A multi-criteria selection of the transport plan of intercity passenger trains

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Abstract. The study proposes a methodology based on Sequential Interactive Modelling for Urban Systems (SIMUS) method for selection the transport plan of intercity passenger trains. The methodology uses linear programming to assess different transport plans. The research includes five steps. First, the alternatives transport plans of movement of passenger trains are determined. Second, the criteria for multi-criteria optimization of transport plan are defined. The SIMUS method is applied in the third step for ranking the alternatives. New approaches of integrated SIMUS-VIKOR and SIMUS-TOPSIS procedures have been proposed and compared. The verification of the results has been conducted in the fourth step by applying the Multi-criteria Optimization and Compromise Solution method (VIKOR) and Technique for Order of Preference by Similarity to Ideal Solution method (TOPSIS). The fifth step includes the determination of the suitable transport plan according the changes in passenger flows. This step takes into account of uncertainty of process. The methodology has been applied for study the transport plan of passenger trains in Bulgaria's railway network. The suitable organization of intercity passenger trains has been proposed. The elaborated new approach could be applied to make decision on a separate railway line or throughout the railway network, as well as for international passenger transport.

1. Introduction
The passenger trains planning are an important element in the railway operation process, which influences to determination of the efficiency of the railway system. It is a basis for draw up the train timetable, crew scheduling, rolling stock planning, and is related to the operating costs and economic benefits. The determination of the transport plan is an optimization problem related to obtain the trains frequencies, categories of trains, stop-schedules and others operating parameters.

The optimization and multi-criteria methods have been applied for studding the choosing of the transport plan of trains. The mixed-integer linear programming models of traffic management in railway have been proposed in [1, 2]. In [1] the authors elaborated model to optimize the train routes and train scheduling using mixed-integer linear programming. The research was conducted to the Chinese railway network. A two-layer optimization model for high-speed railway is elaborated in [3]. The first model determines the service frequencies and achieves an optimal stop-schedule. The nonlinear programming and genetic algorithm are applied to minimize the total operating cost and unserved passenger volume. The second model is based on mixed integer programming to maximize the passenger volume and minimize the total travel time for all passengers. The model has been experimented on Taiwan high-speed railway and also in Beijing-Shanghai high-speed railway line in China. In [4] are proposed an integrated line planning and timetabling model. The objective function presents a minimization of the total time spend by passengers waiting at origin and transfer stations and the operational costs. The
model is used of Israel Railways. The binary integer programming models to optimize the stop planning according the passenger demand is elaborated in [5]. In [6] is proposed a multiobjective model for optimization the transport plan of passenger trains. The objective function consists minimizing the total passenger train stop times and minimization of the transportation costs. The mathematical model that takes into account of the operating costs and the costs of passengers are presented in [7]. The costs of passengers include the transport costs and the costs for waiting the train, train changing and others. The revenue-maximization model for transport planning is elaborated in [8]. The model considers the operating costs and costs of travel time. It accounts of the train scheduling and the trains stop, and also the passenger demand to ticket pricing.

The multi-criteria methods have been applied in [9-12]. The multi-criteria analysis have been applied in [9] to choice and planning the suitable urban transportation. The authors used main criteria and sub-criteria to assess different alternatives. The main criteria that were applied are: economic, social impact, engineering, environmental impact. The model was experimented for monorail planning and route selection for Ankara. In [10] is elaborated a model for railway route planning based on multi-criteria methods. The criteria for assessment the different transport plans that were studied are the investment needed for railway construction, railway operating and maintenance costs, number of train and others. The methodology is applied for four railway routes on the Corridor X. In [11] the efficiency of the highway passenger transport enterprises is analysed according the criteria as the time, comfort, safety and rapidity.

The fuzzy linear optimization model for determination the number of passengers trains in railway network have been elaborated in [12]. As the optimization criterion has been used the minimum of operating costs. The model is integrated with multi-criteria analysis to choose the suitable transport plan of passenger railway transportation.

It can be concluded that the operating costs and the time travel are the main factors that influenced on the transport planning. Different techniques are applied to select the best transport plan as optimization models, multi-criteria analysis. The application of the multi-criteria analysis requires the use of experts to evaluate the criteria connected to transport planning. A major disadvantage of these approaches is subjectivism in decision-making. The multi-criteria method that does not use the expert’s assessment is the SIMUS (Sequential Interactive Modelling for Urban Systems) procedure. It is hybrid approach that uses Linear programming, Weighed Sum Method (WSM) and Outranking, [13-15]. The SIMUS is use in different areas. It is applied in [16] to make decision about the carriage of containers in intermodal transport.

The aim of this study is to elaborate a methodology based on SIMUS application for assessment the alternative transport plans for passenger trains taking into account of different criteria that influence of transportation process.

2. Methodology

The methodology of research includes the following steps, figure 1:

Step 1: Determination the alternatives for transport plan of intercity trains. Determination the number of trains for each transport plans by using linear optimization according the criterion minimum direct operating costs.

