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Model of Multi-Criteria Evaluation for Railway Lines

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Abstract**—**The paper is focused to the evaluation railway tracks in the Slovakia by using Multi-Criteria method. Evaluation of railway tracks has important impacts for the assessment of investment in technical equipment. Evaluation of railway tracks also has an important impact for the allocation of marshalling yards. Marshalling yards are in transport model as centers for the operation assigned catchment area. This model is one of the effective ways to meet the development strategy of the European Community's railways. By applying this model in practice, a transport company can guarantee a higher quality of service and then expect an increase in performance. The model is also applicable to other rail networks. This model supplements a theoretical problem of train formation problem of new ways of looking at evaluation of factors affecting the organization of wagon flows.

Keywords**—**Railway track, multi-criteria methods, evaluation, transportation model.

I. Introduction

THE railway transport is one of the important sectors of the national economy, which substantially affects the development and growth of the economic level in every region. Building and reconstruction of railway network requires the comprehensive view of individual infrastructure projects [1]. The European Commission and government of European countries declared in the documents aim to shift part of the volume of freight transport from road to rail. This transfer should occur in particular in order to lessen environmental pollution, reducing the number of traffic accidents with fatal consequences and elimination of congestion on the road network in areas of large cities.

II. The Description of the Transport Network

From the perspective of modeling the transport network composed of operating control points and sections, which can be interpreted as vertices and edges oriented twice valuation multigraph [2], [4].

Applying the methods of graph theory is the appropriate mathematical apparatus for description, analysis and synthesis of transport networks [3]. Formal transport network is determined by a set of vertices and edges with the double-valued. (permeability and length):

$$S = (V, E, p, l) \tag{1}$$

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The permeability (one-way) is determined by the number of sets that can enter into the section per unit time. Very important is the determination of edge weight. Weight of edges can be expressed not only in units of length (km), as well as in e.g. average time (minutes or hours) required for its passage. In connection with the creation of a model, railway infrastructure can be very suitable to be difficult formulation the optimality criterion. A number of practical problems are defined as multi-criteria tasks**.**

III. Methods of Multi-Criteria Analysis

Analytical methods generally constitute a set of rules and procedures applied, which can come to a proper assessment of the subject that is for adopting the best solution. The current mathematical system offers wide range methods of decisions. Analytical methods can be divided into three groups on empirical, heuristic and exact methods [6].

Empirical methods are based on experience, intuition and subjectivity. These methods can be divided into empirical-intuitive ("trials and errors"), empirical-analytical (analysis replaces intuition), Expert (Delphi method/expert opinions, brainstorming, brain writing, the method of scenarios).

Heuristic methods used the advantages of empirical and statistical methods. They are based on common sense and logic. These methods include the decision table, decision tree, decision analysis, and preference theory (if 60% chance that the decision is correct, it should accept the decision maker) [5].

Exact methods are based on scientific analysis and decision-making designed to solve situations that are repeated, and where relationships between elements are expressed quantitatively. This group of methods include [7]: methods of Mathematical Statistics (probability theory, correlation analysis, time series analysis), methods of mathematical analysis and linear algebra (differential calculus, extrapolation, matrix), Methods of Operational Analysis (Mathematical Methods in Economics, structural analysis, network analysis, queuing models and so on.

Comprehensive evaluation process is carried out in increasingly complex dynamic conditions. Therefore, it is necessary to choose the appropriate method of their choice, which will take into account several criteria:

- Point Method;
- Ratio Index Method;
- Decision Matrix Method (FDMM);
- Forced Decision Matrix Method (FDMM);
- Index of supplier;
- Analytic Hierarchy Process (AHP);
- Preference Ranking Organization Method for Enrichment Evaluations – PROMETHEE.

IV. The Individual Criteria of Railway Tracks

The rail network comprises railway lines, which consists of track sections. The assessment parameters tracks can be based on their characteristics divided according to several criteria.

