THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2009

4(3): 108–114

MULTI-CRITERIA EVALUATION OF CRASH BARRIER SYSTEMS TYPES

Daniel Macek[1], Dana Měšťanová[2]

Dept of Economics and Management in Civil Engineering,
Faculty of Civil Engineering,
Czech Technical University in Prague,
Thakurova 7, 166 29 Prague 6, Czech Republic
E-mails: [1]daniel.macek@fsv.cvut.cz; [2]dana.mestanova@fsv.cvut.cz

Abstract. Improvement of the situation regarding accident rates in the European Union is a subject of an action programme set up by the European Commission and called the European Road Safety Action Programme 2003–2010. The aim of the programme is to lower the number of road fatalities because of road accidents by half. To be successful as far as the fulfilment of the aim is concerned it is necessary to make a right choice of appropriate solutions when designing transport constructions. One possibility is to design appropriate crash barrier systems. The right decision is the matter of the usage of an appropriate type of safety device (for instance, the crash barrier), requires concentration of the essential knowledge and further ability to judge and evaluate thoroughly information available. This article deals with the evaluation of types of crash barriers from the viewpoint of their suitability for communication. The evaluation process covers firstly security aspects, secondly takes into consideration economic aspects and eventually ecological criteria. The aim is to set general priorities when using individual types of crash barriers. By using crash barriers in particular conditions there is fulfilled the effort to protect participants in road traffic from the consequences of traffic accidents. The effort is intended to eliminate losses of lives, to protect the health of those involved in traffic accidents, to minimize losses of the vehicle's value, losses of the construction substance of a road construction, losses of any tangible property, and last but not least to minimize the impact on the environment in a territory surrounding a particular transport construction.

Keywords: concrete crash barriers, cable crash barriers, steel crash barriers, restraint systems, security.

1. Introduction

The evaluation of suitability of a crash barrier for a certain section of communications is a matter of multi-criteria evaluation with the dynamics of a life cycle. When we are making a decision in this area, the location of a crash barrier is the most important issue. We can differentiate crash barriers located on a middle division traffic lane, road-side crash barriers, crash barriers within the context of an exit or slip road, and those before a tunnel, in a tunnel, or on a bridge construction etc. (Lehovec 2006).

The complex of problems regarding evaluation process when designing crash barriers has to be solved within the framework of a life cycle. That means it can be generally understood as preparation including designing, implementation itself, renewal and maintenance of the operation and last, but not least, disposal. For every type of a crash barrier it is necessary to assess technical, transport and economic aspects, including transport and ecological aspects, as well as the standpoint of state administration officials, the general public etc. (Lama *et al.* 2007).

Steel crash barrier is the most frequently used barrier. In the Czech Republic the NH4 type is widely used, and the same situation is also in Slovakia. In Germany the most preferred one is type NH3 and in Austria it is type VEST ALPINE. Commonly there is widely used the term „classical steel crash barriers". In the Czech Republic the usage of these barriers accounts for nearly 100%. The demonstrable experience and availability of companies carrying out assembly is very important too. As well importance of the actual strength of the construction is not negligible.

Cable crash barriers have been used in the Czech Republic only in recent years (Beran, Hromada 2008). Outside the Czech Republic these barriers could be seen in Great Britain, Sweden and Norway (until 2006). The main contractor of the cable crash barriers in the Czech Republic is a company PROZNAK (installation, repairs and maintenance) which has a monopoly on the market. Cable crash barriers carrying a brand BRIFEN indicate innovation in the design of crash barriers. They offer a certain level of security.

ISSN 1822-427X print / ISSN 1822-4288 online DOI: 10.3846/1822-427X.2009.4.108-114

http://www.bjrbe.vgtu.lt

Concrete crash barriers are used especially in places where there is a danger of a skid or a downfall (e.g. above a steep slope, railway track etc.). In practice they do not have a deformation zone (Vaidogas 2007) and entails their invulnerability in case of a direct impact. The use of these crash barriers is given by their very own specifics and the subject of judging types is thus directed especially to steel and cable crash barriers.

The right decision for the use of a crash barrier type must be preceded by a decision process, the formulation of initial principles, setting down principles which will serve to determine the benefits for any crash barrier type during the assessment (Berka *et al.* 2007). An initial basis consists of the setting up of the assessment criteria taking into account a wide spectrum of viewpoints and the proceeding with their analysis. Different views will emerge, those of a building owner, those of an operator, at last but not least those of the general public and users.

