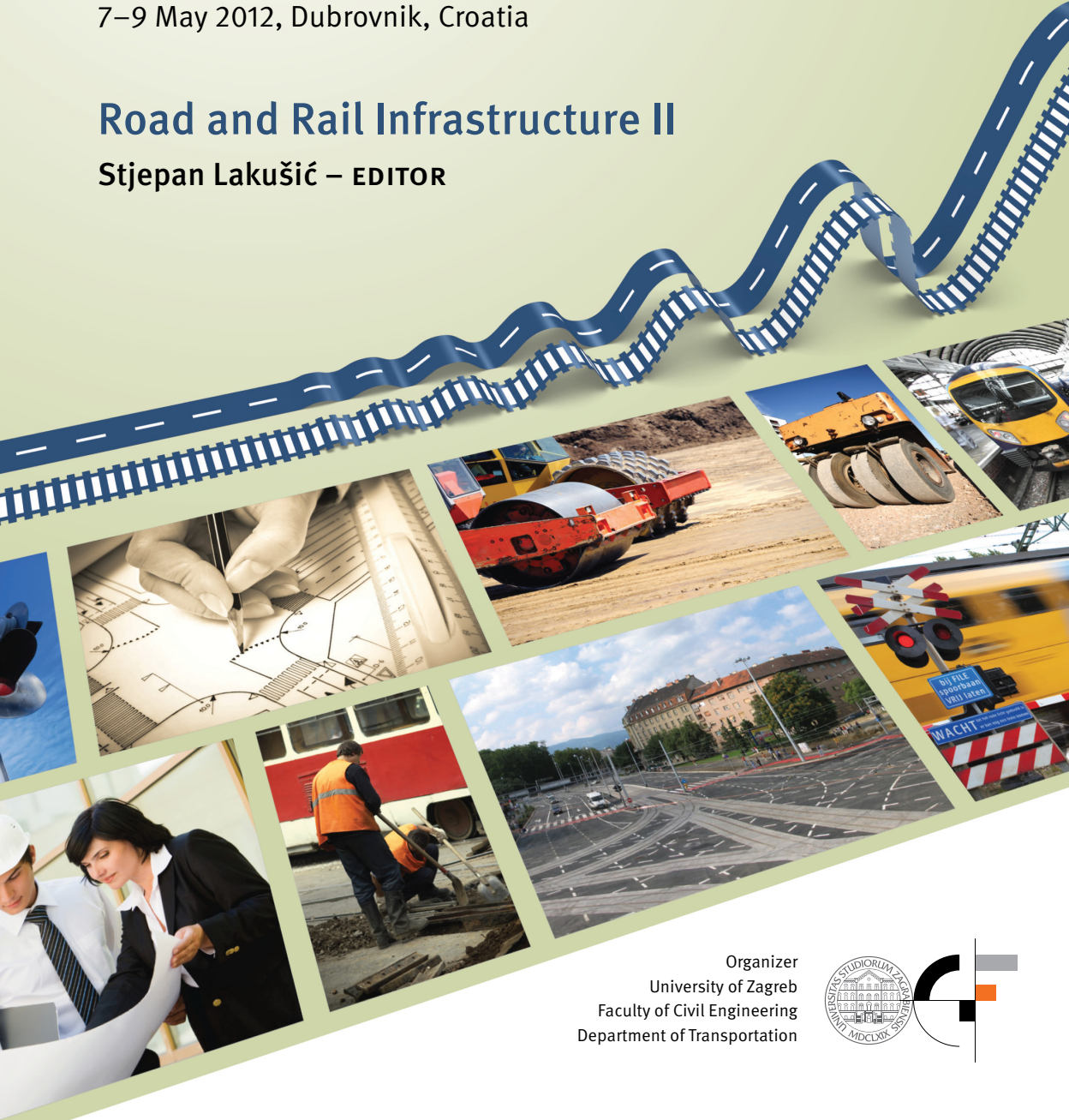


CETRA²⁰¹²

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
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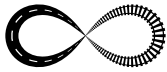
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APPLICATION OF MULTICRITERIA OPTIMIZATION IN THE RAILWAY LINE DESIGNING AT THE GENERAL PROJECT LEVEL

