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Application of multi-criteria optimisation in marina planning on the Montenegrin coast

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ABSTRACT

Development of nautical tourism in Montenegro, seen as a potentially profitable industry segment has started twenty years ago. The first steps taken in this direction were defining the legal framework, in particular: Law on Coastal Zone, Tourism Master Plan of Montenegro, Law on Yachts, followed by establishment of supporting organizations - Maritime Safety Department of Montenegro, Port Authorities and Border Police Department. Having invested efforts in adoption of planning documents and enactment of legislation relating to nautical tourism in recent period, Montenegro is seeking to impose itself as an important nautical destination. The first serious step towards achieving this goal was construction of a world-class marina Porto Montenegro in Tivat in 2010. The Special Purpose Spatial Plan for Coastal Zone provides for development of network of marinas to be constructed on the Montenegrin Coast. In the light of this, contribution of this paper is reflected in application of multi-criteria optimization in defining an optimum order of marina construction. The paper defines selection of criterion functions from the aspects of ecology, economy, security, specific aspect and aspect of suitability assessment for the location. The paper also presents the process of defining different criterion weights. The multi-criteria analysis determines a compromise solution for marina planning at Montenegrin Coast, which reconciles conflicting interests. The compromise solution is only a proposal, while a final decision remains with a decision maker.

Key words: marina location; multi-criteria optimization; criterion functions; ecology

INTRODUCTION

The Montenegrin Coast represents a valuable complex of natural and man-made resources, being a backbone of the main branches of industry of the State, tourism industry in particular. With promulgation of the Law on Coastal Zone in 1992, Montenegro recognized and acknowledged the high importance of extraordinary values of the coastal area and defined frameworks for special preservation regime, utilization and improvement of this important resource. Adopting and implementing key development strategies as defined in Tourism Master Plan of Montenegro (2001), tourism industry is expected to provide directly receivable turnover at the amount of one billion Euros by 2020, provided that the tourism offer is aimed at increase of high-quality capacities.

Tourism branch can derive valuable benefits from development of its nautical segment through making the most of huge possibilities of the existing and new marinas [4, 5, 6]. Equipping marinas to the full extent is a condition precedent for development of nautical tourism. Motivation for writing this paper is to define an optimum order of marina construction on the Montenegrin Coast, otherwise the coast risks to become a sailing destination avoided by sailors, while huge profit will be lost to neighbouring countries. The Special Purpose Spatial Plan for Coastal Zone (2005) specifies locations intended for marina construction without prior necessary analysis of suitable micro-locations and optimum order of implementation. By applying the multi-criteria optimization a compromise solution for marina micro-locations out of the set of alternative locations can be defined, along with the ranking list of alternatives based on the predefined criteria. A finite set of alternatives is then presented to the decision-makers and forms ground for reaching a final decision. Each alternative should be evaluated in terms of each and every criterion. The compromise ranking method in multi-criteria decision making process (referred to as VIKOR) is formed on such methodological grounds which assume that a decision maker is presented with the alternatives representing a compromise between wishes and possibilities, or that reconciling conflicting interests of all relevant shareholders in the decision-making process.

EXISTING AND PLANNED CONDITION OF MARINAS ON THE MONTENEGRIN COAST

Apart from the world-class marina Porto Montenegro in Tivat, present conditions for storage and handling ships in the ports along the Montenegrin coastline are pretty modest. Marinas and ports to be used as mooring spots for sailing vessels are constructed in the coastal towns of Tivat, Bar,

Budva, Prcanj, Kotor, Hereceg Novi, and Meljine, respectively. Project of Porto Montenegro in Tivat was initiated once the major investors lead by Peter Mank, president of the leading gold-mining corporation, had indentified a growing demand for yacht berths in the Mediterranean. Porto Montenegro was constructed in 2010, offering to its customers a full-scale service, from supply of spare parts to technical problem solving. The marina Porto Montenegro in Tivat is the most advantageous luxury yacht marina in the Mediterranean Sea, ranked among the world-class marinas. The marina in Bar has 665 berths on sea and 120 berths on land. The marina in Budva provides 400 for boats and 10 berths for larger vessels. Infrastructure connections are provided in a part of the operative quay. The marina in Prcanj is the first one constructed on the Montenegrin coast and financed with private capital. It is a small marina which represents certain pilot project of this type of tourist offer. Port of Kotor avails of an operative quay with the nautical infrastructure provided in the south part of the quay, the capacity of which is 10 to 15 vessels of different categories. Port of Herceg Novi is dominantly used for excursion boats operating to local destinations and fishing boats. Meljine has a breakwater constructed on its west side. The existing berths are used for local boats, and it can provide berths for 20 nautical vessels.

