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DSS FOR URBAN INFRASTRUCTURE MANAGEMENT, PARKING GARAGES CASE STUDY

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Summary:

Problems of the urban infrastructure management could be found in the lack of systemic and comprehensive approach in problem solving at strategic level, as well as lack of data and procedures at operative level. Therefore, a generic model of a Decision Support System (DSS) for urban infrastructure management is proposed, which includes three decision and management levels (operative, tactical and strategic). In this paper the application of the DSS model is focused on the improvement of the part of urban infrastructure system that is parking garages. A case study deals with big parking garages project for a large urban area and how the DSS can be efficiently used for solving location and sub-project ranking problems, as well as for definition of an investment strategy. Two multicriteria models, AHP 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.

Keywords: urban infrastructure management, Decision Support System, AHP, PROMETHEE methods

1. Introduction

Ever growing urban infrastructure systems, such as water supply system, traffic systems, sewage system and others, 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 infrastructure projects, especially when comes to the compromised and sustainable solutions that have to satisfy all stakeholders. Each long-term planning of an urban 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 such as changing purposes of urban areas 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 on the roads raises the problem of development and maintenance of the parking places. Parking places and accompanied areas are become problems in the densely populated city centres and could endanger functionality of the certain urban space as well as endanger satisfaction of other population needs on the same area. 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. Its aim is the achievement of maximum efficiency and productivity for the whole system through the application of operating, pricing, regulatory and service policies. 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 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. Because of this characteristics many authors provide models for DSS design (Klashnera, R., Sabeta, S., 2007.). Today DSSs becomes very important even we could say a critical factor in modern organization. Their development and implementation is present in various books and research papers (Ahn, T., Grudnitski, G., 1985.; Alavi, M., Joachimsthaler, E., 1992.; Alter, S., 1994.; Sprague, R., Watson, H.J., 1996.; Steiger, D.M., 1998.; Turban, E., Aronson, J., 2000.). Quintero et al. 2005 described an improved DSS named IDSS (Intelligent Decision Support System) that coordinates management of urban infrastructures, such as sewage and waterworks. Authors introduce IDSS as a solution for future urban infrastructure management. Similar approach can be perceived in publications of other authors (Afraim, T., Jaye, A., 1995.; Burstein, F., 1995.; Leclerc, G. et al., 2001.; Pomerol, J. et al., 1996.).

2. 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.

