INTEGRATION OF MULTICRITERIA ANALYSIS INTO DECISION SUPPORT CONCEPT FOR URBAN ROAD INFRASTRUCTURE MANAGEMENT

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Abstract

Urban road infrastructure management deals with complex decision making process. There are several reasons for a complexity such as: multi-disciplinarity, lots of participants, huge quantity of information, limited budget, conflict goals and criteria. These facts indicate that decision making processes in urban road infrastructure management belong to ill-defined problems. In order to cope with such complexity and to help managers during decision making processes this research proposes an application of multicriteria methods. Therefore, a generic concept of decision support for urban road infrastructure management based on multicriteria analysis is proposed. Three multicriteria methods: AHP, SAW and PROMETHHE, in a combination with 0-1 programming are used. The main advantage of an application of multicriteria analysis is that all stakeholders could be objectively included into decision process. Therefore, setting up of criteria weights involves opinions from all stakeholders' groups (stakeholders are divided into three characteristic groups). Evaluation of criteria importance (weights) is based on three sets of opinions processed by Analytic Hierarchic Processing (AHP) method. Three sets of criteria are then processed by Simple Additive Weighting (SAW) method resulting in a final set of criteria weights. By using SAW method, relative importance of opinions of all three stakeholders' groups is introduced. Collected data are then processed by PROMETHEE multicriteria methods. Proposed decision support concept is validated on the problem of improvement of one part of an urban road infrastructure system for a large urban area of town of Split. The concept is efficiently applied on several problems regarding parking garages: location selection, sub-project ranking, definition of an investment strategy.

Key words: *multicriteria analysis, decision support, AHP, SAW, PROMETHEE methods, urban road infrastructure management*

1. INTRODUCTION

Continuously dynamic and ever growing urban road infrastructure systems contribute to the difficulty within a decision making process as regards their management that is very complex and social sensitive. City councils face the problem of managing big urban road infrastructure projects, especially when comes to the compromised and sustainable solutions that have to satisfy all stakeholders. Each long-term planning of an urban road infrastructure is a complex, demanding project management task which should be enriched with decision support tools such as multicriteria methods and other operational research tools thus becoming more efficient.

Urban planning processes usually cause a generation of new transportation flows that result in new distribution of commutation ending points. Besides other problems, urban expansion as well as huge growth of vehicles in the cities raises the problem of development and maintenance of urban road infrastructure especially of the parking places. Lots of authors research in the field of transportation management. In his work Bielli (1992) presents urban traffic management as continuous decision process of coordination of all individual elements (traffic, signals, arterial roads, traffic, parking) and interrelated components (private cars, transit, pedestrians). He demonstrates DSS approach to urban traffic management. Mladineo et al. (2011.) also presented integration of DDS approach into traffic management. Cost and benefits evaluation aspect of potential infrastructure investments is also introduced in literature and several decision support models could be indicated. Two main goals of these papers mostly are selection of adequate model and model accessibility to users (Guisseppi, A., Forgionne, G.A, 2002.). All abovementioned leads to a conclusion that decision support DSS development process is not intuitive and deterministic process, because today we are dealing with very complex problems. A reason for bigger complexity of the problems lies in inclusion of many stakeholders that are needed for reaching an appropriate solution which leads to ill-structured and semi-structured problems. In order to cope with such complexity and to help managers during decision making processes this research proposes an application of multicriteria analysis. Three multicriteria methods: AHP (Saaty, T.L., 2001.), SAW and PROMETHHE (Brans, J.P., Vincke, Ph., 1984., Brans, J.P., Mareschal, B., 1990.) in a combination with 0-1 programming are used within proposed decision support concept for urban road infrastructure management.

2. ORIGINS OF DECISION SUPPORT CONCEPT FOR URBAN ROAD INFRASTRUCTURE BASED ON MULTICRITERIA ANALYSIS - GENERIC MODEL OF DSS FOR URBAN INFRASTRUCTURE MANAGEMENT

Urban infrastructure management system structure is based on the three decision levels concept: strategic, tactical, and operative (Figure 1). Integration of the system is realised through the relationships between three main DSS modules: data, dialog, models. Their interaction aims at support to the decision making process at all management levels. The architecture of the system implements the relationships at the adequate hierarchic level, as well as with information flows between the levels. The hierarchic levels serve as meeting point of adequate models and data. Inversely, according to available data sets at each level, an adequate model could be selected.