A key challenge for development of nautical tourism in Montenegro is the existence of not more than one high-level, fully equipped marina located in Tivat. The existing marinas in Bar, Budva and Prcanj need to be upgraded to a far higher level in terms of equipment and facilities required for provision of nautical services, while the remaining marinas are used as mooring spots for local boats only.

The Special Purpose Spatial Plan for Coastal Zone (2005) foresees establishment of a 2000-berth network in Montenegro to be consisted of two large service marinas with the capacity of 400 to 500 berths, four standard marinas with the capacity of 100 to 300 berths, and four small marinas. The existing mattresses and old docks in the Bay of Boka can be used for the purpose of nautical tourism upon undergoing careful revitalization. Two large service marinas are planned to provide all necessary nautical facilities and other services to its customers, therefore a provision of area on land should be safeguarded for future expansion. Such world-class marina as the Porto Montenegro was built in Tivat in 2010 on the location of former Ship Overhaul Institute, while the other one should be constructed in Bar at the location of the existing marina. The standard four marinas should meet demand of nautical sailors at the key points along the Montenegrin Coast. In this context, marinas at the following locations should be constructed: Rt Kobila, Liman in Ulcinj, byland Lustica in Bigovo, and in Kumbor. Construction of four small marinas is planned at locations of Ada Bojana, Buljarica, Budva and Kotor (along the Old Town). The commercial berths are planned in Njivice, Meljine, Zelenika, Prcanj and Bonici near Tivat, Sveti Nikola Island near Budva, and on the part of the coastline spreading from Rt Djerane to Porto Milena in Ulcinj.

CRITERION FUNCTION IN MULTI-CRITERIA OPTIMIZATION

Multi-criteria optimization is applied to determine the ideal alternative for marina locations out of the set of possible alternatives or the set of suitable alternatives. A criterion is expressed through a criterion function which is expected to reach a global extreme for the best alternative with regards to the limitations represented by capabilities of reaching a goal [1, 2]. In defining the criterion functions for marina micro-location all relevant elements of the system should be considered. The basic criteria applied for the purpose of comparison of alternatives comprise the following groups:

- environmental impact criteria,
- economic criterion,
- maritime security and safety criteria,
- specific criteria,
- assessment of location suitability criterion.

Special consideration is given to the environmental impact criteria which can be classified into two groups. The first group defines impact of marinas on the marine ecosystem, preservation of environment, with an aim to minimize effects to the flora and fauna of the aquatic ecosystem and to safeguard environment for future generations. This criterion function is expressed by the function of environmental risks f1; while the second criterion function f2; relates to preservation of other resources, impact on surrounding beaches and ambient values of the area. Both construction and operational phases of marinas should be aimed at prevention of environmental pollution by ships and protection of marine environment and intertidal zone.

General condition of the sea-shore quality is poorer in the closed sea (example: Bay of Boka) than in the open sea. The latest researches show that the Bay of Boka is exposed to intensive impact of human activities, the wastewaters have been observed to often cause excessive aquatic plant growth (algal bloom), while concrete biocenosis is being devastated. The evaluation of the environmental impact criteria is performed by environmental experts.

A 5-point scale is used for evaluation, where 1 stands for high environmental risk, 2 for moderate environmental risk, 3 for low environmental risk, 4 for no environmental risk, and 5 for positive impact of marina on the environment, e.g. improvement of the location planned for marina construction. Lower values are assigned to the marinas located in the Bay of Boka, somewhat higher to the marinas in the bays of Kotor and Herceg Novi, while the highest values are allocated to the marinas in the southern part of the coast.