A. Infrastructure Fee

The fee for the use of the railway infrastructure in the Slovak Republic is paid by the transport operator to the railway for the use of the railway lines. The total amount for access to the railway infrastructure is defined as:

$$U_C = U_{mp} + U_{tp} \tag{2}$$

The calculation of the total payment for a minimal access packet for the train will be determined as the charge summary for capacity ordering and allocation, charge for traffic management and organization and charge for securing transport ability according to the pattern:

$$U_{mp} = \sum_{i=1}^{6} U_{1i} * L_i + \sum_{i=1}^{6} U_{2i} * L_i + \frac{1}{1000} * \sum_{i=1}^{6} U_{3i} * Q_i * L_i * k_e \tag{3}$$

where: U_{mp}: total reimbursement for the use of the railway infrastructure, U_{1i} : maximum reimbursement for ordering and allocating capacity, U_{2i}: maximum reimbursement for managing and organizing transport, U_{3i}: maximum reimbursement for ensuring the operability of the railway infrastructure, L_i: total track length of the competent category between single transport points in kilometers, Q_i: total gross weight of the train rounded to the whole ton, k_e: coefficient which takes into account the movement of the train with an active driving rail vehicle using diesel traction on electrified tracks, the size of this coefficient being 1.2. The coefficient for the other trains is 1.0. [10]

The calculation for total payment for track access to service devices for freight trains consists of a charge for use of an electric feeding device, a charge for train assignment and it will be determined according to the pattern:

$$U_{tp} = \frac{1}{1000} * Q * L_e * U_e + \sum_{j=A}^{D} P_{Pj} * U_{Nj} \tag{4}$$

where Q -total gross weight of train harnessed on electrified track rounded to the whole ton, L_e maximum reimbursement in €/thousands of gross ton kilometers for electrical supply used, U_e length of electrified stretch utilized in kilometers, P_{Pj} number of train accesses according to the respective category of transport points for freight transport trains, U_{Nj} maximum reimbursement in € for access of freight transport trains. [8]

B. The Traction Energy

By type of traction we distinguish in Slovakia on track:

- electrified,
- non electrified.

Electrified tracks can be split according to the type of current and frequency to:

- DC electrified lines with the traction voltage of 3 kV,
- AC electrified lines with 50 Hz frequency and voltage 25 kV,
- AC electrified lines with 16.7 Hz frequency and voltage 15 kV.

C. The Track Class

The maximum permissible axle load is dependent on the carrying capacity of the railway infrastructure and bridge. Axle weight is given in tones and is calculated by dividing the gross weight of wagons, i.e. the sum of its own weight and the weight of the wagon load by number of axles. Overview categories of track classes are in Table I.

TABLE I
The Track Classes and Their Maximal Loading [9]

The track class	The maximum permissible axle load	The maximum permissible weight of the meter wagon
A	16,0 t	5,0 tpm
B 1	18,0 t	5,0 tpm
B 2	18,0 t	6,4 tpm
C 2	20,0 t	6,4 tpm
C 3	20,0 t	7,2 tpm
C 4	20,0 t	8,0 tpm
D 2	22,5 t	6,4 tpm
D 3	22,5 t	7,2 tpm
D 4	22,5 t	8,0 tpm

D. The Track Construction

The rail line is composed of the railway substructure, railway superstructure and artificial structures.

The track substructure has a fundamental role to ensure a sufficiently stable connection of the rail body with the ground. The track superstructure is used for roadway rolling stock, leading them and carries. While also transmits power to the track substructure which arise while driving vehicles. The main task is keeping artificial construction of the railway line in places where they cannot be used alone embankments and indentations or their implementation would be much cost. The group of artificial structures we include retaining walls and restraint walls, tunnels, bridges, viaducts and culverts.

E. The Type of Track Interlocking System

The track interlocking system has a significant impact on the number of trains running in the interstation sections. Ensuring the movement of trains is carried out in accordance with existing traffic regulations depending on the type of interlocking system.

Track security devices are classified according to the level of security on device:

- 1st. category (train announcing points) the main signaling devices are independent by departures of trains and also by interlocking systems in adjacent operating control points
- 2nd. category (semi-automatic track interlocking system). They provide dependency between adjacent operating control points. Operation of the control unit of section or departures signaling devices is dependent on train movements and requires the cooperation of the operator.
- 3rd. category (full automatic track interlocking system –

automatic block). They mediate dependence between adjacent operating control points. Operation of the control unit of section signaling devices is automatic. The control unit is dependent on drive train and does not require action and servicing staff

F. The Gradient Conditions of Track

On the track of the gradient is determined speed limit between the maximum track speed and running speed by:

- size of the slope or climb on the track,
- according to the type of train brake system and drive performance vehicle,
- According to braking distance with respect to prescribed provisions of infrastructure manager.

The biggest gradient is determined for each track individually. The ruling (decisive) gradient is one that can be designed in a straight section of the track.

The track is proposed in the uniform gradient for the longest sections. Where possible, the route is guided as a constant resistance of track (effect of curvature on the track, where applicable, placed in the tunnel route). The longitudinal gradient of the track is proposed in view of smooth start and safe stopping of trains.

