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„INVESTMENT MANAGEMENT AND SELECTION OF THE RELEVANT PARAMETERS IN ORDER TO MAKE DECISION ON LEVEL CROSSING PROTECTION SYSTEMS “

Summary: The paper herein shows relevant ruling parameters that should be taken into account during the decision making process of which type of level crossing shall be considered as the most suitable from the aspect of traffic safety. Selection of the parameters is based on experience method, while their quantification and assignment of relative weights to each parameter in function of application of multi-criteria analysis is realized by means of experts' method. On the basis of output results, it can be possible to make an adequate investment decision concerning the method and safety level that shall be applied for the each level crossing.

Key words: traffic safety, level crossing, interlocking, multi-criteria analysis, and relevant parameters

INTRODUCTION

A majority of railway accidents happen at level crossings (the intersection of a road and a railway line) and the human and material losses caused by these accidents are enormous. Within the Serbian Railways Network there are numerous level crossings, which during the past decades were opened on railway lines without previously defined methodology, while the system used for their protection was not in compliance neither with track grade nor with road capacity.

According to the both former experiences and researches, even today great number of level crossings are not in compliance with the Traffic Safety Act and current instructions issued by Serbian Railways, meaning that great number of level crossings is not provided with adequate protection systems.

In order to make a qualitative decision concerning investment, one should be familiar with decision quality, since making an enquiry into investment decisions after great material resources were spent, serves no purpose. It should be also mentioned that concerning level crossing protection systems, the state itself did not participate neither in decision-making process nor in creation of investment strategy while absolutely had no access to decisions made within the Serbian Railways Authority.

The paper herein shows relevant ruling parameters that should be taken into account during the decision making process of which type of level crossing shall be considered as the most suitable from the aspect of traffic safety (types of level crossing). Selection of the parameters is based on experience method, while their quantification and assignment of relative weights to each parameter in function of application of multi-criteria analysis is realized by applying the experts' method. On the basis of output results, it can be possible to make an adequate investment decision concerning the method and safety level that shall be applied for the each level crossing.

TYPES OF PROTECTION SYSTEM AT LEVEL CROSSINGS

According to the current laws on Serbian Railways, all level crossings are divided into the two main categories: level (grade) crossings and grade separated crossings. Level crossings can be protected on one of the following ways:

1. Positioning railroad traffic signs on road that shall give information about any intersection of road and railway line that is not protected by any form of protection that could block the flow of road traffic (barriers or half-barriers) or by light and audible warning devices.
2. Providing traffic light signs and road traffic signs intended to warn the road users that they must give way to oncoming train
3. Providing half-barriers with combination of road traffic light signals: semi-barrier blocks the traffic on the right-hand-side of the road on approach to the crossing on the both side of the line. Half-barriers shall be installed only in combination with automatic light signals and shall be equipped with automatic devices that bring barriers in "closed" or "open" position.
4. Providing barriers with combination of road traffic light signals: barriers block road traffic along the whole carriageway width on approach to the crossing on the both side of the line.
5. Providing direct traffic regulation on level crossing and applying necessary measures for the certain situations: in a case that level crossing intersects industrial railway or private sidings, the protection system shall be realized by means of survey triangle warning signs, traffic light signals, half-barriers, or by other adequate combinations
6. Providing footpath crossings primarily for pedestrians and non-motorized vehicles: pedestrian crossings designed to allow pedestrians and non-motorized vehicles to cross the railway line shall be protected with protective barriers

From the aspect of traffic safety, on the arterial railway lines within the Serbian Railways Network, there are 696 level crossings of which 419 are "open", i.e.

sometimes only with road signs, and 277 "closed", i.e. "controlled" crossings equipped with light signals, barriers and half-barriers.

NUMBER OF ACCIDENTS ON LEVEL CROSSINGS

Within the period of 1993-2004, at level crossings all over the arterial lines within Serbian Railway Network, there were 349 accidents in which 67 persons lost their lives, while 242 suffered major injuries. According to estimation for the mentioned period, material damage on vehicles, insurance costs, as well as damages resulted from disruption of train operations, and delay of road traffic born as a result of accidents at level crossings, exceeded sum of 30 million of Euro. The major cause of overall accidents (almost 90%) is negligence of pedestrians and car occupants, while 10% is caused by failure of automatic devices used for level crossing protection.

INVESTMENTS FOR LEVEL CROSSING PROTECTION

Investments are necessary requirement that should be satisfied in order to protect the certain level crossing by means of modern equipment. In a case that there are no investments for the mentioned field, traffic safety level at crossings would stay at the present level (for certain time) with the tendency to become worse in future period (increment of traffic scope, greater speed, and others) and to result in more fatal accidents as well as increment of overall damages born as a result of accidents. Investment comes as a final strategy goal on the basis of which all planned works within the field shall be realized.