The second group of criteria – the preservation of other resources, f2, affects the surrounding beaches and ambient values of the area. According to the available data, the Montenegrin Coasts avails of more than 100 beaches in total length of 70.35 km (area of approximately 271.5ha) visited for swimming and sun tanning. The following beaches are located in the vicinity of the planned locations for marina construction: Njivice (1.800 m), Meljine (325 m), Zelenika (430 m), Kumbor (235 m), Kotor (320 m), Prcanj (2. 820 m), Tivat (375 m), Bigovo (40 m), Budva (Avala – 340 m, Old Town – 230 m, and Slovenska plaza - 1.620 m), Sveti Nikola (575 m), Buljarica (2.350 m), Bar (Topolica – 750 m, Susanj – 870 m), Liman (105 m), Port Milena (100 m) and Ada Bojana (2.750 m). The evaluation of the environmental impact criteria is determined by length in kilometres of those beaches which are near the planned marinas, with the aim to minimize this criterion function. The economic criterion f3; is formulated as a criterion function of the marina construction costs in the currency of Euro. Within the scope of the economic evaluation there are procedures for determining costs of each alternative inclusive of the expropriation. Maritime safety and security criteria are determined by the criterion functions of the nautical conditions f4; and maritime conditions f5. The nautical conditions f4; come as a result of consideration of the navigational safety along the coastline. To navigate along the part of the sea, the nautical sailors are informed in advance if there is sufficient number of marinas on the planned route for a case of unplanned and emergency stops. It is very important that the nautical sailors feel safe and that they can expect all necessary assistance and support and information in case of a defect or

damage, unfavourable weather conditions etc. Authorities in charge in case of a ship incident on the Montenegrin Coast are Maritime Safety Department of Montenegro, Port Authorities in Bar and Kotor, and Border Police Department. The evaluation of the criterion function of nautical conditions is performed based on the required response time (in minutes) in case of an accident at sea. The aim is to minimize this criterion function. The adopted response time ranges from 20 min for Marina Bar to 50 min for marinas located on the north and south ends of the coast (Rt Kobila and Ada Bojana, respectively). The unfavourable maritime conditions f5; have adverse effect on the maritime safety. The sea wave direction at the Montenegrin Coast is defined based on the recorded frequency at certain stations, with special consideration given to the calm sea periods. Based on the available data, periods of calm sea are recorded at the station in Kotor in duration of 57.7 % of the year, at the station in Herceg Novi for 59.1 % of the year, and at the station in Budva for 59.1 % of the year, while the occurrence of calm sea periods has not been recorded at the stations in Bar and Ulcinj.

The evaluation of the maritime condition criterion is performed based on the calm sea period which will not affect the navigation period expressed in percent. The aim is to maximize this criterion function.

Specific criteria refer to specific features of the micro-locations intended for marina construction. The criteria are classified in two groups, the first deals with position and accessibility f6; and the second with project feasibility, f7. The criterion function of position and accessibility f6; is influenced by the level of current conditions and completeness level of the available transport infrastructure, and the distance from airport. Upon sea navigation, the sailors usually use road as well as air transport for their arrival and/or departure. When visiting Montenegro, sailors usually arrive at one of the two Montenegrin airports, i.e. Podgorica and Tivat Airports, and Dubrovnik Airport in Croatia. The road infrastructure is in poor conditions and there is no high-quality road connection with the neighbouring countries. The evaluation of the criterion function of position and accessibility is determined by the length of the road running from the airport to the planned marina location. The aim is to minimize this criterion function. The criterion function of project feasibility f7; relates to consideration of topographic conditions and ownership issues at micro-locations intended for marina construction.

The evaluation of the criterion function of project feasibility uses the 5-point scale, where 1 point is assigned for a low-level of feasibility due to topographic conditions and huge ownership issues, 2 points are assigned for a low-level of feasibility together with the ownership issue, 4 points are assigned for a high-level of feasibility with no ownership issues present, and 5 points are assigned for a high-feasibility project due to favourable topographic conditions (plain terrain, no rocks) and no ownership issues present.

The criterion of location suitability assessment expresses the attractiveness of the location for marina construction from the aspect of the expected demand for nautical berths f8. The marinas on the south and north ends of the Montenegrin Coast are deemed highly attractive for the said purpose, the former due to the vicinity of the Strait of Otranto which would ensure the entering of higher number of nautical vessels, while the latter due to the vicinity to the Croatian coast, known for high presence of nautical vessels. The marinas in the Bay of Boka are also deemed attractive locations due to natural and cultural values. The evaluation uses the 5-point rating scale where 1 stands f or poor rating, 2 for fair rating, 3 for good rating, 4 for very good rating and 5 for excellent rating of the location from the aspect of attractiveness.

EVALUATION AND RANKING ALTERNATIVES

The VIKOR method is introduced in the process of evaluation and multi-criteria ranking [3] of the alternative locations for marina construction on the Montenegrin Coast. This method requires defined values of criterion functions for each alternative.

For the purpose of VIKOR algorithm:

Set of j alternatives is denoted as (a1, ..., aj), set of n group of criterion functions is denoted as (f1, ..., fn); fij is the value of the i-th criterion function for j-th alternative, wi is the weight of the i-th criterion function; v is the weight of the strategy of majority of the criteria, and Qj is the measure of multi-criteria ranking.