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Abstract

This paper presents the application of multicriteria optimization procedure in choosing the most favourable variant solutions of the route for the requirements of the General project of reconstruction and modernization of Belgrade–Niš railway line, at the Stalać (Ćičevac)–Djunis section – in other words, the method of multicriteria compromise ranking of variant solutions, with the following basic activities: variant solutions have been defined, the evaluation of variant solutions made and the decision reached on the most favourable solution.

Keywords: variant solutions, ranking, multicriteria optimization, optimum solution, compromise ranking

1 Introduction

Creating railway line design solutions represents conceiving real corridors – routes, and is based on demand balancing (in other words, traffic demands), goals and limitations, on the one hand and supply expressed in the existence of realistic solutions, on the other hand. This balancing is realized through corresponding design solutions on appropriate foundations. The evaluation of railway line design solutions means a procedure of evaluation and decision-making, including the procedures of defining indicators and criteria relevant for evaluation and decision-making in the course of creation of optimum development and use. The evaluation is carried out after, and in the course of each stage of the project – from creating basic ideas all the way through to the main and execution design. Designing railway lines represents an iterative process of solutions optimization according to a series of criteria which, in its final stage, leads to the most favourable solution. In this way, the evaluation is integrated into the process of designing variant solutions, since their essential tasks, goals and meaning are identical.

2 Multicriteria compromise ranking of alternative solutions

Multicriteria optimum solution is obtained by multicriteria optimization, which is for discreet systems carried out by means of multicriteria ranking of alternatives and choosing an optimum solution. Multicriteria optimization is carried out in several stages as follows: designing of variant solutions, defining criteria and criteria functions for evaluation of variant solutions, evaluation of all variant solutions according to each criterion respectively, multicriteria ranking of variant solutions and adoption of the most favourable solution.

The condition which should be fulfilled is that all alternatives be evaluated according to all criteria. For multicriteria compromise ranking of alternative solutions, the following is valid:

· alternative a_j is better than alternative a_k according to i criterion if:

$$f_{ij} > f_{ik} \tag{1}$$

· alternative a_j is better than alternative a_k according to all criteria if:

$$D(f_1(a_j), \dots, f_n(a_j)) < D(f_1(a_k), \dots, f_n(a_k)) \tag{2}$$

where $D(f_1, \dots, f_n)$ is a resultant of the function which represents the measure of aberration from the reference point.

2.1 VIKOR method

VIKOR method (VIšekriterijumsko Kompromisno Rešenje – Multicriteria compromise solution) complete with programme package (VIKOR) solves optimization tasks with many heterogeneous and conflicting criteria. The solution obtained can be either unique or it can represent a set of close solutions. The compromise solution is that permissible solution which is closest to the ideal one. The ideal solution is determined based on the best values of criteria and is not usually a part of the given set of alternative solutions.

2.1.1 VIKOR method operating algorithm

It is necessary to rank alternative solutions a_1, a_2, \dots, a_j with the set values of criteria functions f_{ij} , $i=1, n$ and $j=1, J$, where n is the number of criteria and J is the number of alternatives. The ranking procedure goes as follows:

a The best f_i^* and the worst f_i^- values for all $i=1, 2, \dots, n$ criteria functions are determined;

$$f_i^* = \max_j f_{ij}, f_i^- = \min_j f_{ij}, \text{ if } i\text{-th function represents a gain,} \tag{3}$$

$$f_i^* = \min_j f_{ij}, f_i^- = \max_j f_{ij}, \text{ if } i\text{-th function represents the costs} \tag{4}$$

b Based on S_j and R_j measures, the alternative solutions are ranked and the position of a_j on $s(a_j)$ and $r(a_j)$, ranking lists are determined, whereas $s(a_j)$ and $r(a_j)$, $j=1, 2, \dots, J$ values are calculated using the following relations:

$$S_j = \sum_{i=1}^n \omega_i (f_i^* - f_{ij}) / (f_i^* - f_i^-), \text{ (for } p=1) \tag{5}$$

$$R_j = \max_i \omega_i (f_i^* - f_{ij}) / (f_i^* - f_i^-), \text{ (for } p=\infty) \tag{6}$$

where: n – is the number of criteria, ω_i – is the weight of i -th criterion and expresses the preference of a decision-maker, i.e. relative importance of a criterion, S_j – is a measure of distance $R(F, 1)$ from an ideal point for alternative j and R_i – measure of distance $R(F, \infty)$ from ideal point for alternative j . Ranking, according to S_j and R_j measures, results in two ranking lists of alternatives. In order to obtain an integrated ranking list, compromise programming is applied according to which S_j and R_j are now criterion functions. The new ranking measure is:

$$Q_j = vQS_j + (1-v)QR_j = v \frac{S_j - S^*}{S^- - S^*} + (1-v) \frac{R_j - R^*}{R^- - R^*} \tag{7}$$

where:

$$S^- = \max_j S_j \quad \text{and} \quad R^- = \max_j R_j \quad (8)$$

$$v = (n + 1) / 2n - \text{difficulty of group benefit decision making strategy} \quad (9)$$

$$(1 - v) - \text{difficulty of individual dissatisfaction} \quad (10)$$

QS_j and QR_j represent normalized values. From the multicriteria point of view, alternative a_j is better than alternative a_k , if $Q_j < Q_k$ and is ranked higher on the list.

c VIKOR method suggests, as the best alternative from the multicriteria point of view, the one which is at the first place of the compromise ranking list for $v=0.5$ only if it holds:

- (C1) – 'sufficient advantage' over the alternative from the next positions. The difference between Q_j measures is used for evaluation of the 'advantage'. Alternative a' has a sufficient advantage over the next position on the ranking list a'' if:

$$Q(a'') - Q(a') \geq DQ \quad (11)$$

where DQ is 'the threshold of advantage': $DQ = \min(0.25; 1/(j-1))$. The threshold for cases with small number of alternatives is limited by 0.25

- (C2) - 'sufficiently stable' first position with the change of difficulty v (for $v=0.25$ and $v=0.75$). a' alternative must also be ranked by QS and/or QR .

If some of the conditions are not fulfilled, a set of compromise solutions is formed which includes the first alternative and the next following it. If the first alternative does not fulfil only the condition (C2), then the set of compromise solutions includes only the second one from the compromise ranking list. If it does not fulfil the condition (C1), then the set of compromise solutions contains alternatives from compromise ranking list up to the one which fulfils the condition that the first alternative does not have sufficient advantage over that particular alternative. The results of the VIKOR method are ranking lists according to measures QR , Q (for $v = 0.5$) and QS and a compromise alternative or a set of compromise solutions. These results represent a basis for decision-making and adoption of the most favourable (multicriteria optimum) solution.

3 Example

For the purpose of the General project of reconstruction and modernization of the railway line at Corridor 10 (Belgrade–Niš railway line, Stalać (Ćićevac)–Djunis section), it is necessary to evaluate the suggested variant solutions using the VIKOR method and to determine the most favourable variant solution.

3.1 Defining variant solutions

Belgrade–Niš railway line (240.8 km) represents an important part of Corridor 10 from both the national and international aspect. The function and technical parameters of the railway line do not meet the requirements of a contemporary railway line. Twin rail tracks are in length of 128.3 km and the single track is 112.5 km long. The project provides for the twin rail track to be constructed along the entire length from Belgrade to Niš. As Stalać–Djunis section is a single-track passing through the Južna Morava river valley, with sharp curves with minimum radius of $R=300$ m and transition curves $L=22$ m, which enable the speed of 65 km/h, there are four variant solutions suggested (Figure 1).