Step 2: Defining the criteria for assessment of the alternatives.

Step 3: Application the SIMUS Method for ranking the alternatives. Experimentation a new approaches of integration of SIMUS and VIKOR methods, and also of SIMUS and TOPSIS methods for ranking the alternatives.

Step 4: Verification of results. This step includes a comparison of results between SIMUS, VIKOR and TOPSIS methods.

Step 5: Determination of the suitable alternative according the changes in passenger flows. This step takes into account of uncertainty of process.
2.1. Determination the alternatives of the transport plan in railway network

The transport plan of passenger trains includes the number of categories trains, number of trains in each category, number of itineraries of trains by categories, number of wagons in train composition. The determination of the parameters of transport plan contains the following steps: first, the itineraries and the categories of intercity trains in each transport plan have to be set; second, the linear optimization model to determine the number of trains of each category is applied for each transport plan. The study applies the fuzzy linear optimization model given in [12]. The number of transport plans defines the number of alternatives, and depends on values of passenger flows, possibilities of the railway infrastructure and the railway operator. The decision maker determines the number of alternatives.

2.2. Defining the criteria for assessment of the alternatives.

The second step of the methodology determines the criteria to assess the alternatives of transportation of intercity trains. The following criteria are proposed in the study:

- \( C_1 \) – Frequency, trains/day. This criterion shows the number of the trains in transport plan.
- \( C_2 \) – Average number of train stops per train. The organization of the category of intercity trains with reduced number of stops allows decreasing the travel time.
• $C_3$ – Average operating speed, km/h. This criterion presents the average speed of transport services of all categories intercity trains in the transport plan.

• $C_4$ – Trains capacity, seats/day. This criterion indicates the number of seats offered by the transport plan per day. The number of seats depends on the number of trains and the number of wagons in the train composition.

• $C_5$ – Direct operating costs, BGN/day. This criterion is important for railway operators, the purpose of which is to make transport with minimal operating costs.

2.3. SIMUS method for ranking the alternatives
The SIMUS procedure consist the following steps, [14]:

First, the decision matrix of criteria and alternatives is made. The columns present the alternatives, and the rows show the criteria. The type of optimization for each criterion is defined.

Second, the normalized matrix is calculated. It could be used different normalization methods, as total sum in row, maximum value in row, Euclidean formula and others. The choice of the method depends of decision maker. The results of the normalization have not influenced of the ranking. The limit to each criterion is determined. The limits can be set by the decision maker or determined by values given in normalized matrix. In the second case when the objective function is of maximum, the value of limit is set as equal of maximum normalized value of the row. In the case of minimum the value of limit is equal of minimum normalized value of the row.

Third, the procedure of SIMUS method is formed based on linear programming. The normalized matrix, the limits, and the type of optimization are used to define the optimization models for each of criterion. The first optimization model is made by using the first criterion as the objective function which. This criterion is removed from decision matrix. The others row of the matrix present the restrictive conditions of the linear model. The procedure is repeated with the other criteria. The number of linear optimization models is equal to the number of criteria. The results of linear models are recorded in Efficient Results Matrix (ERM). The values show the score of each alternative for each linear model.

Fourth, the ranking of alternatives is made. The SIMUS method is based on two approaches to make decision – Weighed Sum Method (WSM) and Outranking. The ranking are named ERM Ranking and PDM Ranking.

The procedure of ERM ranking consist the following steps: normalization of the ERM; summing the elements in each column (SC); determination the number of participation of each alternative in the each column of normalized ERM (PF); normalization the given results by dividing to the number of criteria (NPF); determination the score by multiplication the NPF and SC; ranking according the maximal value of the score.

The procedure of PDM ranking consist the following steps: starting from the highest value of the first row is determined the differences between values in the same row of normalized ERM; summing the elements of each row; summing the elements of the each column; determination the score of each alternative as the difference between row and column values; ranking according the maximal value of the scores.

2.4. New integrated approach
The study proposes new integrated approach for ranking the alternatives by using a combination of both SIMUS and VIKOR methods, and SIMUS and TOPSIS methods.

The VIKOR and TOPSIS methods are multi-criteria decision making approaches. These methods are distance-based. The both methods used the matrix of results of linear optimization models for each of criteria (ERM matrix) as a decision matrix. The calculations are applied to ERM matrix. The new approach could be applied also to verify the results. VIKOR and TOPSIS can be applied also to verify the results by SIMUS procedure.

2.4.1. VIKOR method for ranking the alternatives. The VIKOR method is based on a measure to the ideal solution, [17]. The main steps can be summarized as follows:
• **Step 1:** Determination the decision matrix \((x_{ij})_{mn}\) consisting of \(n\) alternatives and \(m\) criteria, \(i = 1, ..., n; j = 1, ..., m\). Calculation the best and the worst values of all criterion functions.

