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Decision support for management of urban transport projects

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Subject review

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Decision support for management of urban transport projects

The planning phase within the urban-transport project management is a complex process from both the management and techno-economic aspects. The focus of this research is on decision-making processes related to the planning phase during management of urban-road infrastructure projects. The proposed concept is based on multicriteria methods and Artificial Neural Networks. The decision-support concept presented in this paper is tested on the road infrastructure of the city of Split, and it shows how urban road infrastructure planning can be improved.

Key words:
strategic planning, project management, support to decision-making, multicriteria methods, neural networks

Pregledni rad

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Podrška odlučivanju u upravljanju prometnim projektima u urbanim sredinama

Faza planiranja unutar upravljanja urbanim prometnim projektom složen je proces kako sa stajališta menadžmenta tako i s tehničko-ekonomskih stajališta. Ovo istraživanje usmjereno je na procese donošenja odluka vezanih za fazu planiranja prilikom upravljanja urbanim cestovnim infrastrukturnim projektima. Predloženi koncept se temelji na višekriterijskim metodama te na umjetnim neuronskim mrežama. U ovom radu predstavljeni koncept za podršku odlučivanju testiran je na cestovnoj infrastrukturi grada Splita i prikazuje način na koji se može unaprijediti planiranje urbane cestovne infrastrukture.

Ključne riječi:
strateško planiranje, upravljanje projektima, podrška odlučivanju, višekriterijske metode, neuronske mreže

Übersichtsarbeit

Nikša Jajac, Ivan Marović, Tomaš Hanák

Entscheidungsunterstützung zur Verwaltung von Verkehrsprojekten in städtischen Gebieten

Die Planungsphase bei der Verwaltung von städtischen Verkehrsprojekten ist sowohl hinsichtlich des Managements, als auch in Bezug auf technisch-wirtschaftliche Aspekte ein komplizierter Prozess. Dieses Forschungsvorhaben befasst sich mit den Entscheidungsprozessen in der Planungsphase bei der Verwaltung von Projekten bezüglich des städtischen Straßenverkehrs. Das vorgeschlagene Konzept beruht auf Mehrkriterien-Methoden und auf künstlichen neuronalen Netzen. In dieser Arbeit wird das vorgestellte Konzept zur Entscheidungsunterstützung an der Straßeninfrastruktur der Stadt Split getestet und eine mögliche verbesserte Planung der städtischen Straßeninfrastruktur dargestellt.

Schlüsselwörter:
strategische Planung, Projektverwaltung, Entscheidungsunterstützung, Multikriterienmethoden, neuronale Netze

1. Introduction

The development of urban-infrastructure systems, such as water-supply systems, traffic systems, sewage systems, etc., with related investments, is an integral part of continuous modern-city expansion processes. All aspects of the quality of life in cities, such as the residents' health, safety, economic opportunities, and conditions for work and leisure, are significantly influenced by urban infrastructure [1, 2]. The planning process in the field of urban road infrastructure systems, being an integral part of the urban road-transportation management, is highly complex and socially sensitive. City governments encounter considerable problems during the decision-making phase when it is necessary to find a solution that would meet all requirements of stakeholders, while a the same time being a part of a sustainable-development concept. As each municipality has a certain annual budget for the construction, maintenance and remedial activities, the prioritization of projects emerges as one of the most important and most difficult issues to be resolved in the public decision-making process.

There are several reasons for this complexity: various participants or stakeholders with different opinions, multidisciplinary nature of the problem, huge quantities of information, budget restrictions, and conflicting goals and criteria. These facts indicate that the decision-making processes for improving the road infrastructure planning practices are burdened with complex and ill-defined problems, especially in the case of long-term planning. Therefore, long-term planning tasks should be supported by decision-making tools such as multicriteria methods, or other operational research methods, which are likely to contribute to a more efficient realization of such tasks. In order to cope with such complexity, a generic decision support concept, aimed at improving decision making at the road infrastructure planning level in urban areas, is proposed. This concept represents a multicriteria decision-making approach, and is based on multicriteria methods (Simple Additive Weighting - SAW and Analytic Hierarchy Processing-AHP) and Artificial Neural Networks - ANNs.