3.1.1 Variant solution 1 – for the speed up to 100 km/h

The elements of the site plan $R_{\min}=500\text{m}$ with transition curve $L=140\text{m}$ are adopted for this solution. Variant solution follows the route of the existing railway line, uses the bridge built for the second track over the Južna Morava river and provides for the construction of two tunnels $L_1=465\text{m}$ and $L_2=750\text{m}$ long respectively. The route length according to this variant solution is 18 km, with maximum designed longitudinal inclination of 5.5 ‰.

3.1.2 Variant solution 2 – for the speed up to 120 km/h

The adopted elements of the site plan are $R_{\min}=700\text{m}$ with transition curve $L=180\text{m}$. Because of the more comfort elements of this site plan, the variant solution varies more from the existing railway line route. There are three tunnels designed $L_1=350\text{m}$, $L_2=570\text{m}$ and $L_3=710\text{m}$ long respectively. This variant too, where the route is 17.5km long, with designed longitudinal inclination of 6.0‰ uses the already existing bridge for the second track over the Južna Morava river.

3.1.3 Variant solution 3 – for the speed up to 160 km/h

The design elements of the site plan route are: $R_{\min}=1500\text{m}$ with transition curve $L=180\text{m}$. At the beginning, from the station in Stalać, the variant solution follows the route of the existing railway track up to km 178+000, and the remaining part includes the construction of the new railway track all the way to Djunis. The length of tunnels designed according to this variant solutions is $L_1=1100\text{m}$, $L_2=570\text{m}$, $L_3=390\text{m}$, $L_4=3020\text{m}$ and $L_5=540\text{m}$ respectively. It is required to build a new twin rail track bridge $L=156\text{m}$ over the Južna Morava river and secure the river bed at three places. The highest designed longitudinal inclination according to this variant is 3.8 ‰, and the route is 13.40 km long.

3.1.4 Variant solution 4 – for the speed up to 200 km/h

As distinguished from the previous solutions, this variant solution provides for the construction of new railway line route which starts from the station in Čičevac and fits into the existing railway line at km 189+000. The route elements $R_{\min}=3000\text{m}$ with transition curve $L=180\text{m}$ provide for the speed up to 200 km/h. Along this 16.4 km long route, there are tunnels designed $L_1=4\,630\text{m}$, $L_2=1\,355\text{m}$ and $L_3=805\text{m}$ long respectively as well as a bridge over the Južna Morava which is 156m long. At the part of the route within the bridge zone the regulation of the Južna Morava river bed is required.