Multi-criteria ranking by VIKOR method is performed based on the Qj measure which can be of the following relation:

$$Qj = v\,(Sj - S^*)/(S^- - S^*) + (1 - v)\,(Rj - R^*)/(R^- - R^*)$$
$$j = 1, ..., J$$

where:

$Sj = \sum wi\,(fi^* - fij)/(fi^* - fi^-)$

$Rj = \max_i wi\,(fi^* - fij)/(fi^* - f^-)$

$fi^* = \max_i fij; \quad fij^- = \min_j fij;\ i = 1,..., n$

The best values of the limit metrics S and R:

$$S^* = \min_j Sj;\ R^* = \min_j Rj$$

The worst values of the limit metrics are:

$$S^- = \max_j Sj;\ R^- = \max_j Rj$$

Qj measure can also be formulated as here below:

$$Qj = v\,Q\,Sj + (1\text{-}v)\,QRj$$

where:

$QSj = (Sj - S^*)/(S^- - S^*)$

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

Ranking of the alternatives is based on sorting by the values of the measures QR, QS and Q in decreasing order. The best alternative is the one with the minimum value of measure and this alternative will take first position in the ranking list. The alternative aj is better than the alternative ak if the condition $Qj < Qk$ is satisfied. The obtained result is three ranking lists. The measure Qj is a linear function of the weight v of the decision making strategy 'the majority of criteria', therefore the rank in the Q list is a 'linear combination' of ranks in the lists QR and QS. By applying the Q-metrics a rank list of all considered alternatives, e.g. a compromise list, is obtained. If a decision-maker has not predefined values of the weights wi of the criterion functions, and the weights v of the strategy 'the majority of criteria', the initial solution can be considered without giving preference to any individual criterion, with introducing values of the weights wi = 1 and/or v = 0.5.

VIKOR method suggests that the best alternative in terms of multi-criteria evaluation (for defined weights wi) is the alternative best ranked in the compromise ranking list for v = 0.5, i.e. that having the acceptable advantage

and the acceptable stability in decision making. If the first ranked alternative in the compromise ranking list fails to satisfy both of the criteria, this alternative is deemed not to be better than the second ranked alternative. The acceptable advantage is defined by difference between the Qj measures between the first compared to the subsequent alternative for v=0.5. In terms of the acceptable stability in decision making the compromise solution should also be ranked best in the QS or QR ranking list. In the course of the ranking process a decision-maker can vary the criterion weights wi, depending on the evaluation preferences given to certain criterion functions. Specifying weight criteria is a special issue in the multi-criteria optimization and represent input values for the VIKOR method. The compromise solution is reached through the following steps of the VIKOR algorithm: determination of ideal solution, transformation of varied criterion functions, determination of the criterion weight wi, determination of the criterion weight v, determination of the measures Sj, Rj, Qj, j...J, ranking in terms of the values S, R, Q. The compromise solution is a solution closest to the ideal solution based on the adopted distance to the ideal solution.

Tab. 1 shows values of the criterion functions for the multi-criteria ranking.

Tab. 2 shows outputs of the multi-criteria ranking in the form of the measures S,R and Q. The first ranking process gives no preference to certain criteria and the same weights are

Tab. 1. *Values of the criterion functions (f1 – environmental risks, f2 – preservation of other resources, f3 – economic criterion, f4 – nautical conditions, f5 – maritime conditions, f6 – position and accessibility, f7 – project feasibility and f8 – demand of nautical berths)*

varijante	f1	f2	f3	f4	f5	f6	f7	f8
	max	min	min	min	max	min	max	max
A1. Rt Kob.	3	0.1	4.500.000	50	58	58	2	5
A2. Njivice	3	1.8	650.000	40	59.1	55	3	4
A3. Meljine	2	0.32	700.000	30	59.1	50	3	3
A4. Zelenika	2	0.43	600.000	30	59.1	47	3	3
A5. Kumbor	3	0.23	7.200.000	30	59.1	44	3	3
A6.Kotor	1	0.32	3.500.000	30	57	9	4	4
A7. Prcanj	1	2.82	655.000	30	57	13	3	3
A8. Bonici	2	0.1	620.000	30	55	5	3	3
A9. Bigovo	3	0.04	4.200.000	40	54	10	2	2
A10. Budva	2	2.19	6.100.000	30	52	23	4	4
A11. Sv. Nikola	2	0.57	730.000	30	52	24	3	3
A12. Buljar.	3	2.35	2.100.000	40	22	43	3	2
A13.Bar	3	1.62	20.100.000	20	0.0	61	4	3
A14. Liman	2	0.1	8. 800.000	40	0.0	87	3	3
A15.Port Milena	2	10.1	580.000	40	0.0	90	3	3
A16.Ada Bojana	2	2.75	1.100. 000	50	0.0	102	3	3