The best values are calculated when \(j\)-th criterion represents a benefit; the worst values are calculated for non-beneficial criteria.

\[
f^*_j = \max_i f_{ij}; f^-_j = \min_i f_{ij},
\]

where \(f^*_j\) is the best value; \(f^-_j\) – the worst values of all criterion functions.

• **Step 2:** Calculation of the distance from each alternative to the positive ideal solution.

\[
S_i = \sum_{j=1}^m w_j (f^-_j - f^-_{ij});
R_i = \max_i \frac{w_j (f^*_j - f^-_{ij})}{f^*_j - f^-_{ij}},
\]

where \(S_i\) is the distance of the \(i\)-th alternative to the positive ideal solution; \(R_i\) – the maximal regret of each alternative; \(w_j\) – the weights of the criteria.

• **Step 3:** Determination of the index value \(Q_i\)

\[
Q_i = \frac{v(S_i - S^*)}{S^* - S^*} + \frac{(1-v)(R_i - R^*)}{R^* - R^*},
\]

where \(v\) is the coefficient of the decision making strategy, that shows the optimism level of the decision maker; \(0 \leq v \leq 1\).

The value \(v = 1\), and \(v = 0\) indicate the choice of a strategy with maximum or respectively minimum group utility. The value shows a strategy of minimum individual regret. Usually, the value \(v = 0.5\) is chosen to make research.

The minimum value of index \(Q_i\) shows the best alternative.

• **Step 4:** Determination the stability of the results.

The best alternative has to satisfy two conditions. The first condition is:

\[
Q(A^{(1)}) - Q(A^{(2)}) \geq \frac{1}{n-1},
\]

where \(A^{(1)}\) is the best ranked alternative by the minimum of index \(Q_j\), \(A^{(2)}\) – the alternative with second position in the ranking.

The second check is about the ranking for the alternative \(A^{(1)}\) in respect to parameters \(S\) or/and \(R\) for all values of \(v\).

If one of both conditions is not satisfied, the following set of compromise solutions is proposed. \(A^{(1)} A^{(2)}, ..., A^{(n)}\). \(A^{(N)}\) is determined according the satisfaction of the following condition:

\[
Q(A^{(N)}) - Q(A^{(1)}) < \frac{1}{n-1},
\]

If only the condition about the ranking according the parameters \(S\) or/and \(R\) is not met the alternatives \(A^{(1)}\) and \(A^{(2)}\) are the best.

2.4.2. **TOPSIS method for ranking the alternatives.** The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is based on the principle of the shortest distance from the ideal solution and farthest distance from the negative ideal solution. The main steps are as follow, [18]:

• **Step 1:** Determination the decision matrix \((x_{ij})_{mn}\) consisting of \(n\) alternatives and \(m\) criteria.

Calculation of the normalization matrix \((r_{ij})_{mn}\).

\[
r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}}, i = 1, ..., n; j = 1, ..., m,
\]

where \(i = 1, ..., n\) is the number of alternatives; \(j = 1, ..., m\) – the number of criteria.
• Step 2: Determination the weighted normalized matrix \((v_{ij})_{m,n}\).
\[
v_{ij} = r_{ij} w_j; \quad \sum_{j=1}^{n} w_j = 1
\] (8)

where: \(w_j\) is the weight of criterion \(j\).

• Step 3: Determination the ideal best \(v_j^+\) and ideal worst \(v_j^-\) value for each criterion \(j\).
\[
v_j^+ = \min_i v_{ij} \text{ for no benefits criteria}; \quad v_j^+ = \max_i v_{ij} \text{ for benefits criteria};
\] (9)
\[
v_j^- = \max_i v_{ij} \text{ for no benefits criteria}; \quad v_j^- = \min_i v_{ij} \text{ for benefits criteria}.
\] (10)

• Step 4: Calculation the Euclidean distance from the ideal best \(P_i^+\) solution and the Euclidean distance from the ideal worst \(P_i^-\) solution.
\[
P_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^+)^2}; \quad P_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2}.
\] (11)

• Step 5: Determination the Performance score \(C_i\). It presents the relative closeness of each alternative \(i\) with reference to negative ideal solution \(P_i^-\).
\[
C_i = \frac{P_i^-}{P_i^+ + P_i^-}; \quad 0 \leq C_i \leq 1
\] (12)

The maximum value of performance score \(C_i\) shows the best alternative.

2.5. Decision making in the state of variation of passenger flows.

The theory of Decision has been used to determine the best alternative taking into account of the variation of passenger flows. In the study we propose Laplace’s criterion and Hurwicz’s criterion to make decisions, [19].

• Laplace’s criterion (Equal Likelihood). This is based on the principle that all events are equally likely. The criterion of choosing an optimal alternative depends of the type of elements of payoff matrix, i.e.:
\[
L_i = \min_i \left\{ \frac{1}{n} \sum_{j=1}^{n} a_{ij} \right\}, \text{ when } a_{ij} \text{ presents the costs};
\] (13)
\[
L_i = \max_i \left\{ \frac{1}{n} \sum_{j=1}^{n} a_{ij} \right\}, \text{ when } a_{ij} \text{ presents the benefits}.
\] (14)

The main advantage of Laplace’s criterion is its easy way of determining.