The track gradient should be as small as possible. The gradient conditions at operating control points and hump track are designed in accordance with the relevant regulations for the design of railway stations. The length of the horizontal sections should be as far as possible provided that it does not deteriorate the construction and maintenance solutions in traffic routes

G.Number of Line Tracks

The line track, which connects two adjacent operating control points is continuous track of rail. Tracks can be split according to the number of tracks to the single-track lines (allow movement of trains with only one direction) and double-track lines or multi-track lines (allow movement of trains in both directions simultaneously by different track rail).

H.The Type of Structure Gauge

The structure gauge (SG) is defined as the plane perpendicular to the axis of the line, whose axis is perpendicular to the line joining down from the top of the rails, which may not intervene any part of fixed building or any part of the line track. The structure gauge, also called the minimum clearance outline, is the minimum height and width of tunnels and bridges as well as the minimum height and width of the doors that allow a rail siding access into a warehouse. In addition, the term may apply to the minimum distance to railway platforms (passenger or freight), buildings, electrical equipment boxes, railway signal equipment, third rails or to supports for overhead catenaries or overhead lines from the track.

The loading gauge is to determine of spatial pattern that may interest expense on open wagons. On the Slovak railways are using the following gauge in the following breakdowns:

- SG 1 – SM/ŽSR,
- SG 1 - SME/ŽSR,
- the bridges SG,
- the tunnel SG,
- on the reconstruction line of Slovak railways– SG B, C,
- the line for multimodal transport SG UIC GC.

I. The Line Speed

The line speed is defined as a permanent maximum speed limit on the particular line, which is indicated in the Route Book. In addition to the line speed we know the set speed; the speed of the train is determined by its timetable. In the professional standards established the infrastructure manager on Slovak railways (ZSR) defines the rain speed according to different types of train. All speed zones at the Slovak Railway are in Table II.

TABLE II
THE DISTRIBUTION OF THE VARIOUS SPEED ZONES [9]

The speed zone	Track speed
RP 1	to 60 kmph
RP 2	60 – 90 kmph
RP 3	90 – 120 kmph
RP 4	120 – 160 kmph
RP 5	up to 160 kmph

When considering the possibilities of railway transport and routes to take into account the following factors:

- vibration of wagons from inequality on the track,
- adhesion, which is a decreasing of speed,
- curvature - Vertical drop of outer belts in curves, the radius of curvature in the track browsing, the radius of curves into turnout,
- deformation of the rails due to the deformation waves
- deformation of the contact wire collector,
- Sound barrier.

To satisfy human and social needs appears more and more to the fore the time factor, along with the quality of service becomes a decisive factor in transport. Modernization of railway transport focusing on the issue of higher speed as one of the fundamental problems of a technical and economic character.

V. METHODOLOGY FOR COMPREHENSIVE EVALUATION OF RAILWAY LINES

A methodology for rating of lines can serve as support for modeling direction of load in train formation problem.

Methodological aspects consist in applying the procedures leading to determine the meaning indicator and also a partial assessment. This requires the determination of:

- weights of individual indicators
- partial evaluation of indicators.

To determine the weight of the indicators needs to be in two steps:

- determine the weight of each group of indicators,
- determine the weight of each indicator in the group.

Weights of individual groups of indicators and weights of individual indicators in the group is based on a numerical scale by 1 to 6 point. The assignment one point represents a group resp. indicator with little importance and assignment of 6 points represents a group of indicators, resp. indicator of crucial importance

A. Parameters for Evaluation and Their Indicators

After processing of individual assessment parameters lines is in the next step should be to assign to these parameters of individual indicators. These indicators characterize the individual parameters. The structure of indicators is shown in Table III.

