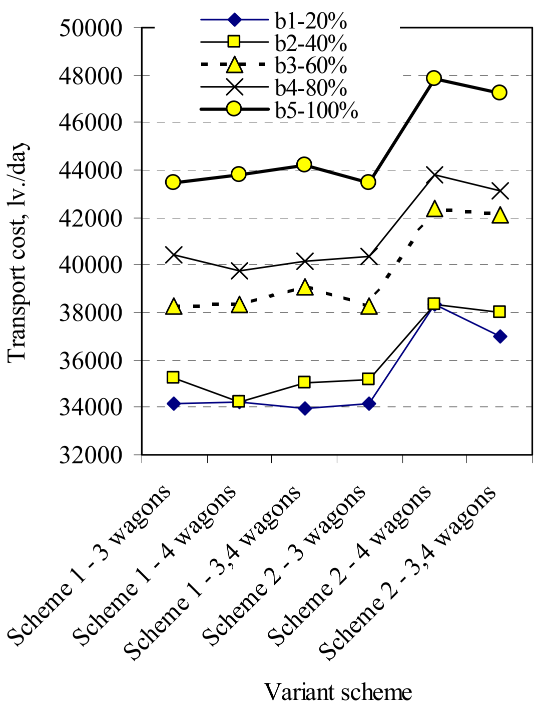


Fig.5. Comparison of transport cost for different passenger flows

For the proposed organization the costs exceed the current situation, but the ratio of costs to profit reduced. In this case there is the income. The number of trains by assignments in the optimal variant are: Sofia - Plovdiv: 9 pairs of trains; Sofia - Burgas: 7 pairs of trains; the current trains schedule have for the route Sofia - Plovdiv 3 pairs of trains and Sofia-Burgas 3 pairs of trains. The optimal variant is (a4) with three categories of passenger trains – direct fast trains, accelerate fast trains and fast trains.

Figure 5 shows the change in transport costs for percentage change of passenger flows. For each of the variants the transport costs are determined by the linear optimization model. At 20%, 60% and 100% increase in passenger flows the optimal variant is fourth variant (a4), and in other cases the optimal variant is the second (a2), that there are different solutions. In such cases, when you need to predict the efficient organization of transport is appropriate to apply the second approach.

3.2. Second approach (combined method)

The combined approach consists of compiling a payment matrix by applying the method of decision tree. Payment matrix is made after a preliminary optimization method of linear programming.

In this approach is considered transport strategies which correspond to the variants discussed above.

The probabilistic environment for decision making is given with the states $P(b_i)$, which corresponds to an average daily demand of traffic with appropriate percentage increase in passenger. In this research was examined an increasing of passengers from 20% to 100% with step 20%. The transport costs for each case are determined separately and are calculated by linear optimization using formulas (3,4,5,6), i.e. the payment matrix is formed by using previously performed optimizations for each strategy and each state. The coefficient of utilization of places was accepted α_i=0,6. For the investigated strategies and states is formed a payment matrix. The payment matrix that determines the transport cost of the company at different strategies in different cases is shown in table 1 .

Tab.1

Strategy	States (A percentage of increasing passenger flows)				
	b1 20%	b2 40%	b3 60%	b4 80%	b5 100%
a1	34150	35212	38276	40399	43464
a2	34256	34256	38316	39722	43781
a3	33973	35035	39094	40155	44215
a4	34140	35201	38266	40388	43453
a5	38320	38320	42380	43786	47845
a6	36971	38032	42092	43153	47212

A decision tree is a diagrammatic presentation of various alternatives, their possible outcomes with associated probabilities and their possible payoffs, in a decision-making situation, [2,3,4,6]. A decision tree is a chronological representation of the decision problem.

Each decision tree has two types of nodes; round nodes correspond to the states, while square nodes correspond to the decision alternatives.

The method of decision tree can be implemented in two versions:

- with the use experts to set the probabilities of different states
- by using experts to set the probabilities of demand of rail transport.

3.2.1. Decision tree with probabilities given by experts for states

The expected value of a decision alternative is the sum of weighted payoffs for the decision alternative.