Many authors have studied possibilities for generating decision support tools for urban-transport management. Bielli [3] presents a decision support system (DSS) approach to urban-traffic management aimed at achieving maximum efficiency and productivity for the entire urban-traffic system, including the urban road infrastructure. A cost-and-benefit aspect of potential infrastructure investments is also introduced in literature, showing that several decision-support models can be generated [4, 5]. Quintero et al. [6] describe an improved DSS named IDSS (Intelligent Decision Support System) that coordinates management of several urban-infrastructure systems, such as the sewage and waterworks. The authors introduce IDSS as a solution for the future urban-infrastructure management. A similar approach can be found in earlier publications presented by other authors [7-9]. Sayers et al. [10] present a multi-criteria evaluation of transport infrastructure by using the SAW method [11] for ranking transport investments aimed at improving infrastructure in small towns. In this context, they analyzed three solutions: minimum interventions on the existing network, building a bypass, and upgrading the existing route. On the other side, the AHP method is predominantly used in big cities to select an environmentally sustainable transport system [12]. It was established that priorities differ significantly depending on the stakeholders included in the process. Shelton and Medina [13] present a simplified transport project ranking methodology with an integrated multiple-criteria decision-making process that prioritizes transport projects in cases when multiple decision makers present various opinions and biases. The AHP was used for weighing a set of criteria through pair-wise comparisons in the El Paso metropolitan area. For solving the problem of prioritizing projects in urban municipalities [14], the use of the AHP and COPRAS-G methods was proposed for specific problems involving evaluation and selection of area for constructing new footbridge alternatives.

As road planning is a spatial problem, it is stated [15] that participatory mapping offers an approach to transport planning with the use of Geographic Information Systems (GIS). The resulting GIS-based cognitive maps and focus-group interviews revealed, among other things, that the community engagement is a good basis for transport planning and decision making. The spatial decision support system for planning urban infrastructure [16] is based on the integration of GIS technology and SAW method, where the authors point out that the presented procedure can be used for planning other types of infrastructure, including transport infrastructure. Jajac focused his research [17] on the development and maintenance of urban road infrastructure by implementing and using various multicriteria methods and artificial neural networks at various decision-making hierarchy levels in urban areas.

In order to improve the decision-making process in such complex circumstances, it is important to develop and apply new tools targeted at raising the level of transparency and objectivity in the solution-selection process [18]. This research is focused on decision support aimed at improving road infrastructure planning in urban areas. It is based on the multicriteria analysis and artificial neural networks that are used to support project management. Since the focus of this research is on improvement of road infrastructure planning, some traffic characteristics were analyzed in addition to those relevant to infrastructure.

2. Decision support concept to improve urban road infrastructure planning

The structure of the proposed decision-support concept is based on previous research [5, 17, 19] through which the architecture of decision support systems for urban-infrastructure management was introduced (Figure 1). Such DSS architecture is not focused on improvement planning only (planning aspect which is in the focus of this paper) but rather on all aspects of planning (such as revitalization, system development, etc.), as well as on all levels of managerial decision-making related to urban road infrastructure management. It can also be applied to any other urban infrastructure system.

The modular concept is based on the DSS basic structure [20, 21]: data base, model base, and dialog. Interactions between these modules are realized through decision-making processes at all management levels, which serve as meeting points of adequate models (from model base) and data (from data base) [5]. The first management level supports decision makers at the lowest, operational decision-making level, and has three basic functions: to support decision-making at the operational level, to process data and information, and to enable information flow to higher decision-making levels. The second management level delivers tactical decisions and creates the information basis and solutions, or models for the strategic decision-making level.

The decisions made throughout the system are based on knowledge generated at the operational decision-making level. The acquired knowledge is structured in an adequate knowledge-based system of the data base. At the tactical level, decisions are made by individual experts and expert teams, employees from local political bodies, and public companies with local responsibilities. At the strategic level, based on expert deliverables from tactical level, a future development of the infrastructure system is estimated. Delivered strategies have to be sound with regard to the existing global development and urban development plans for the city or region. These strategies are frameworks for the lower decision-making and management levels, thus ensuring continuity of decision-making processes throughout both the decision and management systems. For solving various problems, different models, methods, and techniques are stored in the model base, and can be used at different management levels.