2. Method MDA

Method multi-criteria dimensional analysis (MDA) is a modification of a classical multi-criteria decision analysis (MCDA). MCDA represents generally a discipline which promotes decision under the necessary condition of judging often mutually conflicting decision criteria (Zavadskas *et al.* 2007). Multi-criteria decision problems are thus described by a set of variants, a set of criteria for decision and a line of links between criteria and variants (Ren, Vesenjak 2005; Šarka *et al.* 2008). By including this multi-criteria condition into a decision model the solution better approaches the real tasks, the discovered decision and has a far greater chance for implementation in a given decision task (Šelih *et al.* 2008).

MDA (Beran, Dlask 2007) carries out a choice of project solutions on the basis of a collection of criteria, which can be divided into hierarchic levels. Their creation is specific for each individual technical project. They are differentiated by significance (relative weight). The programme product MDA enables a finalisation of options. The evaluation itself is carried out on the basis of an evaluation enabling the introduction of technical or economic risks and developing trends. The resulting solution, i.e. an evaluation of individual variants, is also provided with a statement on the assumed spread (variability) and the assumed developing tendencies (Tománková 2007). The rather demanding information given is not included in a majority of the common decision methods.

The procedure of a hierarchical tree of criteria which are determining the evaluation of individual variants is with the MDA method similar to the classical MCDA (Schneiderová 2007). In the case of this study there has been selected a hierarchical structure which is described in Table 1.

Professionals from the fields dealing with the given topic evaluated each viewpoint according to evaluation scale: A – best, V – very good, D – good, P – average, H – worse, Z – far worse and S – bad. The value expresses an average for the assessment of an appropriate variant. For making the analysis more accurate the evaluating expert allocates to the average value also a risk (dispersion) and a trend (obliqueness) in the evaluated criterion. In practice this means that it is selected with an evaluated risk in the range from 2 (the lowest) to 8 (the highest). The value expresses the certainty with which the average value is selected. The evaluation of the trend is similar to the evaluation with the risk. Again there is a selection in the range from 2 (the trend is worse than the average value) to 8 (the trend is better than the average value). The examples of evaluation are stated in Figs 1–3, where a three-digit code given in brackets determines according to the previously given regulations, an average value, risk and trend of evaluation.

Table 1. Criteria tree of benefit

Criteria of the 1st degree	Criteria of the 2nd degree
Investor's viewpoint	Costs LCC
	Winter maintenance
	Width of communication
	Universality of use
Ecological, aesthetic	Impact on the living environs
	Recycling of damaged material
	Aesthetic influence
User	Security of traffic participants
	Material damage during crash
	Psychological aspects
Technological reinsurance	Longevity
	Challenge of installation
	Vandalism, metal collectors
	Certification, trends abroad
	Supplier's reinsurance
	Absorption of impact power

The procedure of evaluation by the MDA method is gained from assessors of the evaluation of individual criteria in the detail of a statistical distribution function which characterizes this evaluation. By the summation of all expert evaluations there is gained a resulting evaluation of individual variants, which are again statistically described and analyzed. For the final determination of the order of variants there is calculated a utility function which is based on values for the average, dispersion and obliqueness of the total evaluation of variants. The resulting image of this function depends on the processer of the study and the judgemental task whether to emphasise more the average results or to respect trends and what weight to give to the risk evaluation.

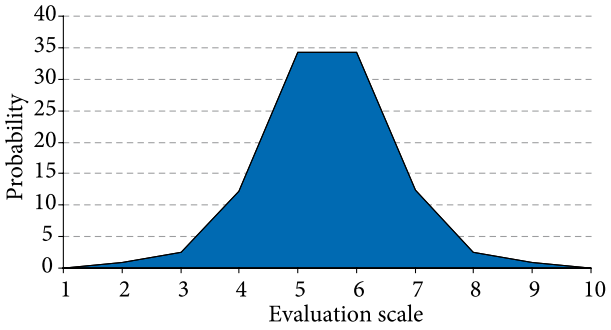

Fig. 1. Example of evaluation (P55)