First management level supports decision-makers at lowest, operative decision level. It has two functions, support of decision making at the operative level and incubation of the data, information and demands for the decision making at higher levels: tactical and strategic. Likewise, second model level delivers tactical decisions and it creates basic information or concepts for further higher decision level. These decisions are based on the system state knowledge that is result of the first level data and models. At second level decision are made by experts and expert teams as well as employees from local political bodies and public companies that match to this management level and have certain responsibilities. The third level corresponds to strategic decision making process. Based on the expert deliverables from the tactical level a future development of the system is carried out. Delivered strategies have to be sound with existing global development or urban plans for the city or region. These strategies are frameworks for lower decision and management levels thus ensuring continuity of decision making process throughout both decision and management system. Both strategic and tactical level uses more complex techniques and knowledge then operative one. The most used methods are those for single or group decision making.

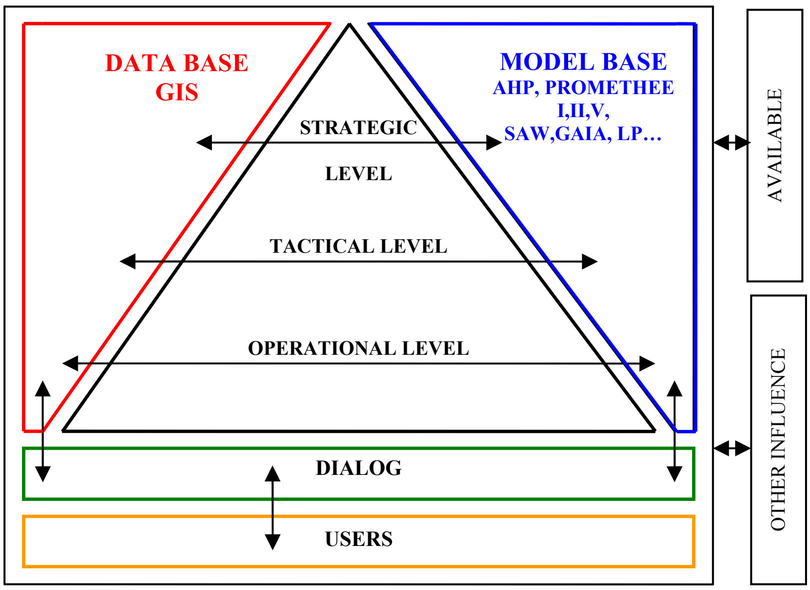

Figure 1: Architecture of the DSS for urban infrastructure management (Jajac, N., 2007).

Many outside factors may influence an urban infrastructure system as it may be seen at Figure 1. Technology influences the system at all levels through diverse appliances that are used at any level. The term “other factors” stands for the influence of local behaviour to the system, such as: established behavioural standards of a local community, actual and traditional styles of management and decision making, local mentality, etc. The described DSS is found to be adequate to support management of various urban infrastructure systems. Since this research is focused only on urban road infrastructure, this concept is used to support urban road infrastructure management.