As shown in Figure 1, the system is open and the proposed urban infrastructure system can be influenced by many outside factors. Besides technology, which obviously influences the system at all levels, other factors like local behavior (traditional styles of management and decision making, local mentality, etc.) have a considerable influence on both the decision-making and management processes [5, 17, 19]. Since this research is focused on the management of urban road infrastructure systems only, and particularly on improvement of its planning process, the

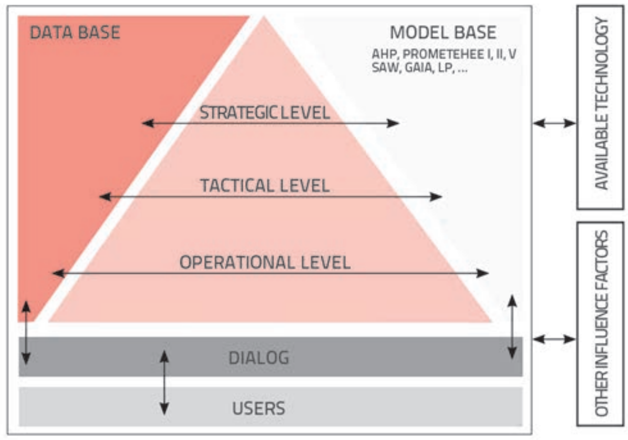

Figure 1. Architecture of the DSS for urban infrastructure management [5, 17, 19]

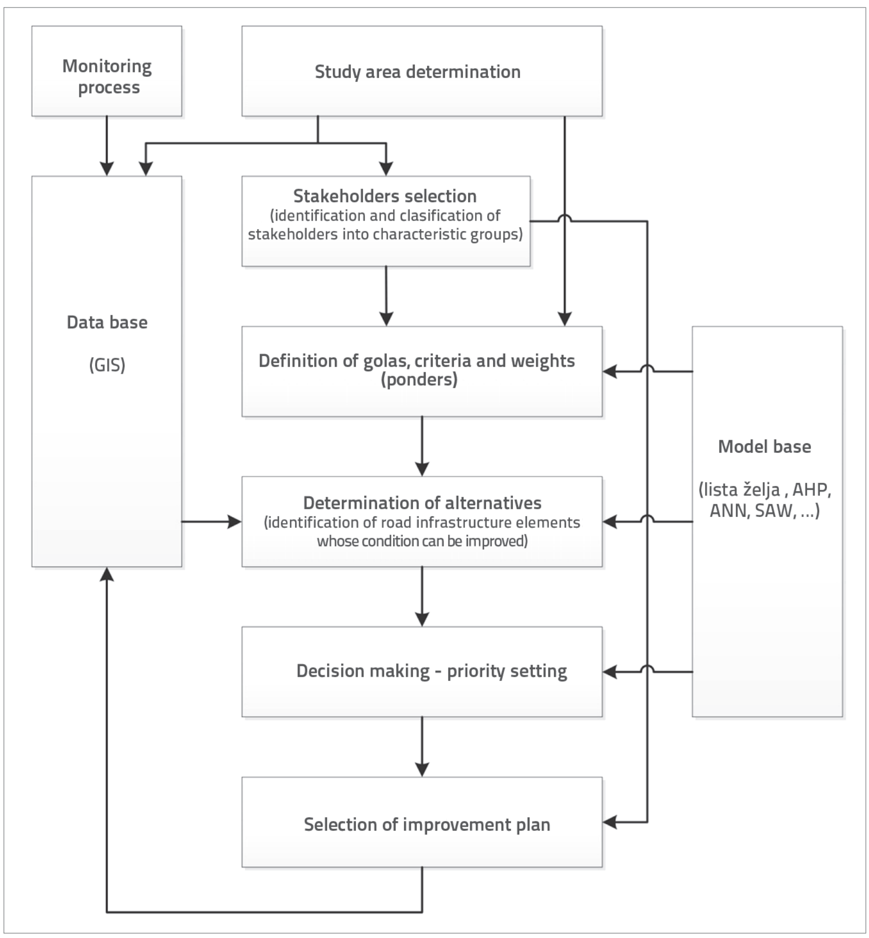

Figure 2. Architecture of decision support concept aimed at improving urban road infrastructure planning

concept is used to support decision-making processes in the realization of these management functions.