According to the current manufacturing prices of equipment used for level crossing protection systems, protection of the single crossing is estimated to be 120,000 EURO/level crossing. Such a protection system includes automatic equipment with barriers or half-barriers (railway interlocking equipment). In a case when the certain level crossing is protected by means of light and audible signals the price is estimated to be 60.000 EURO/level crossing. Concerning the number of level crossings that are not protected yet, it is not real to expect that the state and Serbian Railways Authority (that are public enterprise whose functioning directly depends on budget funding) will be capable to protect all level crossings with modern protection equipment.

SELECTION OF RELEVANT PARAMETERS

On the basis of long-standing research in the area of traffic safety at level crossings, a lot of parameters that could correspond to the decision concerning protection of level crossings with modern equipment were studied. According to the mentioned researches, the most relevant parameters that should be taken into consideration are as follows: track grade, category of road that intersects the certain level crossing, frequency of railway traffic over the level crossing, max. allowed speed on line section where the level crossing is located, angle of intersection of line and road at level crossing, number of tracks at the level crossing, number of accidents on the basis of statistic data. Each of the mentioned parameters includes sub-group shown in the Table below:

No.	Parameter	Sub-group
1	Track grade	More than 120 trains/day From 70 to 119 From 50 to 69 From 1 to 49
2	Number of tracks at level crossing	1 track 2 tracks More than 2 tracks
3	Category of road that intersects the level crossing	More than 500 vehicles/peak hour From 200 to 499 vehicles/peak hour From 50 to 199 vehicles/peak hour Less than 50 vehicles/peak hour
4	Survey triangle	Triangle-visible No triangle-invisible
5	Max. allowed speed on line section on which the level crossing is located	From 100 -120 km/h From 80 - 99 km/h From 60 - 79 km/h From 40 - 59 km/h
6	Angle of intersection of line and road at level crossing	90 75 60 45 30
7	Number of accidents according to the statistic data	1 2 3 >3

QUANTIFICATION OF RELEVANT PARAMETERS

The paper herein intends to introduce a method of defining relative weights that shall be realized into the following three phases:

Phase I: defining relative weights for parameters

Phase II: defining relative weights for parameters in groups

Phase III: correction of relative weights per groups and obtaining final weights for multi-parameter analysis

Note: Concerning the fact that the whole procedure is very long the paper shall show only output results.

For the purpose of applying the multi-criteria analysis, it shall be necessary to quantify the relevant parameters (including separate quantification procedure for sub-group parameters) and to determine the relative weight for each parameter separately. Quantification of parameters is the key step that shall be taken in selection and sequence of level crossings together with apply the multi-criteria analysis. Marks used for description of relative weights are in a scale from 1 to 10. Quantification is a process based on researching carried by applying the experts' method. The method is widely acknowledged in technical sciences, and is based on opinion of competent experts in the certain field as well as statistical data processing and selection of the belonging statistical distribution.

The basic advantages of the experts' method are as follows:

1. Inter-discipline approach
2. Anonymous answers from experts
3. Possibility of adjustment the questionnaire or question mark thanks to the numerous reiterations
4. Elimination of authority influence
5. Elimination of group suggestion

On the basis of questionnaire (Table data), for the quantification of parameter relative weights for the purpose of level crossing protection, three groups of relevant experts were engaged: traffic experts, experts from the field of structural engineering and electrotehnical experts. Two reiterations were performed during the estimation of the each of the mentioned parameter on the basis of model: all experts for all fields. Within the first reiteration, 21 experts (7 from the each field) were interviewed in SS1 questionnaire. On the basis of results obtained from question mark, the purpose of the first reiteration was to define whether there is marked preference of experts group for the field they represent comparing to other parameter groups. Preference includes the two following cases:

- Providing markedly great advantage of group of parameters they represent
- Providing extreme low values to the other parameter groups

Having in mind that the results of the first reiteration showed preferential attitude of traffic experts group, the second reiteration was performed with 30 experts involved (10 from the each field) that were interviewed by SS1-1 questionnaire. Results of relative weights for parameters are shown in the Table below:

	PARAMETER	Total number of systematized evaluations	Relative weight
1	Track grade	269,23	7,80
2	Number of tracks at level crossing	323,08	6,50
3	Category of road that intersects the level crossing	256,10	8,20
4	Survey triangle	636,36	3,30
5	Max. allowed speed on line section on which the level crossing is located	244,19	8,60
6	Angle of intersection of line and road at level crossing	656,25	3,20
7	Number of accidents according to the statistic data	338,71	6,20
	TOTAL	2100,00	

Estimation and assigning of relative weights to sub-group parameters were performed in similar way using the new SS2 questionnaire. Estimation results are shown in Table below:

No.	Parameter	Sub-group	Relative weight of sub-group parameters	Corrective relative weights(FINAL WEIGHT)
1	Track grade	More than 120 trains/day	10,00	9,5
		From 70 to 119	10,00	9,5
		From 50 to 69	8,45	8,0275
		From 1 to 49	3,05	2,8975
2	Number of tracks at level crossing	1 track	4,4	4,18
		2 tracks	6,95	6,6025
		More than 2 tracks	8,1	7,695
3	Category of road that intersects the level crossing	More than 500 vehicles/peak hour	10	9,5
		From 200-499 vehicles/peak hour	9,7	9,215
		From 50-199 vehicles/peak hour	7,8	7,41
		Less than 50 vehicles/peak hour	5,9	5,605
4	Survey triangle	With triangle-visible	1,65	1,5675
		No triangle-invisible	5	4,75
5	Max. allowed speed on line section on which the level crossing is located	From 100 -120 km/h	9,25	8,7875
		From 80 - 99 km/h	9,1	8,645
		From 60 - 79 km/h	7,85	7,4575
		From 40 - 59 km/h	7,7	7,315
6	Angle of intersection of line and road at level crossing	90	2,2	2,09
		75	2,7	2,565
		60	3,3	3,135
		45	3,6	3,42
		30	4,12	3,914
7	Number of accidents according to the statistic data	1	3	2,85
		2	5,4	5,13
		3	7,3	6,935
		=:3	9	8,55

Correction of relative weights in correlation: relative weights of parameters and relative weights of parameters from sub-group. Final relative weights are shown in the Table.

On the basis of obtained results and relative weights defined, it can be possible to perform the multi-criteria analysis.

The most often used multi-criteria analysis of alternatives for the purpose of selecting the optimum one is PROMETEJ method (with expressed preference) and VIKOR method (iterative method). The VIKOR method will be described in short detail.

VIKOR method (method of multi-parameter iterative compromise ranking) was developed at the Faculty of Civil Engineering, Belgrade University, SERBIA.

VIKOR METHOD

Starting from "boundary" forms of LP metrics which is used for compromise programming the VKOR method was developed (iterative compromise ranking) and used in multi parameter ranking of alternatives. Its later modification is the VIKOR method (multi parameter compromise ranking) was developed for the purpose of multi parameter ranking of alternatives by means of a compromise ranking method.

The method takes into account discrete systems of defined of alternative designs. A multi parameter and the best (optimum) solution is obtained by a multi parameter optimization, which for discrete systems is done with multi parameter ranking of alternatives and a selection of an optimum solution.

In some planning procedures of higher complexity, no final solution is adopted in the first pass, but the procedure is iterated after the ranking stage (the set of alternatives or parameters is expanded or the evaluation procedure based on some of the parameters is repeated).

Input data for the VIKOR method are the values of parameter functions of *fij* where *fij* is the value of an *i*-ith parameter function for an *j*-ith alternative (i=1,2,...n; j=1,2..,J), as well as extremization indicators for the parameter function given (0 for minium and 1 for maximum). Next table gives a parameter function of *fi* and the values of functions of *fij* in the alternatives : (The value of a parameter function is a unit value of the relevant parameter expressed in units required. The units by parameters must be identical.)

Table Parameter functions *fi* and values of functions *fij*

ALTERNATIVES / Parameter	V1	V2	......	VJ	Extremization (max-min)	fi*	fi^-	Di
P1	f_{11}	f_{12}	...	f_{1J}	0	f_{1*}	f_{1-}	D_1
P2	f_{21}	f_{22}	..	f_{2J}	1	f_{2*}	f_{2-}	D_2
....			....			....	.....	....
P16	$f_{16,1}$	$f_{16,2}$	...	$f_{16,J}$	1	$f_{16,*}$	$f_{16,-}$	D_{16}

Where:
P- is relevant parameter
f_i^*=max f_{ij} ; f_{i-} =min f_{ij}
$D_i = f_i^* - f_i^-$

$$dij=\frac{(fi*-fij)}{(fi*-fi-)}=\frac{(fi*-fij)}{Di}$$

In the case when an extremization indicator is 0, *Fi* (relativ weight of parameter) takes the minimum value of *fij* for the parameter function *fi*, and *fi*⁻ takes the maximum value for the parameter function *fi*.

Furthermore, the values for *Sj* and *Rj* are introduced in the VIKOR method and we have

$$S_j = \square \frac{\omega i(fi * - fij)}{(fi * - fi-)};$$

where □$_i$ is weight of parameter function i, i=1,..,n

R_j= max □$_i$ $(f_i^* - f_{ij})/(f_i^* - f_{i-})$=max □$_i$ d_{ij}

Sj is a measure for ranking which is a relationship between a deviation from the best values *fi* of a sum of parameter functions *fi** ,(*fi *- fij*) and the maximum difference (*fi**- *fi*⁻). The *Si* measure always varies between 0 and 1.