3. DECISION SUPPORT CONCEPT FOR URBAN ROAD INFRASTRUCTURE MANAGEMNET BASED ON MULTICRITERIA ANALYSIS

According to the previously described DSS generic architecture a decision support concept for urban road infrastructure management is developed. The whole concept is validated on the problem of improvement of one part of an urban road infrastructure system for a large urban area of town of Split. The concept is efficiently applied on several problems regarding parking garages: location selection, sub-project ranking, definition of an investment strategy. Proposed decision support concept is based on multicriteria analysis. Therefore, three multicriteria methods: AHP, SAW and PROMETHHE, in a combination with 0-1 programming are used. There were certain data at operative level so it was easily structured and passed to the tactical level. At the tactical level, because of ill-structured nature of the problem that emerges from incomparable data and conflict stakeholders' demands, adequate multicriteria models should be used. The whole procedure starts with goal analysis which end with structured hierarchic structure of the goals, a goal tree. The goal analysis is the basis for a criteria definition. The importance and/or relevance of the criteria for the certain problem are expressed by weights. Evaluation of criteria weights is based on three sets of opinions processed by Analytic Hierarchic Processing (AHP) method. Using multicriteria Analytic Hierarchic Processing (AHP) method (Saaty, T.L., 2001.) it is very easy to assign weights through group decision making process by interviewing experts as well as other stakeholders such as representatives of citizens or NGOs etc. Three sets of criteria are then processed by Simple Additive Weighting (SAW) method resulting in a final set of criteria weights. By using SAW method, relative importance of opinions of all three stakeholders' groups is introduced. Further analysis is based on PROMETHEE methods (Brans, J.P., Vincke, Ph., 1984.) for multicriteria analysis and 0-1 programming. The parking garage problem is quite complex, because there is an interaction between locations, because any selected location influence the attractiveness of the near-by one. Therefore, by construction of one garage the need for neighbouring garages will be changed. This is handled by applying 0-1 analysis (PROMETHEE V method, Brans, J.P., Mareschal, B., 1990) after multicriteria ranking, that helps to model the interactions between garages' locations. Obtained solution, expressed in form of list of the highest ranked locations according to the criteria, as well as further selection of the locations, according to some additional elimination constraints, obtained by PROMETHEE V method are saved into a data base and they serve as possible strategic alternatives. The strategic decision level helped by experts selects the most convenient solution in accordance with current political orientation.

3.1. Analysis of the problem for the parking garages in the town of Split

The study area is wider city centre with high concentration of public facilities and of pedestrian concentration. The area was surveyed in detail and as a result a demand for parking places is defined. At the same time, the optimal number parking places with potential location of garages. It was shown that 6800 parking places are missing in a wider city centre. Sustainable development of the transportation system in Split was detected as main goal.

3.2. Multicriteria analysis

Multicritera analysis begins with determination of criteria and it was done by creation of objective tree. The Figure 2 shows the goal hierarchy for defined problem. As the main goal is Sustainable development of the transportation system in Split, the solution is based on the stepwise approach in a construction of the garages on the 13 potential locations. During the definition of the lower goals' levels all stakeholders were involved and the "wish list" was created. According to the "wish list" and to the priorities the whole objective tree was defined. As criteria for multicriteria analysis emerge form an objective tree, last hierarchic level of this particular tree derives the criteria set.