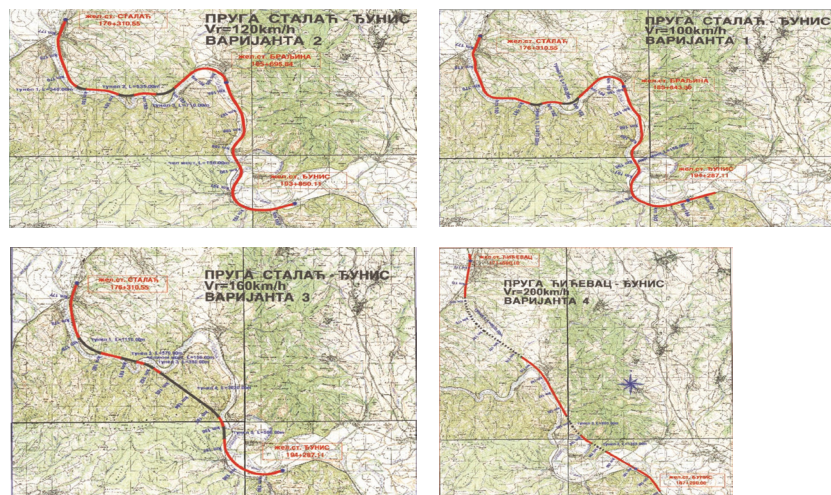


Figure 1 Variant solutions of Stalać (Čičevac) – Dunis section

3.2 Defining goals and criteria

The following goals have been defined: minimum construction costs (construction and electrical–technical infrastructure, expropriation, and other), minimum maintenance costs (regular and investment maintenance of superstructure and foundation, electrical engineering facilities and units, buildings and other), maximum benefit for railway line users (train–handling capacity of the track section, passenger train journey time in international traffic), minimum effects on location development (fitting into directions of development of network and other traffic systems as well as territorial spreading) and minimum effect on the environment (noise, vibrations, water pollution, soil pollution and degradation, territorial spreading, flora and fauna, micro climate and visual pollution). The pattern of relative goal difficulties resulted from the use of simplified Delphi method at the sample of 30 respondents, who analyzed the importance of each criterion taking into account both general knowledge and specific conditions of the location. The results of the statistic processing – relative goal difficulty (\hat{w}), standard deviation (s) and variation coefficient (v) are shown in Table 1.

The tabular statement of defined goals, criteria, indicators and their relative difficulties for variant solutions is shown in Table 5. Based on the chosen goals, criteria and the relations of their difficulties, the first ranking of variant solutions was made. The results obtained are shown in Table 2.

After the ranking, a set of variant solutions was obtained as a compromise solution for final decision which includes the variant solutions for $V_r=120\text{km/h}$, $V_r=160\text{ km/h}$ and $V_r=100\text{km/h}$ as well as the advantages of the given solutions when compared with other options. Variant solution $V_r=200\text{km/h}$ is not included in the set of compromise solutions and it was rejected as uneconomical. Compromise solution for the final decision makes the set which comprises the solutions within $WD_{1\leq w} \leq WG_1$ difficulty interval, while for the interval $WD(i) \leq w \leq WG(i)$ these solutions will be a part of compromise set of 'S' variant solutions. 'S' value is read off the right side of Table 4. FAC is the factor of increase (right) or decrease (left FAC) of input value of difficulty in order to obtain a different compromise solution. 888.8 value is marked as ∞ , for $WG(i)=1.000$.

The previous ranking gives precedence to economic goals. Taking into account the recommendations of the European Parliament and the EU Directive on environmental liability and elimination of harmful effects of the occurred environmental damage according to 'polluter–pays' principle, the second ranking gives precedence to the goal – Minimum effects on the environment in comparison with other goals and new relations among the difficulty criteria were set (trade–off). The result obtained by this ranking is a set of variant solutions which comprises the variant solution $V_r=160\text{km/h}$ and the variant solution $V_r=120\text{km/h}$, whereas the variant solution $V_r=160\text{km/h}$ is given preference of 11.5%. The results obtained by second ranking are shown in Table 3.

Table 1 The results obtained using Delphi method

1	Max. benefit for the railway line users	29.7	7.9	0.266	0.297
2	Min. investment costs	22.1	8.8	0.398	0.221
3	Min. maintenance costs	19.2	4.8	0.250	0.192
4	Min. effects on location development	14.5	5.3	0.366	0.145
5	Min. effects on the environmental development	14.5	7.8	0.538	0.145

Table 2 The first ranking of variant solutions

Ranking list of variant solutions	Compromise solution for final decision	
1 0.147 Vr=120km/h	Set of alternatives	Advantage
2 0.151 Vr=160km/h	A2. Vr=120km/h	0.4%
3 0.337 Vr=100km/h	A3. Vr=160km/h	18.6%
4 1.000 Vr=200km/h	A4. Vr=200km/h	

Table 3 Second ranking of variant solutions

Ranking list of variant solutions	Compromise solution for final decision	
1 0.151 Vr=160km/h	Set of alternatives	Advantage
2 0.266 Vr=120km/h	A3. Vr=160km/h	11.5%
3 0.463 Vr=100km/h	A2. Vr=120km/h	
4 1.000 Vr=200km/h		

Table 4 The pattern of goals, criteria and indicators with their relative difficulties and values of criteria functions