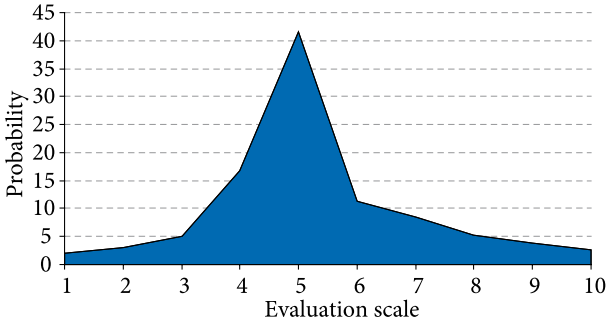

Fig. 2. Example of evaluation (P82)

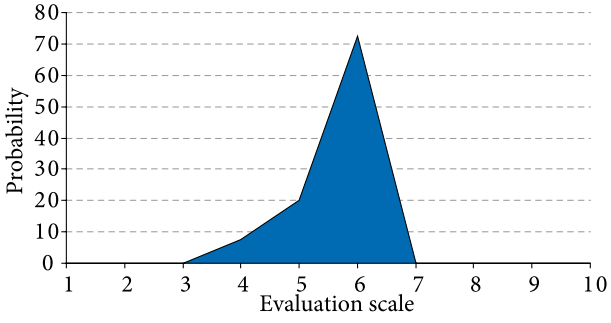

Fig. 3. Example of evaluation (P28)

3. Evaluation of crash barrier systems types by MDA

For the evaluation of the suitability of individual crash barrier types there were selected four basic spheres, which touch on this complex of problems. They concern an investor's viewpoint, ecological and aesthetic viewpoints, a user's viewpoint and the technological reinsurance of a chosen variant. The assigned evaluation weights are shown in Table 2.

Table 2. Evaluating criteria of the 1st degree

Criterion	Weight
Investor's viewpoint	0.3
Ecological, aesthetic	0.1
User	0.3
Technological reinsurance	0.3

In the 2nd phase the individual criteria of the 1st degree were divided into more details and evaluated by significance or weight within the context of a given standpoint. The resulting division including the final evaluation of criteria significance on a 2nd degree level of evaluation is shown in Table 3.

Table 3. Evaluating criteria of the 2nd degree

Criterion	Partial weight	Total weight
Investor's viewpoint		
Costs LCC	0.700	0.210
Winter maintenance	0.050	0.015
Width of communication	0.150	0.045
Universality of use	0.100	0.030
Ecological, aesthetic		
Impact on the living environment	0.450	0.045
Recycling of damaged material	0.350	0.035
Aesthetic influence	0.200	0.020
User		
Security of traffic participants	0.600	0.180
Material damage during crash	0.250	0.075
Psychological aspects	0.050	0.015
Technological reinsurance		
Longevity	0.200	0.060
Challenge of installation	0.100	0.030
Vandalism, metal collectors	0.050	0.015
Certification, trends abroad	0.150	0.045
Supplier's reinsurance	0.200	0.060
Absorption of impact power	0.300	0.090

For a professional evaluation there were chosen cable crash barriers, steel crash barriers, concrete crash barriers and non barriers. The evaluation of the individual variants by experts is given in Tables 4, 5.

Figs 4–7 show resulting graphs of evaluation of individual variants on the level of the 1st degree criteria. The graphs show probabilities in the spread of evaluations, in the way the chosen group of experts evaluated them. It concerns the probability spread of an absolute evaluation of individual viewpoints of the 1st degree of criteria evaluation, which is the complex of criteria evaluation of the 2nd degree.

The de scription of Figs 4–7 showed in Table 6.

Table 4. Expert evaluation of variants (part I)

Criterion	Cable			Steel			Concrete			Non-barriers		
	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.
Investor's viewpoint:												
Costs LCC	D	7	3	D	7	4	P	6	4	A	2	8
Winter maintenance	V	5	3	D	5	4	P	6	4	A	2	8
Width of communication	D	6	4	D	5	5	P	6	4	A	8	8
Universality of use	P	6	5	V	4	4	P	6	4	D	8	5
Ecological, aesthetic:												
Impact on the living environment	D	5	4	D	5	4	P	5	4	A	6	8
Recycling of damaged material	D	5	4	D	5	3	P	7	4	A	8	8
Aesthetic influence	V	5	4	D	7	4	P	6	4	A	3	8

Table 5. Expert evaluation of variants (part II)