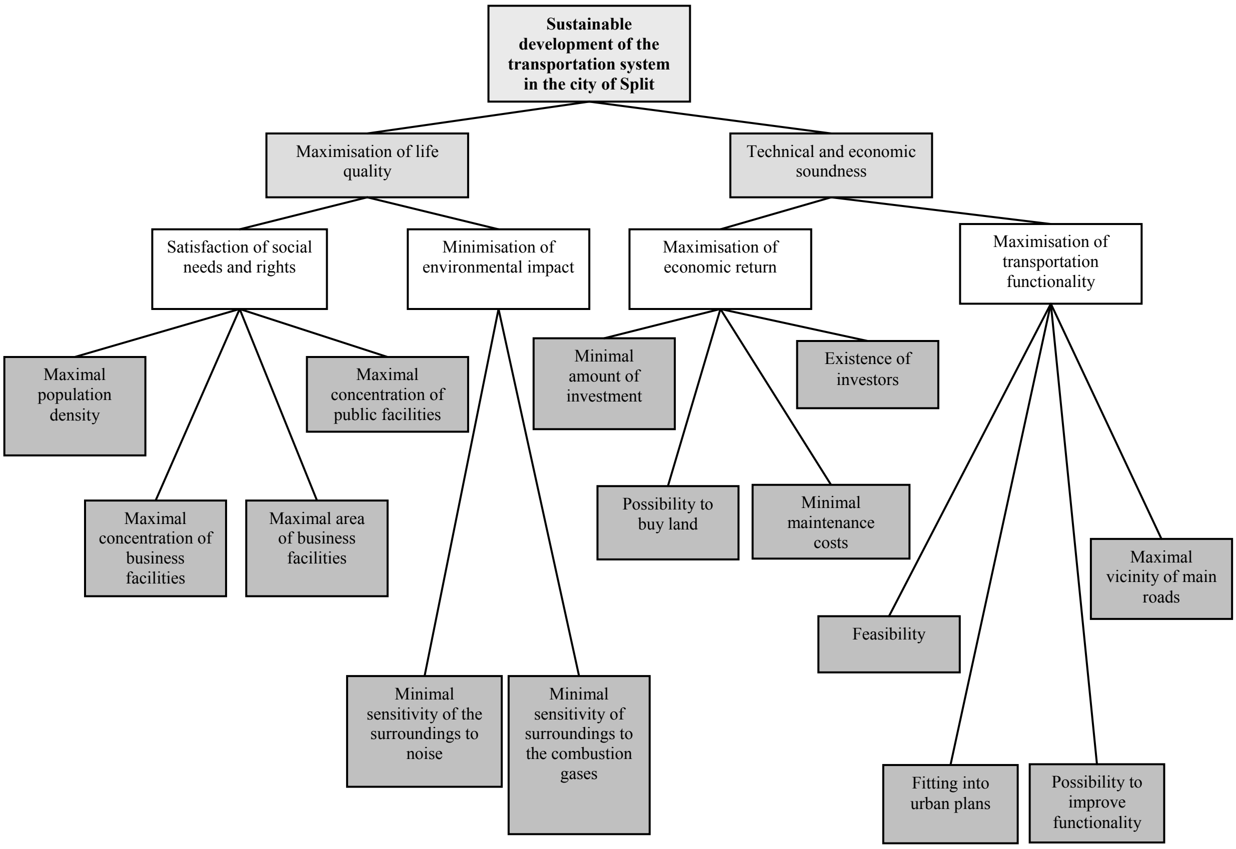

Figure 2: Hierarchy structure of the objectives as well as criteria for parking garage problem in town of Split

Weights for the criteria were defined by involving all stakeholders and with AHP method (Saaty, T.L., 2001.). According to the stakeholder group's main goal, three scenarios were developed (Table 1). The first scenario describes preferences of citizens, the second one of the transportation experts, and the third scenario represents how city authorities see the problem. Three sets of criteria are then processed by Simple Additive Weighting (SAW) method resulting in a final set of weights. Representatives from all three group are involved in process of ponders' values selection required for SAW. They are equally important and have same rights during selection process which results in unanimously accepted ponders. By using SAW method, relative importance of opinions of all three stakeholders' groups is introduced.

Table 1: Criteria weights and scenarios

Criterion	**Description of criteria**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Final weight**	**%**
C1	Population density	0,417	0,006	0,072	0,304	22,81
C2	Business facilities density	0,035	0,064	0,065	0,066	4,98
C3	Area of business facilities	0, 409	0,013	0,214	0,108	8,13
C4	Concentration of public institutions	0,155	0,029	0,024	0,121	9,08
C5	Feasibility	0,006	0,104	0,103	0,073	5,48
C6	Fitting into urban plans	0,071	0,036	0,035	0,071	5,33
C7	Possibility to improve functionality	0,004	0,101	0,052	0,054	4,03
C8	Vicinity of main roads	0,013	0,204	0,248	0,159	11,95
C9	Investment	0,003	0,052	0,014	0,024	1,80
C10	Possibility to buy land	0,017	0,051	0,030	0,038	2,88
C11	Minimal maintenance costs	0,005	0,101	0,015	0,042	3,15
C12	Existence of investors	0,005	0,018	0,004	0,011	0,80
C13	Sensitivity of the surroundings to noise	0,073	0,111	0,042	0,100	7,48
C14	Sensitivity of surroundings to the combustion gases	0,146	0,111	0,083	0,162	12,15