• The Hurwicz’s criterion. This criterion uses an additional parameter – coefficient of optimism \(\alpha\) that allows making decision according different decision approaches. The value of \(\alpha\) can be set between 0 and 1. Generally, \(\alpha = 0.5\). While \(\alpha=1\) represents an optimistic approach, \(\alpha = 0\) represents a totally pessimistic approach.

The optimal alternative is determined as:
\[
H_i = \min_i \left\{ \alpha \min_j a_{ij} + (1 - \alpha) \max_j a_{ij} \right\}, \text{ when } a_{ij} \text{ presents the costs} \quad (15)
\]
\[
H_i = \max_i \left\{ \alpha \min_j a_{ij} + (1 - \alpha) \max_j a_{ij} \right\}, \text{ when } a_{ij} \text{ presents the benefits} \quad (16)
\]

The main advantage of Hurwicz’s criterion is the application of a parameter that allows the variability of the results to be examined.

3. Results and discussion

3.1. Application of SIMUS method for ranking the alternatives

The proposed methodology is applied to make decision about transport plan of intercity trains in Bulgarian network. 17 routes between initial and finals points are studied. The categories of intercity...
trains have been set for these routes. In this study we investigated three categories of intercity trains –
direct express trains (TC1) with reduced number of stops in comparison of the current train timetable
(new category), accelerate fast trains (TC2) and faster trains (TC3) that stopped in the stations defined
in the current train timetable. The direct intercity trains are studied for itineraries Sofia-Plovdiv, Sofia-
Plovdiv-Burgas, and Sofia-G. Oryahovitsa-Varna taking into account of passenger flows, [12]. It was
accepted that the all train compositions have 4 wagons. The direct trains Sofia-Plovdiv do not stop in
other stations; the direct trains Sofia-Plovdiv-Burgas stop in stations Plovdiv and Stara Zagora; the direct
trains Sofia-G. Oryahovitsa-Varna stops in stations Mezdra, Pleven, G. Oryahovitsa and Varna. The
scheme of itineraries is presented in [12].

The alternatives have been formed according the number of train categories that are included in
transport plan. Table 1 presents the main parameters of alternatives.

Table 1. Parameters of alternatives.

| Alternative | Categories of train | Number of itineraries |
|-------------|---------------------|-----------------------|
|             | Number   | Type     | TC1 | TC2 | TC3 | Total |
| A1          | 3        | TC1, TC2, TC3 | 3   | 7   | 17  | 27    |
| A2          | 2        | TC1, TC3   | 3   |      | 17  | 20    |
| A3          | 2        | TC2, TC3   | 7   |      | 17  | 24    |

The number of trains in each category for the alternatives and the values of criteria have been
determined using fuzzy linear optimization model given in [12].

The influence of change the passenger on the ranking the alternatives flows has been investigated.
The following variants of the increase of passenger flows have been studied: Variant 1 – current
situation; Variant 2 – 10%; Variant 3 – 20%; Variant 4 – 30%. Tables 2-5 consist two parts. In the first
part are presented the decision matrices that contain the values of criteria for each alternative. The
normalized matrices, type of optimization of criteria, type of operator, and limits of criteria determined
by SIMUS method are shown in the second part. The last columns of the tables present the limits that
are set as equal of the maximum normalized value of the row when the criterion is of maximum and the
minimum value of the row if the criterion is of minimum.

Table 2. Parameters of Variant 1.

| Criterion | Decision matrix | Normalized matrix | Action | Operator | Limits |
|-----------|-----------------|-------------------|--------|----------|--------|
|           | A1   | A2   | A3   | A1   | A2   | A3   |        |         |        |
| C1        | 38.00| 35.00| 37.00| 0.60 | 0.55 | 0.58 | max   | ≤       | 0.60   |
| C2        | 15.45| 16.17| 16.19| 0.56 | 0.59 | 0.59 | min   | ≥       | 0.56   |
| C3        | 63.00| 63.00| 63.00| 0.58 | 0.58 | 0.58 | max   | ≤       | 0.58   |
| C4        | 10640.00| 9800.00| 10360.00| 0.60 | 0.55 | 0.58 | max   | ≤       | 0.60   |
| C5        | 51583.00| 48772.00| 49716.00| 0.60 | 0.56 | 0.57 | min   | ≤       | 0.56   |

Table 3. Parameters of Variant 2.