Criterion	Cable			Steel			Concrete			Non-barriers		
	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.
User:												
Security of traffic participants	P	7	4	V	4	5	D	6	4	H	8	6
Material damage during crash	P	7	4	D	5	5	P	7	4	P	8	5
Psychological aspects	P	7	4	D	4	5	D	7	4	P	8	5
Technological reinsurance:												
Longevity	D	5	4	D	4	4	V	6	3	A	2	8
Challenge of installation	D	5	4	D	5	3	P	6	4	A	2	8
Vandalism, metal collectors	P	7	4	P	5	5	V	5	3	A	2	8
Certification, trends abroad	P	6	5	V	5	4	D	5	4	D	8	4
Supplier's reinsurance	P	6	5	V	3	3	V	5	3	A	2	8
Absorption of impact power	D	8	4	V	5	5	D	8	4	Z	8	2

Table 6. Detailed statistic of a variant evaluation

Criterion	Cable			Steel			Concrete			Non-barriers		
	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.	Eval.	Risk	Dev.
Investor's viewpoint:	0.38	–0.68	0.24	–0.39	**0.67**	**0.07**	**–0.57**	**–0.67**	**0.39**	**1.42**	**–3.93**	**–1.56**
Costs LCC	0.44	–0.81	0.41	–0.55	1.07	0.15	–0.57	–0.67	0.39	1.75	–5.21	–0.82
Winter maintenance	1.34	–1.31	–0.84	–0.34	–0.55	1.18	–0.57	–0.67	0.39	1.75	–5.21	–0.82
Width of communication	0.40	–0.59	0.13	–0.34	–0.55	0.50	–0.57	–0.67	0.39	1.05	–1.46	–0.65
Universality of use	–0.53	–0.90	0.11	0.59	–0.80	0.16	–0.57	–0.67	0.39	–0.50	–2.67	0.46
Ecological, aesthetic:	**0.65**	**–1.04**	**0.62**	**–0.40**	**–0.29**	**0.48**	**–0.57**	**–0.56**	**0.36**	**1.42**	**–3.27**	**–1.18**
Impact on the living environm.	0.47	–1.15	0.78	–0.34	–0.55	1.18	–0.55	–1.22	0.72	1.60	–4.09	–0.84
Recycling of damaged material	0.47	–1.15	0.78	–0.38	–0.76	0.57	–0.58	0.34	0.21	1.05	–1.46	–0.65
Aesthetic influence	1.38	–1.26	0.26	–0.55	1.07	0.15	–0.57	–0.67	0.39	1.69	–4.99	–1.15
User:	–0.56	0.41	0.26	0.31	–0.50	0.10	0.12	**–0.08**	**–0.11**	**–1.79**	**–1.96**	**0.92**
Security of traffic participants	–0.57	0.40	0.28	0.60	–0.77	–0.11	0.38	–0.65	0.06	–2.05	–1.63	1.11
Material damage during crash	–0.57	0.40	0.28	–0.34	–0.55	0.50	–0.58	0.34	0.21	–1.40	–2.71	0.73
Psychological aspects	–0.57	0.40	0.28	–0.34	–0.80	0.50	0.25	0.40	–0.31	–1.40	–2.71	0.73
Technological reinsurance	**–0.53**	**0.48**	**0.11**	**0.54**	**–0.46**	**0.08**	**0.25**	**0.40**	**–0.31**	**–1.40**	**–2.71**	**0.73**
Longevity	–0.04	0.01	–0.01	0.21	–0.42	0.32	0.64	0.08	–0.62	-0.10	1.07	–0.04
Challenge of installation	–0.57	0.40	0.28	–0.34	–0.80	0.80	1.34	–1.13	–0.38	1.75	–5.21	–0.82
Vandalism, metal collectors	–0.57	0.40	0.28	–0.38	–0.76	0.57	–0.57	–0.67	0.39	1.75	–5.21	-0.82
Certification, trends abroad	–0.57	0.40	0.28	–1.34	–0.55	0.50	1.32	–1.38	–0.91	1.75	–5.21	–0.82
Supplier's reinsurance	–0.53	0.48	0.11	0.56	–0.66	0.66	0.45	–1.22	0.72	–0.75	–1.63	0.36
Absorption of impact power	–6.03	–2.40	0.11	0.63	–1.12	1.12	1.32	–1.38	–0.91	1.75	–5.21	–0.82