The expected value (EV) of decision alternative a_i is defined as:

$$EV(a_i) = \sum_{j=1}^{n} P(b_j).R_{ij} \qquad (7)$$

where: a is the alternatives, b is the states, n is the number of states, $j = 1,\dots,n$; $P(b_j)$ is the probability of state b_j; R_{ij} is the payoff corresponding to decision alternative a_i and state b_j.

$$\sum_{j=1}^{n} P(b_j) = 1 \,, P(b_j) \geq 0 \text{ ,for } j = 1,\dots,n \qquad (8)$$

In this research for alternatives are chosen the variant schemes, for states are chosen the percentage variation of passenger flows b_j.

The probabilities of states are determined by individual decision maker or by experts. In the study probabilities of states $P(b_j)$ are determined by 5 experts - specialists marketing passenger railway transportation. The values are shown in table 2. For data that are given for experts are determined the expected value of transport cost (EV) and the optimal strategy a. In all cases the optimal strategy is for variant 2 (a2). To assess the opinion of experts are defined the statistical indicators:

- Average value:

$$\overline{p_j} = \sum_{i=1}^{n} p_{ij} \Big/ n \qquad (9)$$

where: $j = 1,..,m$ is the number of states, n is the number of expert.

- Standard deviation:

$$\delta = \sqrt{\frac{(p_{ij} - \overline{p_{ij}})^2}{1-n}} \qquad (10)$$

- Coefficient of variation:

$$\nu = \frac{\delta}{\overline{p_j}} \qquad (11)$$

where: p_{ij} is the value given by experts for each column for payment matrix; $\overline{p_{ij}}$ is the average value.

The evaluation of the opinion of experts is carried out in columns for each state b_j separately. The evaluations of experts for each states are relatively homogeneous (ν <0,5). High degree of homogeneity are estimated at 20% and 40% increase in passenger flows.

Tab.2.

№	b1 20 %	b2 40%	b3 60%	b4 80%	b5- 100%	EV	a
1	0,35	0,300	0,150	0,100	0,100	36364	a2
2	0,50	0,200	0,100	0,100	0,100	35958	a2
3	0,40	0,350	0,100	0,100	0,050	35685	a2
4	0,60	0,250	0,050	0,050	0,050	35209	a2
5	0,65	0,225	0,075	0,025	0,025	34935	a2
$\overline{p_j}$	0,51	0,245	0,095	0,075	0,075	35630	
δ	0,11	0,06	0,03	0,03	0,03		
ν	0,22	0,23	0,35	0,42	0,42		

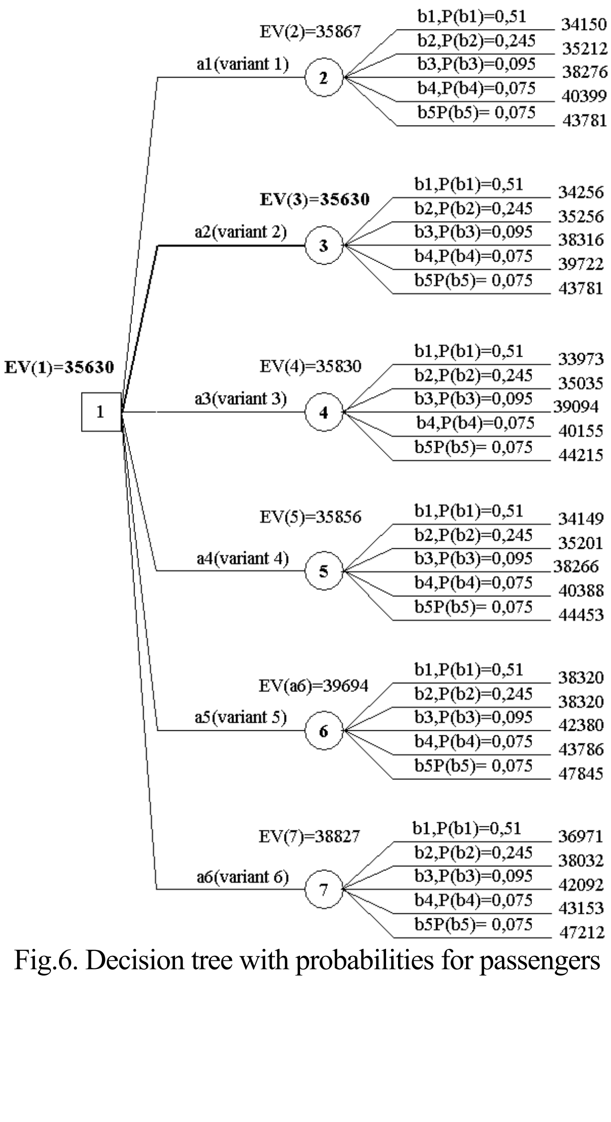


Fig.6. Decision tree with probabilities for passengers

In fig.4 is drown the decision tree using average probabilities $\overline{p_j}$.