Using the previously described generic architecture of the DSS for urban-infrastructure management, a concept of decision support for improving urban road infrastructure planning is developed. Such management system deals with many stakeholders and constrained resources. Since limited finances are a common and primary restriction, decision-making problems are generally the priority-setting problems. Herein, a step-by-step approach for improving urban road infrastructure planning-for priority setting and strategy selection-is proposed (Figure 2).

The decision-making process starts at the strategic and tactical levels with the determination of the study area, and with selection of stakeholders. Because of the spatial character of road infrastructure, the model database is structured as a Geographic Information System (GIS). As such, the infrastructure register and key characteristics of each infrastructure element are stored centrally, and are easily accessible, and open for new information input (periodically collected at the operational level) during the continuous monitoring program and maintenance process defined in [5].

The definition of key characteristics for each element is very important for setting up criteria and their weights during the priority-setting process. They directly influence final decisions. During the first step, decision-makers are usually faced with the stakeholder selection problem [1]. There are several important limitations hindering current stakeholder analysis methods. For example, stakeholders are usually identified and categorized through subjective assessment of their relative power, influence, and legitimacy [22, 23]. Although widely varied categorization schemes have emerged from literature, the methods have often overlooked the role of communication networks in the categorisation and understanding of stakeholder relationships. In order to provide a good basis for an efficient decision-making process, stakeholders are divided into three groups: local government, experts, and citizens (i.e. users). A local government group is formed of the deputy mayor who is responsible for utility affairs, and principals of several administrative offices (e.g. Office for Strategic Planning and Development, Office for Finance, Office for Physical Planning, etc.). The expert group consists of civil engineering, transport engineering, environmental, and economics experts of both academic and practical backgrounds. The citizens group is generally formed of the representatives of city districts or similar city formations. As stakeholders change over time - due to four year terms in office - their identification is an ongoing process, which also has some historical dimensions.

After decision is made about the location and stakeholders, the next step is to define goals, criteria, and weighting factors. The goal analysis ends with a hierarchical structure of goals which is the basis for the criteria definition. Due to the ill-structured nature of the problem that emerges from incomparable data and conflicting stakeholders' demands, appropriate multicriteria models are proposed. The criteria definition process involves participation of local government and relevant experts, while definition of criteria weights includes seeking opinions from all stakeholder groups. Using the AHP method [24], weights can easily be assigned through a group decision-making process by interviewing all stakeholders. The decision-making process of each stakeholder group must be repeated until the AHP method requirements are met with regard to consistency (measured by the consistency index - CI). After having determined the hierarchy of goals and stakeholder groups, three scenarios were developed: one for each stakeholder group. The final scenario (Scenario 4) was determined as an average value, representing the stakeholders' compromise view of the problem. Weighted values of the stakeholders' compromise are introduced as weights for the SAW method, which is used to set priority of selected road elements according to their improvement requirements.

Once the goal hierarchy was defined, all road infrastructure elements within the study area were analysed, and only those with conditions that can be improved were identified using the trained and tested ANN. That network provided the condition assessment for all elements in the study area. Among the identified elements, only those with conditions evaluated as insufficient and unsuitable were selected for further analysis and priority-setting.

After applying the SAW method, the list of elements was ranked according to defined criteria, and the elements were saved to the database. They serve as potential strategic alternatives. Strategic decision-makers, i.e., local-government representatives assisted by the group of experts select the most convenient solution based on the multicriteria analysis and actual policies. The selected solution constitutes a strategic plan for the improvement of infrastructure conditions in the study area. The proposed concept was tested with regard to improvement of the road infrastructure planning in the city of Split.

3. Improvement of road infrastructure planning – case study: city of Split

3.1. Definition of study area and selection of stakeholders

Rapid expansion of urban areas, and huge growth in the number of vehicles and pedestrians, raises many questions about road infrastructure planning, especially in the densely populated city centres. One such centre is the city of Split with the total population of just over 180 thousands (according to [25]), which makes it the second largest city in the Republic of Croatia.