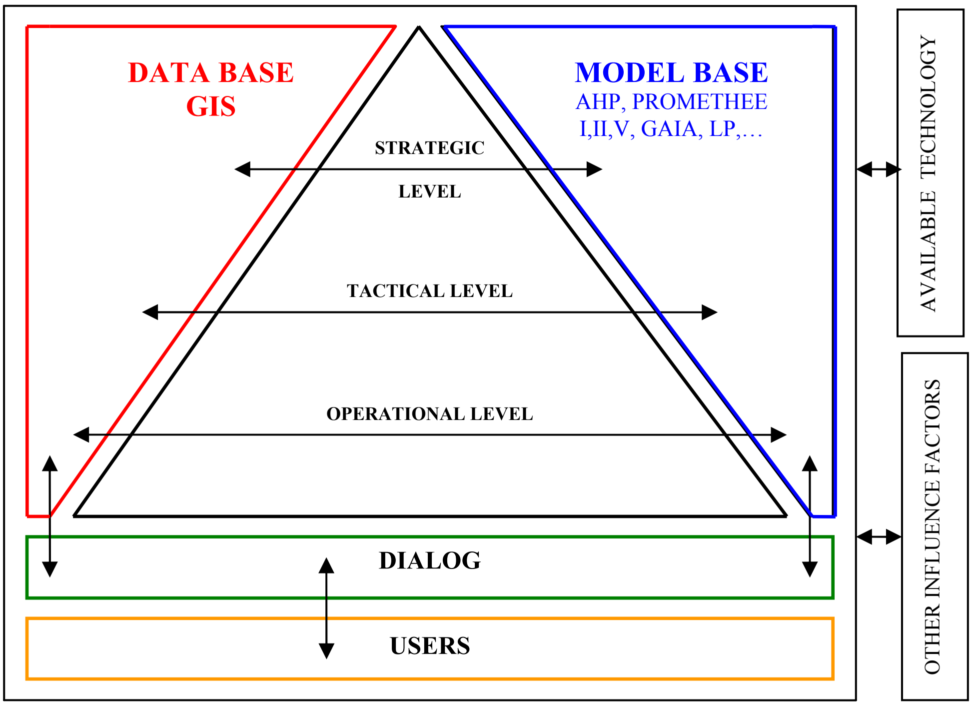

Figure 1: Architecture of the DSS for urban infrastructure management (Jajac, N., 2007).

Many outside factors may influence an urban infrastructure system as it may me 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.

3. The case study – Parking garages in the town of Split

3.1. DSS for transportation infrastructure system

According to the previously described DSS generic architecture a DSS for transportation infrastructure system is developed. The whole concept is tested on a problem of selection places for parking garages in town of Split. 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. 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. Further analysis is based on PROMETHEE

methods (Brans, J.P., Vincke, Ph., 1984.) for multicriteria analysis and 0-1 programming, as well as GAIA method, a principal component based method for visual presentation of a multicriteria problem. 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.

3.2. Analysis of the problem for the parking garages of the town of Split

The case 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 (Cvitanić, 2005.). It was shown that 6800 parking places are missing in a wider city centre.