From the initial peak go six branches corresponding to the strategies (alternatives) of the company. End of each branch ends with a node - a result that is marked with a circle. These nodes are numbered consecutively with number 2, 3 to 7. They correspond to the probability state decision-making. Of any such peak go several branches corresponding to the possible states of the company b_1, b_2 to b_5. The branches are marked with conditional probabilities of the corresponding states. The values of the payment are recorded to nodes - result, i.e. to peaks 2, 3 and 7. The smallest value determines the optimal solution, which is Variant 2, i.e. service by express and fast trains, composed with 4 cars.

In figure 7 is shown a comparison of expected value for both variant schemes. Figure 6 and figure 7 shows the optimal organization of passenger intercity trains. The optimal variant is (a2) with direct fast trains and fast trains composed with 4 wagons.

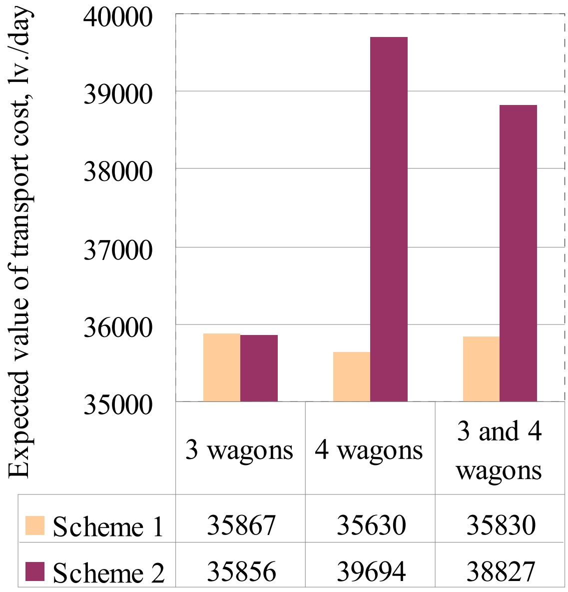


Fig.7. Expected value of transport cost for decision tree with probabilities for passengers.

3.2.2. Decision tree with probabilities of expert for states and transport demand

The choice of decision for the best alternative by application the method of decision tree could be done also with experts by setting the probabilities of different conditions for transport demand. In this case, the experts give the probabilities in different transport demand $P(I_k / b_j)$, $k = 1,\dots,K$. These are the probabilities to different transport demand. In the paper is investigated big (I_1) and small (I_2) transport demand.

The conditional probability of states b_j, provided that the expert opinion is given by the indicator I_i is given by Bayes's formula:

$$P(b_j / I_k) = \frac{P(b_j).P(I_k / b_j)}{P(I_k)} \qquad (12)$$

$$P(I_k) = \sum_{j=1}^{n} P(b_j).P(I_k / b_j) \qquad (13)$$

The sum of the conditional probabilities that come from the same vertex is equal to one.

The expected value (EV) of decision alternative in this case a_i is defined as:

$$EV(a_i) = \sum_{j=1}^{n} P(b_j / I_k).R_{ij} \qquad (14)$$

In the study the experts set the probabilities for transport demand for case of the average probability of increasing of passenger flows that is determined at the first stage. In table 3 is shown data given by experts and statistical indicators. In table is shown data for big transport demand (I_1). The values of coefficients of variation show a relatively homogeneous of data. In table 4 is shown the parameters of research with decision tree. The probabilities of states are determined by averages values in table 2, the probabilities of big and small demand of passengers transport are determined by data in table 3.

Tab.3

№	b1 20%	b2 40%	b3 60%	b4 80%	b5 100%
1	0,35	0,15	0,3	0,25	0,2
2	0,4	0,3	0,2	0,3	0,3
3	0,3	0,35	0,3	0,4	0,4
4	0,2	0,35	0,3	0,25	0,2
5	0,3	0,4	0,4	0,3	0,3
$\overline{p_j}$	0,31	0,31	0,3	0,3	0,28
δ	0,07	0,10	0,07	0,06	0,08
ν	0,21	0,31	0,24	0,20	0,30

Tab.4

States	b1 20%	b2 40%	b3 60%	b4 80%	b5 100%
Number of passengers	2875	3086	3297	3508	3719
Probability	0,51	0,245	0,095	0,075	0,075
I_1 - big transport demand	0,31	0,31	0,3	0,3	0,28
I_2 - small transport demand	0,69	0,69	0,7	0,7	0,72

In fig. 8 is shown the decision tree for this case. The first peak is associated with the node - result (node 2). From this node have two branches that correspond to indicators of the expert - big and small demand for railway transport.