Goals of railway line section reconstruction	Cost difficulty	Criteria	Criteria difficulty	Extremes	Indicators	Unit of measure	Indicator difficulty	VARIANT SOLUTION			
								Vr=100km/h	Vr=120km/h	Vr=160km/h	Vr=200km/h
Min. investment costs	0.221			MIN.		€		47.000.000	54.000.000	105.550.000	131.000.000
Min. maintenance costs	0.192			MIN.		€		950.000	1.000.000	2.100.000	2.600.000
Max. benefit for railway line users	0.297	Train-handling capacity of railway line section.	0.50	MAX.		Number of trains		207	206	213	201
		Train journey time.	0.50	MIN.	Fitting of railway line section into the location plan	min		14.51	13.05	9.43	6.28
		Fitting into directions of development of network and other traffic systems	0.50	MAX.	Fitting into the international traffic network	Ordinary (1-5)	0.35	4	6	9	10
					Connection with road traffic systems		0.35	1	2	8	9
Min. effects on location development	0.145				Connection with road traffic systems		0.30	10	10	5	5
					Area of cultivable land		0.20	5.04	7.50	7.05	13.08
					Areas with perennial plants	ha	0.30	5.52	1.86	4.08	8.67
		Terrestrial spreading	0.50	MIN.	Areas of construction land		0.50	11.46	11.52	6.3	1.2
					Expressed influence*			4441	4279	2630	2801
		Noise	0.24		Less expressed influence**			1254	1254	663	132
		Vibrations	0.12					7692	6657	1572	1505
		Water pollution	0.15					1782	1967	2044	3892
		Soil pollution	0.16					3157	3487	2200	1723
		Terrestrial spreading	0.12	MIN.		m	0.67*	5560	4964	5405	6739
		Flora and fauna	0.10				0.33**	5716	5477	2660	3963
		Microclimate	0.05		No influence***		0.00***	3389	4040	1287	2728
Min. effects on the environment	0.145										
		Visual pollution	0.06								

Table 5 Analysis of preference stability – Difficulty intervals for individual criteria

F(i)	S.	FAC.	WD(i)	WD1	W0(i)	WG1	WG(i)	FAC.	S.
F 1	3	0.994	0.220	0.220	0.221	0.296	0.522	3.8	2
F 2	3	0.987	0.190	0.190	0.192	0.271	0.703	10.0	2
F 3	1	0.000	0.000	0.077	0.149	0.154	0.154	1.0	3
F 4	3	0.517	0.082	0.082	0.148	0.149	0.149	1.0	3
F 5	3	0.000	0.000	0.000	0.072	0.075	0.075	1.0	3
F 6	3	0.000	0.000	0.000	0.073	0.075	0.075	1.0	3
F 7	3	0.000	0.000	0.000	0.035	0.037	0.037	1.1	3
F 8	3	0.000	0.000	0.000	0.017	0.020	0.020	1.2	3
F 9	3	0.000	0.000	0.000	0.022	0.024	0.024	1.1	3
F10	3	0.714	0.017	0.017	0.023	0.422	0.422	31.0	3
F11	3	0.000	0.000	0.000	0.017	0.019	0.019	1.1	3
F12	3	0.711	0.010	0.010	0.014	0.405	1.000	888.8	2

4 Conclusion

Optimization of complex systems such as traffic system represents a process in which both theoretical knowledge and experiences of the experts from several disciplines are united. It is of essence to consider the goals, to set boundaries, to divide entities and to establish interactions, to determine necessary resources and to provide for the optimum functioning and use of the system. This imposes the need for the optimization to be made according to the criteria which will take into account all major components or consequences of the system development. This paper has presented the use of the VIKOR method. It has presented the set list of goals and criteria, as well as the manner of determining their relative difficulties. Compromise ranking has been made based on which a set of alternative solutions has been obtained. The difficulty intervals have been set using trade-off (variation of mutual relations of goals and criteria) in which the variant solution can be stable, as well as a wider interval within which the first ranked variant solution remains within a compromise set of several variant solutions.

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