| Criterion | Decision matrix | Normalized matrix | Action | Operator | Limits |
|-----------|-----------------|-------------------|--------|----------|--------|
|           | A1   | A2   | A3   | A1   | A2   | A3   |        |         |        |
| C1        | 40.00| 36.00| 38.00| 0.61 | 0.55 | 0.58 | max   | ≤       | 0.61   |
| C2        | 14.85| 16.36| 16.47| 0.54 | 0.59 | 0.60 | min   | ≥       | 0.54   |
| C3        | 64.00| 63.00| 63.00| 0.58 | 0.57 | 0.57 | max   | ≤       | 0.58   |
| C4        | 11200.00| 10080.00| 10640.00| 0.61 | 0.55 | 0.58 | max   | ≥       | 0.61   |
| C5        | 55336.00| 50687.00| 51969.00| 0.61 | 0.56 | 0.57 | min   | ≤       | 0.56   |
Table 4. Parameters of Variant 3.

| Criterion | Decision matrix | Normalized matrix | Action | Operator | Limits |
|-----------|-----------------|-------------------|--------|----------|--------|
| C1        | 44.00 42.00 42.00 | 0.60 0.57 0.57 | max    | ≤        | 0.60   |
| C2        | 15.11 15.55 15.38 | 0.57 0.58 0.58 | min    | ≥        | 0.57   |
| C3        | 64.00 64.00 63.00 | 0.58 0.58 0.57 | max    | ≤        | 0.58   |
| C4        | 13200.00 11760.00 11760.00 | 0.60 0.57 0.57 | max    | ≤        | 0.60   |
| C5        | 60696.00 59227.00 55197.00 | 0.61 0.56 0.57 | min    | ≥        | 0.55   |

Table 5. Parameters of Variant 4.

| Criterion | Decision matrix | Normalized matrix | Action | Operator | Limits |
|-----------|-----------------|-------------------|--------|----------|--------|
| C1        | 48.00 44.00 45.00 | 0.61 0.56 0.57 | max    | ≤        | 0.61   |
| C2        | 15.00 15.36 15.58 | 0.57 0.58 0.59 | min    | ≥        | 0.57   |
| C3        | 64.00 64.00 63.00 | 0.58 0.58 0.57 | max    | ≤        | 0.58   |
| C4        | 13440.00 12320.00 12600.00 | 0.60 0.56 0.57 | max    | ≤        | 0.61   |
| C5        | 65518.00 61824.00 60134.00 | 0.60 0.57 0.56 | min    | ≥        | 0.56   |

When the criterion is of maximum the type of operator is “≤”, in the case of minimum the operator is “≥”.

Table 6 presents the optimization models by SUMUS method for Variant 1. The scores of each alternative are labelled accordingly \(x_1\), \(x_2\) and \(x_3\). The similar models have been formed also for the other variants.

Table 6. Optimization linear models by SIMUS method for Variant 1

| Optimization model for Criterion C1 | Optimization model for Criterion C2 | Optimization model for Criterion C3 |
|-------------------------------------|-------------------------------------|-------------------------------------|
| 0.60\(x_1\)+0.55\(x_2\)+0.58\(x_3\)→max | 0.56\(x_1\)+0.55\(x_2\)+0.58\(x_3\)→min | 0.58\(x_1\)+0.58\(x_2\)+0.58\(x_3\)→max |
| 0.56\(x_1\)+0.59\(x_2\)+0.59\(x_3\)≥0.56 | 0.60\(x_1\)+0.55\(x_2\)+0.58\(x_3\)≤0.60 | 0.60\(x_1\)+0.55\(x_2\)+0.58\(x_3\)≤0.60 |
| 0.58\(x_1\)+0.58\(x_2\)+0.58\(x_3\)≤0.58 | 0.58\(x_1\)+0.58\(x_2\)+0.58\(x_3\)≤0.58 | 0.56\(x_1\)+0.59\(x_2\)+0.59\(x_3\)≤0.56 |
| 0.60\(x_1\)+0.55\(x_2\)+0.58\(x_3\)≤0.60 | 0.60\(x_1\)+0.56\(x_2\)+0.57\(x_3\)≤0.56 | 0.60\(x_1\)+0.55\(x_2\)+0.58\(x_3\)≤0.60 |
| 0\(\leq\)x_1,x_2,x_3\leq1 | 0\(\leq\)x_1,x_2,x_3\leq1 | 0\(\leq\)x_1,x_2,x_3\leq1 |

Table 7 and 8 show the results of SUMUS procedure for Variant 1. The ERM matrix in Table 7 presents the results of optimization. The results of both ranking are equally. It can be seen that the alternative A1 is the best. It is the best for three of criteria when they are given as objective function. This includes: maximum of frequency, minimum of average train stops for transport plan and maximum of train capacity. The scores of criteria for alternative A3 are equal to zero. Figure 2 shows the results of individual linear optimization by each criterion that represents the scores of criteria by alternatives. The summarized results of ranking for all studied variants are given in table 9. The alternative A1 is the best according the SIMUS procedure for all cases.
Table 7. ERM Ranking for Variant 1.