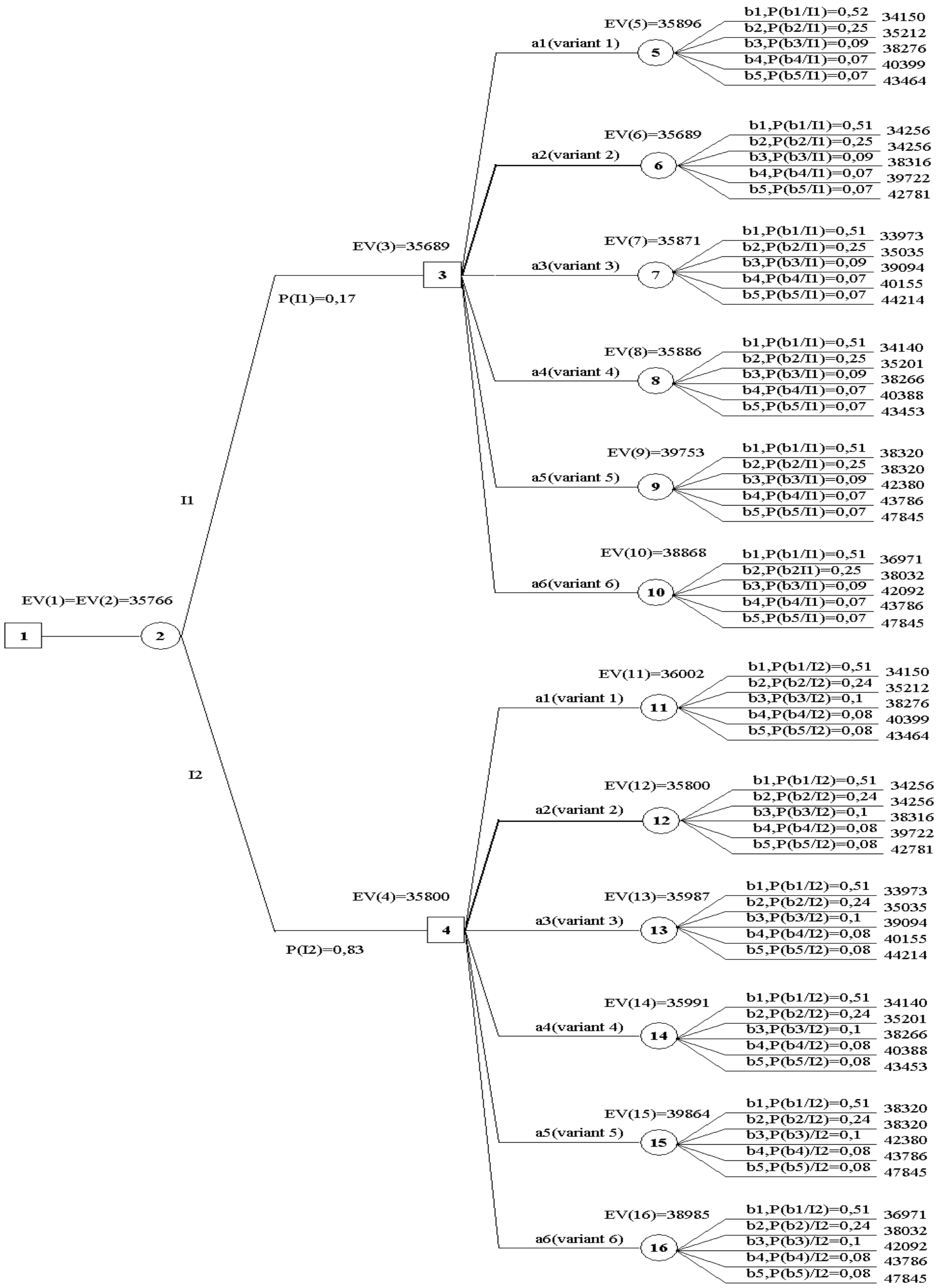


Fig.8. Decision tree with probabilities for passengers and transport demand

At the end of these branches are connected node 3 and 4, which are nodes - solution. From them go six branches corresponding to the strategies of the company. Of any such peak go several branches corresponding to the possible states of the company. On the branch is marked Bayesian probability. The minimum expected value (EV) of decision alternative is determined by a formula 14. It is in variant 2 for both the case of transport demand (big and small). The optimal organization of transportation in this case also has express and fast trains composed with four cars.