Table 2: Criteria values for the locations

ALTERNATIVES		**CRITERIA**													
NO	**LOC**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
1.	**3**	0.002055	0.0003	0.17706	8	5	1	5	0	104	1	17,4	0	0	0
2.	**4**	0.004044	0.00018	0.01497	6	3	1	4	0	144	1	21,4	0	4	4
3.	**5**	0.02229	0.0055	0.66213	6	5	1	3	0	84	0	15,4	1	0	0
4.	**6**	0.0168	0.0005	0.05763	10	1	1	2	1	75	1	14,5	1	2	2
5.	**7**	0.015912	0.00114	0.12762	2	3	0	3	1	15	1	8,5	0	8	9
6.	**9**	0.01087	0.00015	0.06638	1	5	1	4	0	11	0	8,1	0	4	5
7.	**10**	0.01729	0.0011	1,26413	2	3	1	5	1	76	1	14,6	0	0	0
8.	**11**	0.010512	0.00042	0.100974	1	3	1	4	1	27,8	1	9,75	0	0	0
9.	**12**	0.007587	0.00012	0.047148	1	3	1	3	0	90	1	16	0	3	4
10.	**13**	0.016566	0.00042	0.456036	2	3	1	1	0	27	0	9,7	0	8	9
11.	**18**	0.001416	0.00018	0.197526	2	5	1	2	1	45	1	11,5	1	0	0
12.	**19**	0.007401	0.00018	0.040554	1	3	0	4	1	10	1	8	0	4	5
13.	**20**	0.005709	0.00021	0.032202	2	3	1	5	0	15	1	8,5	0	4	4

Table 2 shows evaluated multicriteria model for ranking potential locations in the centre of the town of Split. Regarding expressed conflicts between the scenarios, stakeholder-tailored and compromised weights are found by SAW method. Therefore a new and final scenario came out.

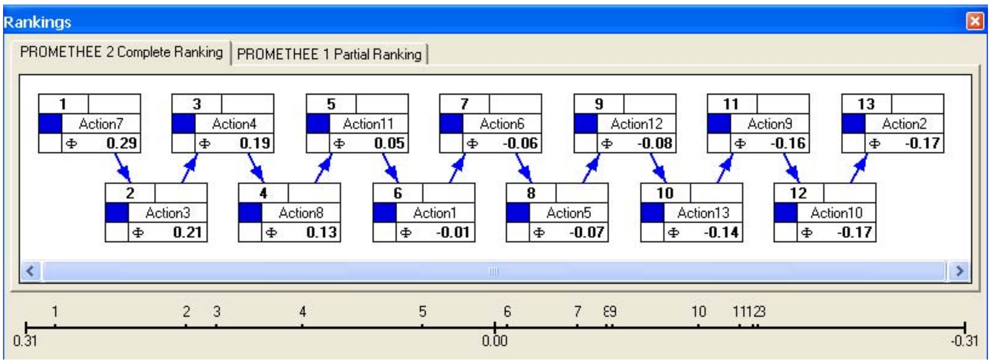

Figure 3: Preference flows and PROMETHEE II complete ranking for the compromised scenario

Figure 3 shows the final rank of all locations. If total flow Phi is considered as bonitet or worthiness of a location, the first location seems to prevail after all the rest. The following two locations have the almost same bonitet, and so on.