Rj is the ranking measure that takes maximum value of the (*fi**- *fij*)/(*fi**- *fi*⁻) always has the value of o or 1.

Table: Shows the values of *dij*, *Sj* and *Rj*.

	Alternative / **PARAMETER**	V_1	V_2	...	V_J
Dij	P1	d_{11}	d_{12}	...	d_{1J}
	P2	d_{21}	d_{22}	...	d_{2J}
	....	....	......	...	....
	Pn	$dn_{,1}$	$dn_{,2}$	...	$Dn_{,J}$
	Sj	S_1	S_2	...	S_J
	Rj	R_1	R_2	...	R_J

Further in VIKOR method procedure the value of *Qj* is introduced. This value is used to establish a ranking list which is a compromise between the strategies: maximum group benefit *QSj* (better variants are good according to majority of parameter functions) and the minimum of the maximum deviation from ideal values - *QRj* (better alternative must not have a bad position according to any of the parameter functions *fi*). The values of *QSj*, *QRj* and *Qj* vary between 0 and 1.

The value of *Qj* is the measure of multiparameter ranking and is given by the expression:

$Q_j = v \cdot \mathbf{QS_j} + (1 - v) \cdot \mathbf{QR_j}$; where is

$\mathbf{QS_j} = (S_j - S^*) / (S^- - S^*)$, i

QRj = $(R_j - R^*) / (R^- - R^*)$

When developed, *Qj* is given by the expression of :

$Q_j = v(S_j - S^*)/(S^- - S^*) + (1-v) (R_j - R^*)/(R^- - R^*)$, where is

S^*=min S_j; S^- = max S_j;

R^*=min R_j; R^- =max R_j
-where *v* is a weight of a strategy of decision-making by means of "parameter majority".

The *Vj* varijant is better on a multi parameter basis than *Vk*, if *Qj<Qk* and has a higher position on the ranking list. In this way a "compromise" ranking list is obtained for given *v*.

It follows from the relation for *Qj* that it is a linear combination of *QSj* and *QRj* values, which means that a compromise ranking list may be considered to be a "linear combination" of the ranking lists obtained on the basis of the *Sj* and *Rj* measures. The above relation can be written in the following form :

$Q_j = v \cdot (QS_j - QR_j) + QR_j$

which means that *Qj* is a linear function of the weight of *v*.

In some cases, the VIKOR method introduces a modified value of *Rj* and to the value obtained from the expression:
$R_j = \max w_j \cdot (f_i^* - f_{ij})/(f_i^* - f_i^-)$ the following value is added:

$r_j = (S_j - R^-)/100$, j = 1,2,.......J ;

only when *Rj=R* for a higher value of j. If all the *Rj* values differ, this modification is not used. It has been introduced to enable ranking according to *Rj* in the cases when *Rj* = 1 for each j.

With the VIKOR method the best alternative is the one which takes the first place on the compromise ranking list for *v* = 0.5 and which has to meet two more requirements:

U1: the condition of "sufficient precedence" over the first next variant
U2: the condition of "sufficient stability" from the aspect of decision making.

A variant has sufficient precedence over the next variant on the ranking list if:

Q (a") - Q (a') > DQ ;

DQ is a precedence threshold determined from the theoretical values of *Q*,

Qmax-*Qmin* = 1-0,
and the number of variant J:

The top variant on the compromise list will have a sufficiently stable position if one of the following conditions is fulfilled:

- to be at the top according to the *QS* value - majority of parameter strategy
- to be at the top according to *QR* value - minimax strategy
- to have the top place according to *Q* value for $v = 0.25$ and $v = 1$

The outputs of the VIKOR method are:

- the ranking lists according to values for *QR*, *Q* (for v=0.25) and *QS*;
- a compromise variant or a set of compromise solutions.

The VIKOR method is used to analyze the impact of weight *v*. The value for *v* is not entered as an input data.

The results of VIKOR methods represent a base for decision-making and adoption of the final (multiparameter optimum) solution.

CONCLUSION

However, to make the obtain results usable in practice, the each data base containing information about level crossing, shall include, beside km point of level crossing and their location on railway line, all data from the sub-group defined. Applying of multi-criteria analysis, the output results shall show both selection and sequence of level crossings that shall be protected. There is also a model, which, on the basis of obtained results, can give suggestion of protection type for the each level crossing. The purpose of the paper herein is to point at relevant parameters and their influence during the investment decision-making process of level crossings that shall be protected with modern equipment in order to improve overall traffic safety.