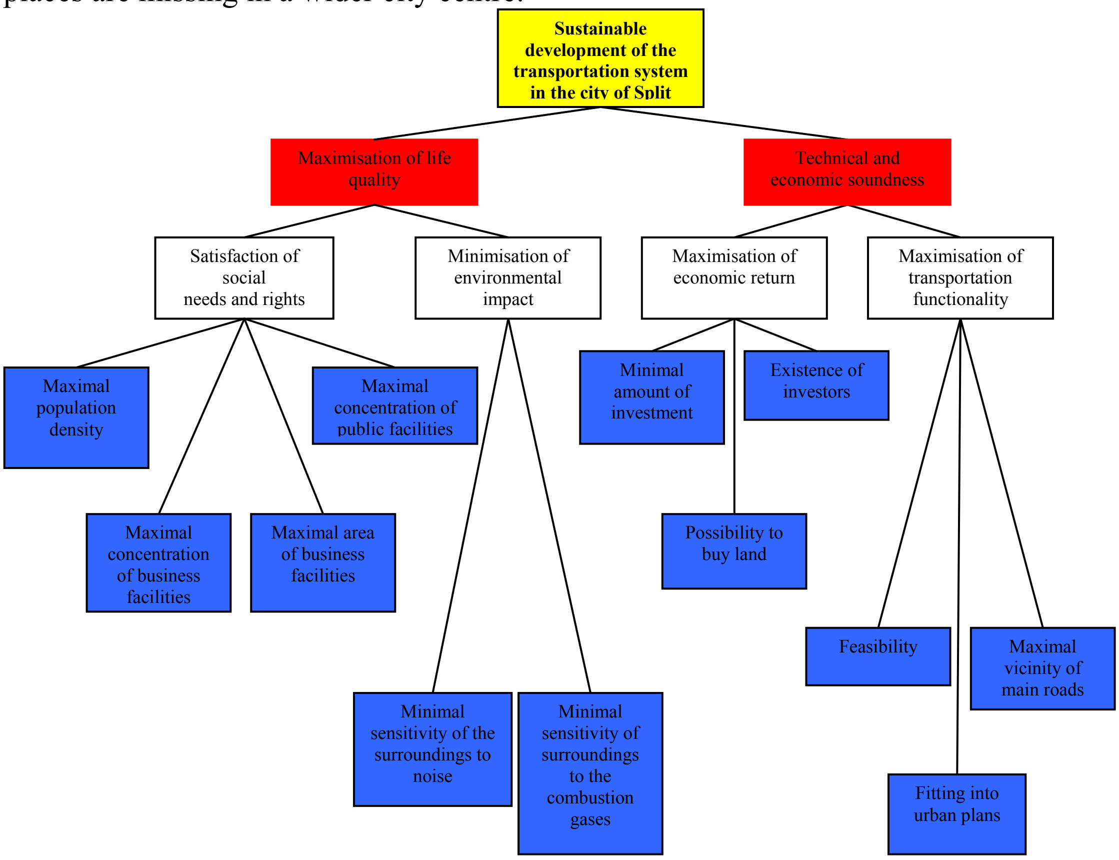

Figure 2: Hierarchy structure of the objectives as well as criteria for parking garage problem in town of Split (Jajac, N., 2007).

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 29 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.

3.3. Multicriteria analysis

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. The fourth scenario is an average value of them and stands for a compromised view to the problem.

Table 1: Criteria values and scenarios

Criterion	Description of criteria	Scenario 1	Scenario 2	Scenario 3	Average weight	%	MIN/MAX
C1	Population density	0,417	0,006	0,072	0,165	16,5	MAX
C2	Business facilities density	0,035	0,064	0,065	0,055	5,5	MAX
C3	Area of business facilities	0,049	0,013	0,214	0,092	9,2	MAX
C4	Concentration of public institutions	0,155	0,029	0,024	0,069	6,9	MAX
C5	Feasibility	0,006	0,104	0,103	0,071	7,1	MAX
C6	Fitting into urban plans	0,071	0,036	0,035	0,047	4,7	MAX
C7	Vicinity of main roads	0,017	0,305	0,300	0,207	20,7	MAX
C8	Investment	0,003	0,052	0,014	0,023	2,3	MIN
C9	Possibility to buy land	0,023	0,152	0,045	0,073	7,3	MAX
C10	Existence of investors	0,005	0,018	0,004	0,009	0,9	MAX
C11	Sensitivity of the surroundings to noise	0,073	0,111	0,042	0,075	7,5	MIN
C12	Sensitivity of surroundings to the combustion gases	0,146	0,111	0,083	0,113	11,3	MIN

Table 2 shows evaluated multicriteria model for ranking potential locations in the centre of the town of Split. Regarding expressed conflicts between the scenarios, compromised weights are found by simple average of scenarios' weights, thus giving equal importance for all groups of stakeholders. Therefore a new compromised scenario came out. Table 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 same bonitet, and so on.