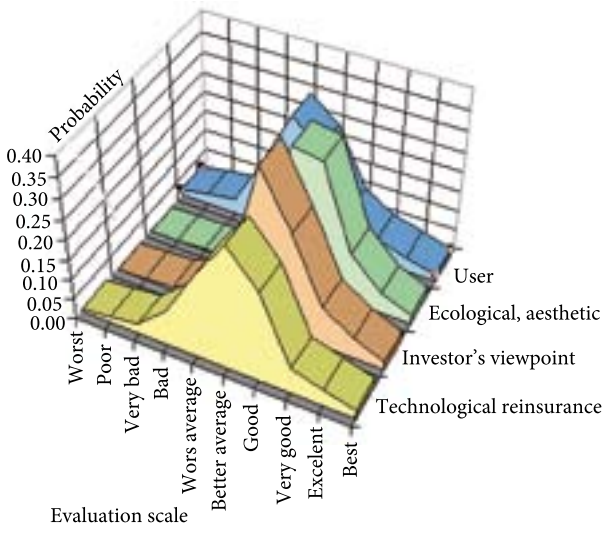

Fig. 4. Graph of a variant evaluation: cable

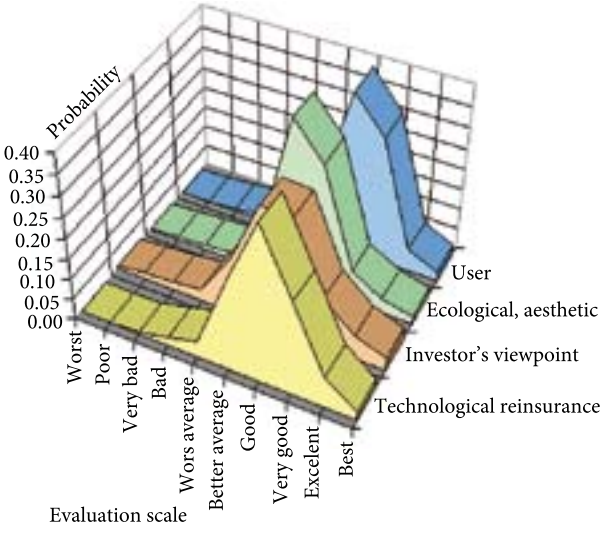

Fig. 5. Graph of a variant evaluation: steel

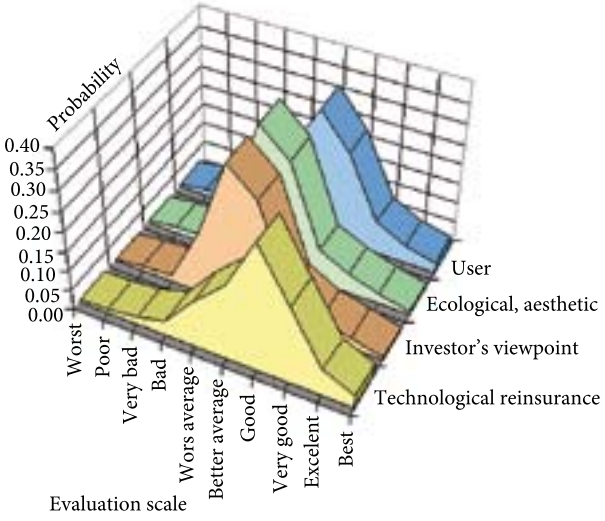

Fig. 6. Graph of a variant: concrete

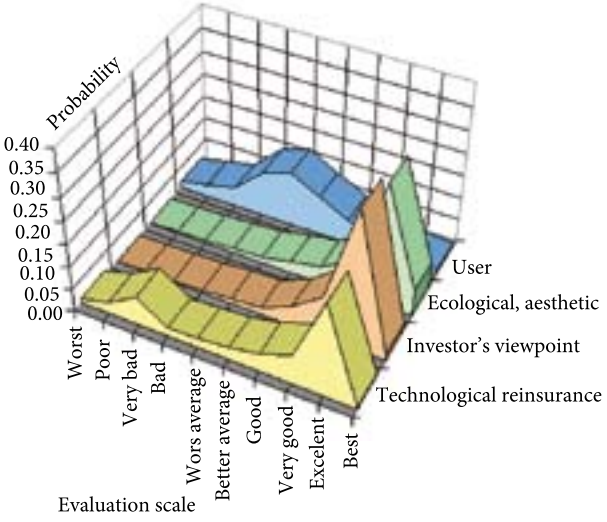

Fig. 7. Graph of a variant evaluation: non barriers

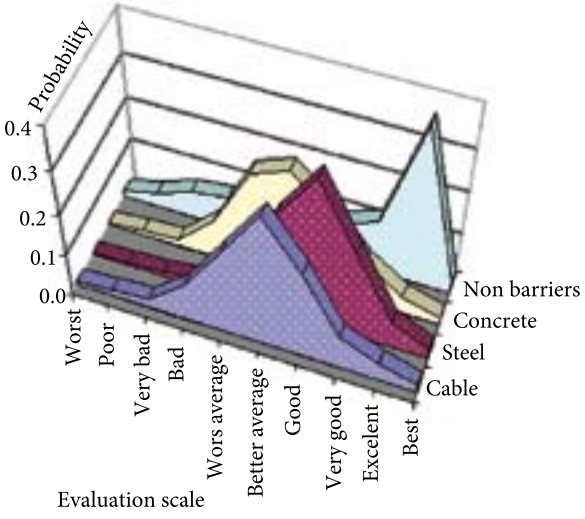

Fig. 8. Graph of a total evaluation for all variants

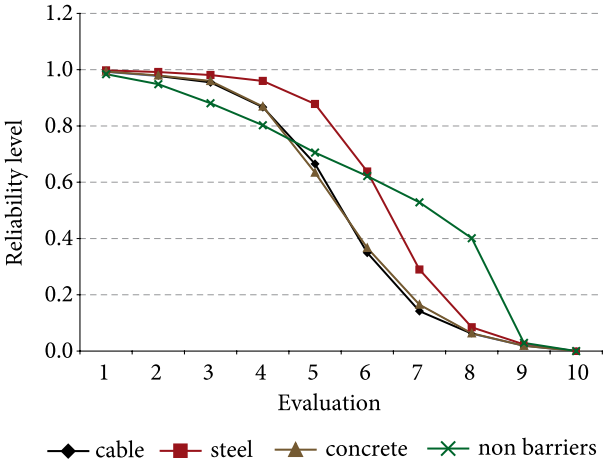

Fig. 9. Graph of a evaluation reliability level for all variants

Table 7. Evaluation of individual variants

Variant	Statistical			Resulting	
	Evaluation average value x	Risk spread σ^2	Development coefficient of skewness γ_1	Total profit U	Order place in evaluation
Cable	6.030	2.402	–0.106	5.101	2
Steel	6.845	1.799	–0.501	6.276	1
Concrete	6.050	2.468	–0.040	5.075	3
Non barriers	6.902	5.590	–0.732	4.886	4

The evaluation of the tested variant possibilities brought the following results. As the most suitable solution, from the viewpoint of benefits and risks of crash barriers at motorway constructions, is the variant using steel crash barriers. The 2nd and the 3rd order places in a tight sequence were the variants using cable technologies and concrete crash barriers. Detailed results are shown in Table 7. Figs 8, 9 show total evaluation for all variants.

Total benefit for a variant was calculated according to the relation:

$$U = x - (\sigma^2 \times 0.4 + \gamma_1 \times 0.3),$$

where U – a total benefit; x – an average value; σ^2 – a spread; γ_1 – a coefficient of skewness.

4. Conclusions

These wide enumeration of viewpoints were portioned out into blocks and into any subsequent judgement there were included additional standpoints: living cycle costs, winter maintenance, width of a communication, universality of use, impact on living environment, recycling, aesthetic influence, security, material damage, psychological aspects, visibility, longevity, the challenges of assembly, vandalism, contractor's reinsurance, experience from abroad, restraint. The criteria had the aim of an objective viewpoint judged and evaluated by a number of respondents (during the course of the conducted inquiry) – experts working within the framework of the Czech Technical University in Prague. The data thus gained were subsequently evaluated by MDA.

From the opinions of professional respondents (from a number of work centres – Dept of Road Structures, Dept of Mechanics, Dept of Steel and Timber Structures, Dept of Concrete and Masonry Structures, Dept of Landscape Engineering, Dept of Social Sciences, Dept of Construction Technology, Dept of Economics and Management in Civil Engineering etc.) there emerged a recommended order of applicability: as the most appropriate solution, from the viewpoint of the benefit and risk of crash barriers, is the variant using steel crash barriers, and in the 2nd and 3rd place in close sequence were cable and concrete crash barriers. Gaining the opinions of respondents and those derived from their specialist standpoint may be appraised as very valuable.