| Criterion | ERM | Objective function | ERM Normalized |
|-----------|-----|--------------------|----------------|
|           | A1  | A2     | A3 | A1 | A2 | A3 |
| C1        | 1.00| 0.00  | 0.00 | 0.60 | 1.00 | 0.00 | 0.00 |
| C2        | 0.95| 0.00  | 0.00 | 0.53 | 1.00 | 0.00 | 0.00 |
| C3        | 0.00| 1.99  | 0.00 | 0.63 | 0.00 | 1.00 | 0.00 |
| C4        | 1.00| 0.00  | 0.00 | 0.60 | 1.00 | 0.00 | 0.00 |
| C5        | 0.00| 0.96  | 0.00 | 0.54 | 0.00 | 1.00 | 0.00 |

Sum of Column (SC) 3.00
Participation Factor (PF) 3
Norm. Participation Factor (NPF) 0.60
Final Result (SC x NPF) 1.80
ERM Ranking: A1 - A2 - A3

Table 8. PDM Ranking for Variant 1.

| Dominant | Subordinated | Row sum | Net dominance |
|----------|--------------|---------|---------------|
| A1       | 0.0 3.0 3.0 6.0 | 4.0 3.0 3.0 | 4.0 |
| A2       | 1.0 0.0 2.0 4.0 | 2.0 0.0 2.0 | 1.0 |
| A3       | 0.0 0.0 0.0 0.0 | 0.0 0.0 0.0 | -5.0 |

Column Sum 2.0 3.0 5.0
PDM Ranking: A1 - A2 - A3

Figure 2. Score of criteria by alternatives.

Table 9. Ranking SIMUS (ERM, PDM).

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
| A1          | 1.8 ERM 4 PDM 1 rank | 1.8 ERM 4 PDM 1 rank | 1.8 ERM 4 PDM 1 rank | 1.8 ERM 4 PDM 1 rank |
| A2          | 0.8 ERM 1 PDM 2 rank | 0.8 ERM 1 PDM 2 rank | 0.2 ERM -2 PDM 2 rank | 0.2 ERM -2 PDM 2 rank |
| A3          | 0.0 ERM -5 PDM 3 rank | 0.0 ERM -5 PDM 3 rank | 0.2 ERM -2 PDM 3 rank | 0.2 ERM -2 PDM 3 rank |

3.2. New integrated approaches SIMUS-VIKOR, SIMUS-TOPSIS

Tables 10 and 11 present the results of new integrated approaches SIMUS-VIKOR and SIMUS-TOPSIS proposed in this study. In this case the decision matrix is the ERM matrix of results of SUMUS linear optimization models for all criteria. The calculations by VIKOR and TOPSIS methods have been conducted taking into account that the weights of the criteria are equal (in this case \( w_j = 0.2 \)). We made this acceptance because SIMUS does not use weightings on the criteria. The results by VIKOR method are for value of parameter \( \nu = 1 \) that indicates the choice of a strategy with maximum group utility. The other values of the parameter \( \nu \) are not applicable due to the specification of the data. The results show that according to the conditions of the stability of the results, the all three alternatives are suitable. The results of TOPSIS method present the same ranking as the ERM and PDM ranking by the SIMUS procedure.

The comparison of the results by new approaches and SIMUS is shown in table 12. The type of optimization is different. The VIKOR method use a minimization of the score as a criterion for ranking, while SIMUS (ERM, PDM) and SIMUS – TOPSIS applied the maximum of the score of the ranking’s criterion. Figure 3 presents the ranking by the different approaches. It was found that the procedure SIMUS-TOPSIS is more appropriate than the procedure SUMUS-VIKOR due to the specification of the data in the decision matrix. Therefore, we recommend the SIMUS-TOPSIS integrated approach.
**Table 10. Ranking SIMUS-VIKOR.**

| Alternative | Variant 1 | Variant 2 |
|-------------|-----------|-----------|
|              | Decision matrix | Decision matrix – 10% |
|              | $Q_l$ rank | $Q_l$ rank |
| A1          | C1 0.95 C2 0.90 C3 1.00 C4 0.00 C5 0.00 | C1 0.90 C2 0.90 C3 1.00 C4 0.63 C5 0.00 |
| A2          | C1 0.00 C2 0.00 C3 1.09 C4 0.00 C5 0.96 | C1 0.00 C2 0.11 C3 0.00 C4 1.00 C5 0.00 |
| A3          | C1 0.00 C2 0.00 C3 0.00 C4 0.00 C5 1.00 | C1 0.00 C2 0.00 C3 0.00 C4 1.00 C5 0.00 |

| Alternative | Variant 3 | Variant 4 |
|-------------|-----------|-----------|
|              | Decision matrix – 20% | Decision matrix – 30% |
|              | $Q_l$ rank | $Q_l$ rank |
| A1          | C1 0.91 C2 0.00 C3 1.00 C4 0.00 C5 0.67 | C1 0.92 C2 0.00 C3 1.00 C4 0.00 C5 0.67 |
| A2          | C1 0.33 C2 0.00 C3 1.05 C4 0.00 C5 0.00 | C1 0.33 C2 0.10 C3 0.00 C4 1.00 C5 0.00 |
| A3          | C1 0.00 C2 0.00 C3 0.00 C4 0.98 C5 1.00 | C1 0.00 C2 0.00 C3 0.96 C4 1.00 C5 0.00 |