Table 2: Criteria values for the locations

ALTER-NATI-VES		CRITERIA											
		SOCIAL CRITERIA				TECHNICAL – URBAN CRITERIA			ECONOMIC CRITERIA			ECOLOGICAL CRITERIA	
NO	LOC	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1.	**3-1**	0.002055	0.0003	0.17706	8	5	1	0	104	1	0	0	0
2.	**3-2**	0.00411	0.0006	0.35412	9	3	0	0	91	1	1	2	2
3.	**4-1**	0.004044	0.00018	0.01497	6	3	1	0	144	1	0	4	4
4.	**4-2**	0.004044	0.00018	0.01497	3	3	1	0	60	1	0	0	0
5.	**4-3**	0.01348	0.0006	0.0499	4	1	0	0	28	0	0	0	0
6.	**4-4**	0.004044	0.00018	0.01497	1	5	1	0	21,6	0	0	10	10
7.	**5-1**	0.02229	0.0055	0.66213	6	5	1	0	84	1	1	0	0
8.	**6-1**	0.0168	0.0005	0.05763	10	1	1	1	75	1	1	2	2
9.	**6-2**	0.01008	0.0003	0.034578	7	3	0	1	30	0	0	0	0
10.	**7-1**	0.015912	0.00114	0.12762	2	3	0	1	15	1	0	8	9
11.	**9-1**	0.01087	0.00015	0.06638	1	5	1	0	11	0	0	4	5
12.	**9-2**	0.017392	0.00024	0.106208	1	3	0	0	20	1	0	8	9
13.	**10-1**	0.01729	0.0011	1,26413	2	3	1	1	76	1	0	0	0
14.	**11-1**	0.010512	0.00042	0.100974	1	3	1	1	27,8	1	0	0	0
15.	**11-2**	0.01752	0.0007	0.16829	6	1	0	1	30	1	0	6	7
16.	**12-1**	0.007587	0.00012	0.047148	1	3	1	0	90	1	0	3	4
17.	**12-2**	0.020232	0.00032	0.125728	1	3	0	0	12	1	0	2	2
18.	**12-3**	0.02529	0.0004	0.15716	2	5	0	0	37	1	0	4	5
19.	**12-4**	0.007587	0.00012	0.047148	4	5	0	1	35	0	0	4	5
20.	**13-1**	0.016566	0.00042	0.456036	2	3	1	0	27	1	0	8	9
21.	**13-2**	0.02761	0.0007	0.76006	8	5	1	0	61	1	1	8	8
22.	**13-3**	0.008283	0.00021	0.228018	3	5	1	1	55	0	1	0	0
23.	**18-1**	0.001416	0.00018	0.197526	2	5	1	1	45	1	1	0	0
24.	**18-2**	0.00236	0.0003	0.32921	3	5	1	1	31,2	0	0	4	4
25.	**19-1**	0.007401	0.00018	0.040554	1	3	0	1	10	1	0	4	5
26.	**19-2**	0.014802	0.00036	0.081108	2	3	1	1	20	0	0	0	0
27.	**20-1**	0.005709	0.00021	0.032202	2	3	1	0	15	1	0	4	4
28.	**20-2**	0.011418	0.00042	0.064404	1	3	1	0	18	0	0	4	5
29.	**20-3**	0.011418	0.00042	0.064404	4	3	0	1	24	1	0	0	0

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

Ranking	Φ	Alternatives	**Ranking**	Φ	Alternatives	**Ranking**	Φ	Alternatives
1	0.3191	13	**11**	0.0584	15	**21**	-0.1281	20
2	0.2147	8	**12**	0.0408	24	**22**	-0.1418	27
3	0.2143	7	**13**	0.0182	10	**23**	-0.1428	16
4	0.1794	14	**14**	0.0167	25	**24**	-0.1454	3
5	0.1759	23	**15**	-0.0017	19	**25**	-0.1552	5
6	0.1583	29	**16**	-0.0070	1	**26**	-0.1639	11
7	0.1538	22	**17**	-0.0299	18	**27**	-0.1957	28
8	0.1389	26	**18**	-0.0558	17	**28**	-0.2067	12
9	0.0931	9	**19**	-0.0764	4	**29**	-0.3192	6
10	0.0697	21	**20**	-0.0818	2			

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.

3.4. 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 seventeen constrains concern a limitation of the number of garages in one zone, and total amount of money for the investment.
Objective function presents locations attributed by phi values. Table 4 shows results from PROMETHEE V method obtained by Branch and Bound method implemented in WINQSB.

Table 4: The results obtained by PROMETHEE V method

No	**Location**		**Description**
1.	1	3-1	Zona 3 - Matejuška
2.	4	4-2	Zona 4 - Varoš
3.	7	5-1	Zona 5 - Grad
4.	8	6-1	Zona 6 - Manuš
5.	9	6-2	Zona 6 - Manuš
6.	10	7-1	Zona 7 – Lučac
7.	12	9-2	Zona 9 - Spinut jug
8.	14	11-1	Zona 11 - Bol zapad
9.	22	13-3	Zona 13 - Lovret sjever
10.	23	18-1	Zona 18 – Turska kula
11.	24	18-2	Zona 18 - Turska kula
12.	A29	203	Zona 20 - Gripe

4. Conclusion

For the problem of a garage construction priority ranking for the selected places in the town of Split, a DSS 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. 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. They were divided in three significantly different groups (citizens, transportation experts, city authorities). 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 DSS, such as DSS for urban infrastructure, may be successfully realised by application of both multicriteria methods and well defined goal analysis.