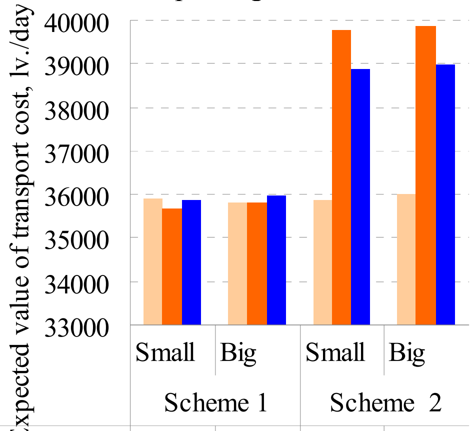
In fig. 9 are shown the results for expected value of transport cost for decision tree.

The proposed optimal organization by combined approach is shown in table 5 (for 20% increase of passengers). The trains are composed with four wagons.

Tab.5

Categories / Destination	Direct Fast Trains	Accelerate Fast Trains	Fast Trains
Sofia-Plovdiv	3	1	5
Sofia-Burgas	3	1	3

The proposed organization is characterized by an increased frequency of service, offering direct trains assignments, rapid transportwith which intercity rail services could become competitive in the transport market. Taking into account the provided track of rehabilitation in BDZ programs to 2020, the time needed to travel in investigated direction will be reduced by about 20%. It will result to attractive and competitive railway passenger's transport. It could be expected an increase in passenger flows.



	Scheme 1 Small	Scheme 1 Big	Scheme 2 Small	Scheme 2 Big
3 wagons	35896	35800	35886	35991
4 wagons	35689	35800	39753	39864
3 and 4 wagons	35871	35987	38868	38985

Fig. 9. Expected value of transport cost for decision tree with probabilities for passengers and transport demand

Conclusions

The conducted research allows us to make the following conclusions:

- In research have been developed a complex methodology for the selection of the optimal scheme of organization of intercity passenger transport based on combinatorial method of linear optimization and decision tree.
- In the study are introduced coefficients of directness of passenger flow, with which is defined scheme for direct fast trains. It is proposed a minimum value of these coefficients with which can be formed a train assignment in the variant scheme.
- The conditions for stopping of direct fast trains at station have been determined.
- In research is examined an organization of transportation by a new category of long-distance passenger trains – direct fast trains. The calculations by methodology prove the effectiveness of movement of three categories intercity fast trains: direct, accelerate and fast trains.
- The alternatives of transportation with railway transport are proposed.
- The data given by experts for probabilities of passenger flows and transport demand have been evaluated.
- The payment matrix is composed to study by the theory of decision tree. The elements of this matrix are determined in each case by a linear optimization model with criterion minimum transportation costs.
- The methodology for selecting the optimal organization of railway intercity passenger transportation can be applied to determine the organization of others categories passengers trains as suburban trains, as well as a complex an organization of all categories of passenger trains on the railway line or railway network.

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ИЗСЛЕДВАНЕ НА СХЕМАТА НА ДВИЖЕНИЕ НА ПЪТНИЧЕСКИТЕ ВЛАКОВЕ С КОМБИНИРАНО ПРИЛАГАНЕ НА ТЕОРИЯТА ЗА ИЗБОР НА РЕШЕНИЕ И ЛИНЕЙНО ОПТИМИРАНЕ

В изследването е приложен методът на линейното оптимиране и на дървото на решенията за определяне на оптимална отганизация на различни категории междуградски влакове. Изследвана е възможността за въвеждане на директни ускорени бързи влакове, чрез намаляване броя на спиранията. Въведен е коефициент на директност на пътникопотоците, като показател за избор на директни назначения ускорени бързи влакове. Определени са алтернативи (вариантни схеми) и състояния на изменение на пътникопотока. В изследването е приложен експертен метод за определяне на вероятностите на изменение на пътникопотока и на транспортно търсене на услуги. Разработената методика е експериментирана за жп направление София – Пловдив – Бургас и е предложена организация на превоз.