**Table 11. Ranking SIMUS-TOPSIS – Ranking SIMUS (ERM).**

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
|              | $D_i^+$ $D_i^-$ $C_i$ rank | $D_i^+$ $D_i^-$ $C_i$ rank | $D_i^+$ $D_i^-$ $C_i$ rank | $D_i^+$ $D_i^-$ $C_i$ rank |
| A1          | 1.41 1.17 0.55 1 | 1.00 1.37 0.63 1 | 1.41 1.17 0.55 1 | 1.41 1.17 0.55 1 |
| A2          | 1.41 1.41 0.45 2 | 1.73 1.37 0.37 2 | 2.01 1.00 0.33 2 | 2.01 1.00 0.33 2 |
| A3          | 2.24 0.00 0.00 3 | 2.01 0.00 0.00 3 | 2.01 1.00 0.33 3 | 2.01 1.00 0.33 3 |

**Figure 3.** Comparison of the ranking by SIMUS-VIKOR, SIMUS-TOPSIS and SIMUS procedures.

**Table 12. Comparison of ranking SIMUS-VIKOR, SIMUS-TOPSIS, SIMUS (ERM, PDM).**

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
| SIMUS-VIKOR | SIMUS-TOPSIS | ERM | PDM | SIMUS-VIKOR | SIMUS-TOPSIS | ERM | PDM | SIMUS-VIKOR | SIMUS-TOPSIS | ERM | PDM | SIMUS-VIKOR | SIMUS-TOPSIS | ERM | PDM |
| A1          | 0.00 0.55 1.80 4 | 0.00 0.63 1.80 4 | 0.67 0.55 1.80 4 | 1.00 0.55 1.80 4 |
| A2          | 0.33 0.04 0.80 1 | 0.67 0.37 0.80 1 | 1.00 0.33 0.20 -2 | 1.00 0.33 0.20 -2 |
| A3          | 1.00 0.00 0.00 -5 | 1.00 0.00 0.00 -5 | 1.00 0.33 0.20 -2 | 1.00 0.33 0.02 -2 |

3.3. Verification the results

The verification of results given by SIMIS method has been conducted by using VIKOR and TOPSIS methods. The decision matrix in this case coincides with the initial decision matrix of values of criteria for each alternative. The results of all studied variants have been verified. Table 13 shows the results by VIKOR method for value of parameter $\nu = 1$ that is applicable. Table 14 shows the parameters of
TOPSIS method. Table 15 presents the comparison of the scores. The ERM Ranking is used for SIMUS procedure to compare the results. The ranking of the alternatives by both applied methods are the same as those given by SIMUS. Figure 4 shows the rank by the three methods. It can be seen that the results are equal.

**Table 13. Ranking VIKOR.**

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
| Decision matrix | $Q_l$ rank | Decision matrix | $Q_l$ rank | Decision matrix – 10% | $Q_l$ rank | Decision matrix – 20% | $Q_l$ rank | Decision matrix – 30% | $Q_l$ rank |
| C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | |
| A1 | 38 15.45 64 10640 51583 | 0.00 | 1 | 40 14.85 64 11200 55336 | 0.00 | 1 |
| A2 | 35 16.17 63 9800 48772 | 1.00 | 3 | 36 16.36 63 10080 50687 | 1.00 | 3 |
| A3 | 37 16.19 63 10360 49716 | 0.44 | 2 | 38 16.47 63 10640 51969 | 0.56 | 2 |

**Table 14. Ranking TOPSIS.**

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
| Decision matrix | $D_t^+$ $D_t^-$ $C_i$ rank | Decision matrix | $D_t^+$ $D_t^-$ $C_i$ rank | Decision matrix – 20% | $D_t^+$ $D_t^-$ $C_i$ rank | Decision matrix – 30% | $D_t^+$ $D_t^-$ $C_i$ rank |
| C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | | C1 C2 C3 C4 C5 | |
| A1 | 0.83 1.00 0.55 | 1 | 0.81 1.00 0.55 | 1 | 1.41 1.73 0.55 | 1 | 0.82 0.94 0.53 | 1 |
| A2 | 0.97 0.83 0.46 | 2 | 0.93 0.81 0.47 | 2 | 2.00 1.00 0.33 | 2 | 0.64 0.67 0.51 | 2 |
| A3 | 1.04 0.56 0.35 | 3 | 1.02 0.59 0.36 | 3 | 2.00 1.00 0.33 | 3 | 0.94 0.82 0.47 | 3 |