TABLE III
PARAMETERS FOR EVALUATION AND THEIR INDICATORS

Parameters	Indicators	
1.The infrastructure fee	Train	**6**
	Transport quantum	**1**
	Distance covered	**4**
2.The type of traction	Electric traction	**6**
	Without electric traction	**1**
3.The track class	A	**1**
	B	**2**
	C	**5**
	D	**6**
4.The line construction (age of railway superstructure)	0 - 5 year	**6**
	6 - 10 r.	**5**
	11 - 15 r.	**4**
	16 - 20 r.	**3**
	21 - 25 r.	**2**
	Up to 25r.	**1**
5. Type of line interlocking system.	Telephonic communication	**1**
	Train announcing points	**2**
	Semi-automatic block system	**5**
	Automatic block system	**6**
6.The gradient conditions	horizontal	**6**
	to 5 ‰	**5**
	to 10‰	**4**
	to 20‰	**2**
	up to 20‰	**1**
7.Number of line track	Single-line track	**1**
	Double-line track	**5**
	Multi-line track	**6**
8.Character of traffic	Passenger	**1**
	Freight	**6**
	Mixed traffic	**5**
9. The type of structure gauge	1 – SM/ŽSR	**5**
	1 - SM_E	**5**
	The bridges SG	**2**
	The tunnel SG	**1**
	Intermodal transport SG UIC GC	**4**
	Modernized lines ŽSR – SG B	**6**
10. Maximum line speed	60 kmph	**1**
	100 kmph	**3**
	120 (140) kmph	**5**
	160 kmph	**6**

Some factors in Table III should be merged because of the high frequency of the sub-groups, but it has no impact to the overall results. The differences of their influence and their subsequent evaluation have the same weight. As an example, we are presenting parameter of track class and their maximal loading where the track class is assigned a score of categories by alphabetic indexing without numerical index.

B. Determination of the Conditions for "Ideal Track"

The ideal track is a track where individual factors are assigned the highest rating. This assessment will be a maximum assessment rate in all parameters.

For the evaluation of lines is necessary to establish conditions that would allow the creation of a comprehensive assessment model, relative to the track capacity, technical equipment etc.

VI. SOLUTIONS

The solution to this design is the use and application of several optimization methods and algorithms. The final evaluation of the track is the sum of individual evaluation parameters that characterize a particular railway line.

Selection can be performed for any lines on the transport network, where is the possibility of building the new lines, ("building from scratch") or to determine directly choice the existing tracks.

The objective of the methods of multi-criteria evaluation is the transformation and synthesis values of different variables to a single summary indicator (the resulting characteristics). This indicator shows the comprehensive level of individual objects in the surveyed lines. It is a summary indicator representation of the overall level (importance) of the line.

$$Kj = \frac{\sum_{i=1}^{n} a_{ji}}{\sum_{i=1}^{n} a_{mi}}.100 \quad ; j \in 1,...,m-1 \tag{5}$$

where *Kj coefficient of the j-th line;* $\sum_{i=1}^{n} a_{ji}$ sum of the evaluation j-th line; $\sum_{i=1}^{n} a_{mi}$ sum of the evaluation the "ideal" line.

"Ideal line" is marked the fictional line that all evaluation factors meets in full. Thus, the value x_{m1}, ... , x_{mn} are the maximum. Summary of indicators reflects the importance of the point. The basis of multi-criteria evaluation is processing the initial matrix of objects and their characteristics. The objects represent all railway lines on the network, which in each case meet the criteria for inclusion in a specific choice.

In the construction of the initial matrix of railway lines is necessary to observe the following steps:

1. Selection of railway lines included in the analysis file.
2. The assignment the "ideal line" in the list of railway lines.
3. Selection of parameters characterizing every railway lines.
4. Election of weights of indicators.
5. The preparation of the initial matrix.

TABLE IV
INITIAL MATRIX FOR EVALUATION

Indicator Line	a_1	a_2	...	a_i	...	a_n	$\sum$
1	x_{11}	x_{12}				x_{1n}	$\sum_{i=1}^{n} a_{1i}$
2	x_{21}	x_{22}				x_{2n}	$\sum_{i=1}^{n} a_{2i}$
...	...						...
j				x_{ji}			$\sum_{i=1}^{n} a_{ji}$
...	...						...
m-1	$x_{m-1,1}$	$x_{m-1,2}$				$x_{m-1,n}$	$\sum_{i=1}^{n} a_{m-1,i}$
m (the ideal line)	x_{m1}	x_{m2}				$x_{m\,n}$	$\sum_{i=1}^{n} a_{mi}$

$a_{1,\dots,n}$ – evaluation indicators; x_{ij} – value of i-th indicator in the j-th railway line; n – number of indicators; m -1 – number of railway lines included to the initial matrix; m – the ideal line.

VII. CONCLUSION

The guaranteed support railway by funding European Union or national governments is necessary that railway undertakings provide competitive transport services like other kinds of transport. This model for evaluation railway lines represents one of the possible ways to meet the development strategy of the European Community's railways. By applying this model in practice can the infrastructure manager guarantee a higher quality of service and then expect an increase in performance. The model is also applicable for other network transport systems.

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