From the result it is obvious that on the basis of an average evaluation in 1st order there was placed the variant non barriers, but for understandable reasons the spread of the total evaluation is very (unacceptably) high (e.g. zero costs, but also zero absorption of impact power) and therefore the use of a zero variant in a total evaluation of utility lapses to the last order place which does not guarantee requirements for the fulfilment of given aims. With other variant solutions there were not brought about fundamental shifts, there was only increased the distance of the evaluation of steel crash barriers by the following two possibilities.

The negative skewness of the evaluation indicates that the majority of evaluations for all variants were better than their average value. In case of the evaluation of concrete crash barriers, the coefficient of skewness approaches zero and attests to the symmetrical evaluation of this variant.

In the next elaboration it could be possible to investigate the critical amount of necessary effort for removing narrow profiles in such a way as is shown in the evaluation.

The resulting evaluation does not state an absolute result, but states the present situation, which can be further developed. Technical solutions (individual types of crash barriers) can be found in any further improved development simply on the basis of the gained evaluations. The authors of the research consider the gained evaluations as the greatest added value to stating of priorities in the order of technical variants.

Acknowledgement

This paper originated as a part of a Czech Technical University in Prague, Faculty of Civil Engineering research project on the "Management of Sustainable Development in the Life Cycle of Buildings, Building Enterprises and Territories" (MSM 6840770006) financed by the Ministry of Education, Youth and Sports of the Czech Republic.

References

Beran, V.; Dlask, P. 2007. Nonlinear optimisation and rational cash flow, *Engineering, Construction and Architectural Management* 14(3): 277–292. DOI:10.1108/09699980710744917

Beran, V.; Hromada, E. 2008. Dynamic simulations in cost and time estimation of the construction process, *Acta Polytechnica* 48(1): 30–35.

Berka, V.; Dlask, P.; Schneiderová, R. 2007. The technical economic optimizing using the GRID procedures, in *Proc of CTU Workshop*. Ed. by Hájek, V.; Bittnar, Z. January 16–18, 2007, Prague, Czech Republic. Prague: Czech Technical University in Prague, 407–412.

Lama, A.; Smirnovs, J.; Naudžuns, J. 2007. Effectiveness of the 2000–2006 national road traffic safety programme implementation in Latvia, *The Baltic Journal of Road and Bridge Engineering* 2(1): 13–20.

Lehovec, F. 2006. The influence of road infrastructure on regional development, in *Proc of the 4th International Scientific Conference "Challenges in Transport and Communication"*. Ed. by Novák, K. August 5–8, 2006, Pardubice, Czech Republic. Pardubice: University of Pardubice, 177–182.

Ren, Z.; Vesenjak, M. 2005. Computational and experimental crash analysis of the road safety barrier, *Engineering Failure Analysis* 12(6): 963–973.
DOI: 10.1016/j.engfailanal.2004.12.033

Schneiderová, R. 2007. The building's value assessment using the utility and the LCC, in *Proc of International Conference "Central Europe towards Sustainable Building"*. Ed. by Frková, J. June 14–15, 2007, Prague, Czech Republic. Czech Technical University in Prague, 126–131.

Šarka, V.; Zavadskas, E. K.; Ustinovičius, L.; Šarkienė, E.; Ignatavičius, Č. 2008. System of project multicriteria decision synthesis in constructions, *Technological and Economic Development of Economy* 14(4): 546–565.
DOI:10.3846/1392-8619.2008.14.546-565

Šelih, J.; Kne, A.; Srdić, A.; Žura, M. 2008. Multiple-criteria decision support system in highway infrastructure management, *Transport* 23(4): 299–305.
DOI:10.3846/1648-4142.2008.23.299-305

Tománková, J. 2007. Cost planning for renewal and maintenance over the building life cycle, in *Proc of International Conference "Central Europe towards Sustainable Building"*. Ed. by Frková, J. June 14–15, 2007, Czech Republic. Czech Technical University in Prague, 105–110.

Vaidogas, E. R. V. 2007. Risk oriented design of protective highway structure, *The Baltic Journal of Road and Bridge Engineering* 2(4): 155–163.

Zavadskas, E. K.; Kaklauskas, A.; Peldschus, F.; Turskis, Z. 2007. Multi-attribute assessment of road design solutions by using the COPRAS method, *The Baltic Journal of Road and Bridge Engineering* 2(4): 195–203.

Received 11 August 2008; accepted 27 August 2009