**Table 15. Comparison of ranking by VIKOR, TOPSIS, SIMUS.**

| Alternative | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|-------------|-----------|-----------|-----------|-----------|
| VIKOR SIMUS (ERM) SIMUS (PDM) | VIKOR SIMUS (ERM) SIMUS (PDM) | VIKOR SIMUS (ERM) SIMUS (PDM) | VIKOR SIMUS (ERM) SIMUS (PDM) |
| A1 | 0.00 0.55 1.80 | 4 | 0.00 0.55 1.80 | 4 | 0.00 0.55 1.80 | 4 | 0.00 0.55 1.80 | 4 |
| A2 | 1.00 0.46 0.80 | 1 | 1.00 0.47 0.80 | 1 | 0.37 0.33 0.20 | -2 | 0.83 0.33 0.20 | -2 |
| A3 | 0.44 0.35 0.00 | -5 | 0.56 0.36 0.00 | -5 | 1.00 0.33 0.20 | -2 | 1.00 0.33 0.20 | -2 |

**Figure 4.** Comparison of the ranking by SIMUS, VIKOR and TOPSIS methods.
3.4. Decision making in variation of passenger flows

The Laplace’s criterion and Hurwicz’s criterion according formulas (13-16) have been applied to make decision. We used five values of the coefficient of optimism $\alpha$, that are presented in figure 4. The results of both criteria are equal that verify the solutions. Figure 5 and table 16 present the ranking. The type of decision making by Laplace’s criterion and Hurwicz’s criterion for scores of TOPSIS and SIMUS (ERM ranking) is of minimum according formulas (13) and (15). When are used the scores of VIKOR to assess the changes in passenger flows we used formulas (14) and (16). In this case the maximum values of Laplace’s criterion and Hurwicz’s criterion determine the best solution. It can be seen in figure 5. Finally, it could be conclude that the best alternative of transport plan between studied ones in railway network is A1. It proposes three categories of intercity trains, as the direct trains suggested for itineraries Sofia – Plovdiv, Sofia – Plovdiv – Burgas, and Sofia – G. Oryahovitsa – Varna.

![Figure 5](image)

**Figure 5.** Comparison of SIMUS-VIKOR, SIMUS-TOPSIS and SIMUS (ERM).

**Table 16.** Comparison of the ranking by SIMUS-VIKOR, SIMUS-TOPSIS, SIMUS.

| Alternative | TOPSIS | VIKOR | SIMUS (ERM Ranking) |
|-------------|--------|-------|----------------------|
|             | Laplas | Hurwicz | $L_t$ rank | $L_t$ rank | $L_t$ rank |
|             | $\alpha$ | 0.5 | 0.75 | 0.25 | $\alpha$ | 0.5 | 0.75 | 0.25 | $\alpha$ | 0.5 | 0.75 | 0.25 |
| A1          | 0.57   | 1     | 0.59 | 0.61 | 0.57 | 1     | 0.33 | 0.34 | 0.50 | 0.16 | 1     | 1.8  | 1     | 1.80 | 1.80 | 1.80 |
| A2          | 0.37   | 2     | 0.39 | 0.42 | 0.36 | 2     | 0.75 | 0.84 | 0.92 | 0.75 | 2     | 0.5  | 0.50  | 0.65 | 0.35 | 2     |
| A3          | 0.17   | 3     | 0.16 | 0.25 | 0.08 | 3     | 1.00 | 1.00 | 1.00 | 1.00 | 3     | 0.1  | 0.16  | 0.24 | 0.08 | 3     |

4. Conclusions

The methodology for selection the transport plan of intercity passenger trains that is based on integration of SIMUS and VIKOR, and SIMUS and TOPSIS methods has been elaborated. It was found that the procedure SIMUS-TOPSIS is more appropriate than the procedure SUMUS-VIKOR due to the specification of the data in the decision matrix. Therefore, we recommend the SIMUS-TOPSIS integrated approach as new procedure of decision making.

The indices for multi-criteria optimization of transport plan of passenger trains have been defined.

The methodology has been experimented for passengers transport in Bulgaria’s railway network. Three transport plans of intercity trains have been proposed and studied.

Each criterion is applied as objective function of linear optimization according SIMUS procedure and the solution has been determined. The alternative A1 that includes accelerate fast trains, fast trains
and additional service with direct trains with reduced number of stops are chosen as the suitable. It is the best alternative for three of criteria when they are given as objective function. This includes: maximum of frequency, minimum of average train stops for transport plan and maximum of train capacity.

The verification of results shows the applicability of the developed methodology. The new approach could be used also for verification the results.

An approach based on application of Laplas’s criterion and Hurwicz’s criterion to make decision in the state of variation of passenger flows is proposed. The results show that the proposed alternative retains its position as the best transport plan.

The proposed methodology and defined criteria could be used to investigate the different transport alternatives in railway network. It can be applied also to assess the organization of passenger trains of different categories and different number of wagons in train composition. The separated railway lines or the whole railway network can be explored to propose a suitable transport plan.

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