Tab. 2. *Outputs of the multi- criteria ranking (W (I)- the first ranking process, W (II)- the second ranking process and W (III)- the third ranking process)*

R.L.	W(I) (0.125 0.125 0.125 0.125 0.125 0.125 0.125 0.125 0.125)			W(II) (0.167 0.167 0.167 0.083 0.083 0.083 0.167 0.083)			W(III) (0.083 0.083 0.083 0.167 0.167 0.167 0.083 0.167)		
	QR	Q	QS	QR	Q	QS	QR	Q	QS
1.	A10	A10	A6	A2	A2	A2	A10	A10	A6
2.	A2	A8	A10	A3	A10	A10	A6	A6	A10
3.	A3	A2	A8	A4	A8	A8	A2	A8	A8
4.	A4	A5	A2	A5	A5	A6	A3	A5	A5
5.	A5	A11	A5	A8	A11	A5	A4	A11	A11
6.	A8	A4	A11	A10	A4	A11	A5	A2	A2
7.	A11	A3	A4	A11	A3	A4	A7	A4	A4
8.	A6	A6	A3	A12	A12	A3	A8	A3	A3
9.	A1	A1	A1	A14	A14	A1	A11	A7	A7
10.	A7	A7	A7	A16	A16	A9	A1	A1	A1
11.	A9	A9	A9	A6	A6	A12	A9	A9	A9
12.	A13	A13	A13	A1	A1	A13	A13	A13	A13
13.	A12	A12	A12	A9	A9	A7	A12	A12	A12
14.	A14	A14	A14	A13	A13	A14	A14	A14	A14
15.	A16	A16	A16	A7	A7	A16	A15	A15	A15
16.	A15	A15	A15	A15	A15	A15	A16	A16	A16

introduced for all criterion functions (wi = 0.;125). The weight of the decision - making strategy for the majority of criteria is v = 0.5. In the second ranking process the preference is given to the criteria f1, f2, f3 and f7, while the third ranking process gives preference to the criteria f4, f5, f6 and f8.

In the first ranking, the compromise solution for decision-making is the alternative A10 with 17 % of advantage compared to the alternative A8. According to the outputs of the second ranking, the compromise solutions are the alternatives A2, A10, A8 and A5 with the advantage of 1.1 %, 1.4 %, 0.8 % and 3.7 %, respectively. The compromise solutions within the third ranking are the alternatives A10 and A6 with the advantage of 9.6 % and 16 %, respectively.

CONCLUSION

Proposal of optimum locations for marina construction on the Montenegrin Coast is determined based on the analysis of the outputs listed in Tab. 2. Additionally, consideration should be given to the type of marina e.g. whether the marina is classified as service, standard, small or marina intended for commercial berths. Among service marinas, the alternative A13 (Bar) is at the same time the only marina of this type taken into consideration for multi-criteria optimization, given that the service marina with all the required facilities was constructed in Tivat in 2010. Among standard marinas, the alternatives A5 (Kumbor) and A1 (Rt Kobila) are well ranked, while the alternatives A9 (Bigovo) and A14 (Liman in Ulcinj) rank near bottom of the rank list. Among small marinas, the alternative A10 (Budva) is best ranked. The alternative A6 (Kotor) is well ranked in the first and third ranking, yet it is ranked worst in the second ranking with the 11.6 % lag compared to the alternative A16 (Ada Bojana). In the group of commercial berths, the best ranked alternatives are A8 (Bonici), A2 (Njivice), A11 (Sv. Nikola), A4 (Zelenika) and A3 (Meljine). Based on the finite set of compromise solutions in these three rankings, it can be ascertained that the best locations among the total set are A13 (Bar) for service marina, A5 (Kumbor) for standard marina, A10 (Budva) among small marinas and A8 (Bonici) among commercial berths. The obtained results can be a useful tool for a decision maker in defining the order of marina construction on the Montenegrin Coast. Therefore, identification of the micro-location for marina construction should be based on a modern approach which harmonizes all objectives expressed in terms of the criterion functions and leads to determination of the compromise solution. The compromise solution derived from multi-criteria optimization is only a proposal, while a final decision remains with a decision maker.

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