5. References

1. Ahn, T., Grudnitski, G., 1985. Conceptual perspectives on key factors in DSS development: a systems approach. Journal of Management Information Systems 21, pp. 18–32.
2. Afraim, T., Jaye, A., 1995. Decision Support Systems and Intelligent Systems. (fifth ed.), Simon and Schuster Company, Upper Saddle River, NJ.
3. Alavi, M., Joachimsthaler, E., 1992. Revisiting DSS implementation research: a meta-analysis of the literature and suggestions for researchers. MIS Quarterly 16 1, pp. 95–116.
4. Alter, S., 1994. What do you need to know to develop your own DSS?. P. Gray, Editor, Decision Support and Executive Information System, Prentice-Hall, Englewood Cliffs, NJ, pp. 58–65.
5. Brans, J.P., Mareschal, B., 1990. PROMETHEE V: MCDM problems with segmentation constraints. Centrum voor Statistiek en Operationeel Onderzoek, Vrije Universiteit, Brussel
6. Brans, J.P., Vincke, Ph., 1984. Preference Ranking Organisation Method for Enrichment Evaluations (The PROMETHEE Method for Multiple Criteria decision Making). Centrum voor Statistiek en Operationeel Onderzoek, Vrije Universiteit, Brussel
7. Burstein, F., 1995. IDSS: Incorporating knowledge into decision support systems. Burstein, F., O'Donnell, P.A., Gilbert, A. (Eds.), Proceedings of the Workshop on Intelligent Decision Support—IDS'95, Monash University, Melbourne, pp. 93–96.

8. Jajac, N., 2007. Oblikovanje sustava podrške odlučivanju u upravljanju infrastrukturnim sustavima urbane sredine. Magistarski rad, Sveučilište u Splitu Ekonomski fakultet Split, Split
9.Klashnera, R., Sabeta, S., 2007. A DSS Design Model for complex problems: Lessons from mission critical infrastructure. Decision Support Systems, Volume 43, Issue 3, Special Issue Section: Integrated Decision Support, pp. 990-1013.
10. Leclerc, G., Hmiya, S., Aïmeur, E., Quintero, A., Pierre, S., Ochoa, G., 2001. An intelligent decision support system (IDSS) for an urban infrastructure complaint management module. World Multiconference on Systemics, Cybernetics and Informatics, ISAS/SCI 2001, Orlando, Florida, vol. XVIII, pp. 143–147.
11. Pomerol, J., Roy, B., Rosenthal-Sabroux, C., 1996. Development of an ‘intelligent' system for the evaluation of railway timetables: Problems and issues. Journal of Decision Systems 5, pp. 249–267.
12. Quintero, A., Konaré, D., Pierre, S., 2005. Prototyping an intelligent decision support system for improving urban infrastructures management, European Journal of Operational Research 162 (3), pp. 654–672.
13. Saaty, T.L., 2001. Decision Makink for Leaders, The Analytic Hierarchy Process SFOR Decisions in a Complex World, Third Edition,University of Pittsburgh, 322 Mervis Hall, Pittsburg
14. Sprague, R.H., Carlson, E.D., 1982. Building Effective Decision Support System, Englewood Cliffs, Prentice Hall, NJ
15. Sprague, R., Watson, H.J., 1996. Decision Support for Management, Prentice-Hall, Upper Saddle River, NJ
16. Steiger, D.M., 1998. Enhancing user understanding in a decision support system: a theoretical basis and framework. Journal of Management Information Systems 15 2, pp. 199–221.
17. Turban, E., Aronson, J., 2000. Decision Support Systems and Intelligent Systems (6th edn. ed.),, Prentice-Hall, Upper Saddle River, NJ
18. Zelenika, R., 2001. Prometni sustavi, Ekonomski fakultet Sveučilišta u Rijeci, Rijeka, p. 257 – 269., 287-289.
19. Cvitanić, D., 2005. Znanstveno-istraživačka studija planiranja parkirališta i garaža u centru grada, Građevinsko-arhitektonski fakultet Split, Split