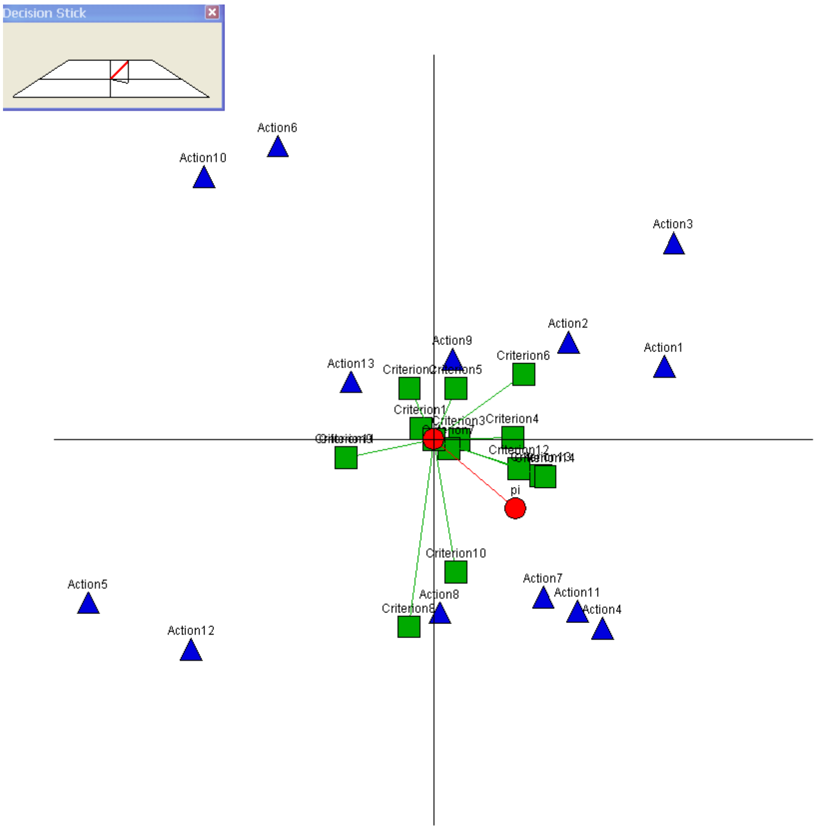

Figure 4: Graphical presentation of criteria using GAIA method

Graphical presentation of criteria using GAIA principal component analysis of total flows Phi shows that criteria stands in a positions that proves that the problem is ill-structured, and application of multicriteria analysis was appropriate.

3.3. Strategy selection by application of PROMETHEE V method

The intention is to build finite number of garages in accordance with available financial means. Therefore, using bonitet expressed by phi value as input data for 0-1 programming method - PROMETHEE V a final construction strategy can be defined. There exist certain interactions between garages, so by finishing one garage input values of others for multicriteria analysis change, namely the need of nearby garages. So additional constrains are implemented in the 0-1 model. The implemented ten constrains concern a limitation of the number of garages in neighbouring zones, and total amount of money for the investment. Objective function presents locations attributed by phi values. Table 3 shows results from PROMETHEE V method obtained by Branch and Bound method implemented in WINQSB.

Table 3: The results obtained by PROMETHEE V method

No	Location	Description
1.	3	Zona 3 - Matejuška
2.	5	Zona 5 - Grad
3.	6	Zona 6 - Manuš
4.	7	Zona 7 – Lučac
5.	11	Zona 11 - Bol zapad
6.	18	Zona 18 – Turska kula

4. CONCLUSION

For the problem of a garage construction priority ranking for the selected places in the town of Split, a proposed decision support concept is applied. For the moment, a multicriteria analysis and 0-1 programming methods are used. Multicriteria analysis points out several methodological and socio-political advantages of this approach in resolving complex problems such as garage construction priority ranking, regardless of decision maker hierarchy level. Both problem complexity and decision making process become more complex as decision making process goes towards higher management levels. In that order selecting strategies for development, i.e. construction of infrastructure could be the difficult, tricky task. Multicriteria analysis process, if applied properly, requires involvement of all stakeholders. They were divided in three significantly different groups (citizens, transportation experts, city authorities). Proper segmentation like proposed and participation of stakeholders in a selection process makes implementation and realisation of obtained results much easier and clears all mistrust and assumptions of bias existence during problem solving process. Stakeholders are directly involved in a decision making process by their opinions expressed by criteria weights, as well as by additional constrains implemented in the 0-1 programming. Furthermore, "fine tuning" of each group relative importance is provided throughout group decision making by SAW method. From methodological point of view multicriteria analysis implies system approach which represents most efficient and functional way of problem solving. An application of the combination of multicriteria analysis and 0-1 programming represents methodological framework for modelling decision makers' opinions. All abovementioned leads to a conclusion that concept of problem oriented decision support, such as this one for urban road infrastructure management, may be successfully realised by application of multicriteria analysis.

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