The study area is the wider city centre with a high concentration of public facilities and high density of numerous pedestrian flows. The area was surveyed in detail, resulting with the determination of 236 infrastructure elements that needed

Table 1. Classification of surveyed infrastructure elements according to type

No.	Type of element	Number of elements within surveyed area	Share of element type within surveyed area
1.	Street	19	8,1
2.	Street section	144	61,0
3.	Crossroad	39	16,5
4.	Garage	2	0,8
5.	Parking	10	4,2
6.	Bus station	14	5,9
7.	Bus terminal	1	0,4
8.	Petrol station	4	1,7
9.	Overpass	1	0,4
10.	Tunnel	2	0,8

improvement. The determined infrastructure elements were divided into 10 types according to their geometric and structural characteristics (Table 1).
Only public-infrastructure elements were considered such as public garages and public parking spaces, streets, and street sections with the average length of 180-200 m. All determined infrastructure elements were stored in a GIS-based infrastructure register according to the type of element, number of elements, and their share within the surveyed area, as shown in Table 1.
In order to establish a good basis for an efficient decision-making process, stakeholders are divided into three groups: local government, transport experts, and citizens (i.e. users). The local-government group consists of the city deputy mayor responsible for utility services, and representatives from several other administrative offices that are also responsible for utility services, transport, planning, and development. The expert group consists of transport, civil-engineering and environmental experts from University of Split, local engineers with experience in the field of urban road-traffic management and infrastructure maintenance, and economics experts specialising in the urban road maintenance. The third group consists of representatives from each of 27 districts within the city of Split. This diversity of stakeholders implies the existence of collaborative mind-set for achieving change in such a complex environment.
The following should also be noted: although the expert group is formed of experts from University of Split only, and does not include representatives from other universities (except for two co-authors), this fact can not be perceived as lack of unbiased opinion because some of the University experts are not currently (or never were) residents of the city of Split, and most of them have spent a significant part of their professional career abroad. Furthermore, all of them have experience in international scientific research in the field of their expertise relevant for this research, but related to some other parts of the world. On the other hand, their familiarity with situation regarding road infrastructure in the city of Split is in our opinion an added value in processes such as the establishment of goal hierarchy, and determination of criteria weights. In addition, they can perceive even subtle specifics of the road infrastructure in the city of Split, while also being able to grasp the "broader picture". They can also detect criteria that are inappropriate for this specific area (criteria that can be perceived as generally important but are unable to focus on the differences in the evaluation of scores between the analysed zones, and are therefore irrelevant for this kind of analysis).

3.2. Definition of goals, criteria and their weights

The hierarchical structure of goals for the defined problem is shown in Figure 3. It consists of the main goal and 16 supporting goals that are divided into three levels. As the main goal is "Sustainable development of road infrastructure in the city of Split", the solution is based on the stepwise approach to improve conditions of the determined road infrastructure elements, i.e., streets and street sections within the surveyed area.
During the activity aimed at establishing a goal hierarchy, the above mentioned stakeholders were involved in the goal-generation process based on the "wish-list" procedure. The stakeholders were gathered together in a panel discussion, which resulted in the hierarchical structure of goals (Figure 3) and their preferences (given in Appendix and summarized in Table 3). During the first phase, all goals proposed by the stakeholders were taken into account. As some of the proposed goals can overlap, or their meanings can be similar to one another, or similar to the main goal, all proposed goals must be synthesized during the second phase of the procedure, the aim being to avoid any redundancy. The second phase resulted in 16 synthesized goals and criteria (Figure 3). After opinions of all experts involved in determining the goal hierarchy were taken into account, i.e. after identification of all important goals that are needed to ensure achievement of the main goal, each of these goals was attributed to an appropriate hierarchy level, according to its importance for the achievement of the main objective. In this way, the position of each proposed goal within the goal hierarchy was defined. The hierarchical structure of goals is presented in form of a goal tree (cf. Figure 3) based on results of the "wish-list" procedure, and according to priorities identified for all proposed goals.
The goals placed at the penultimate level of the defined goal tree are then selected as an appropriate set of criteria for conducting the priority ranking of infrastructure elements based on the multicriteria SAW method. These criteria

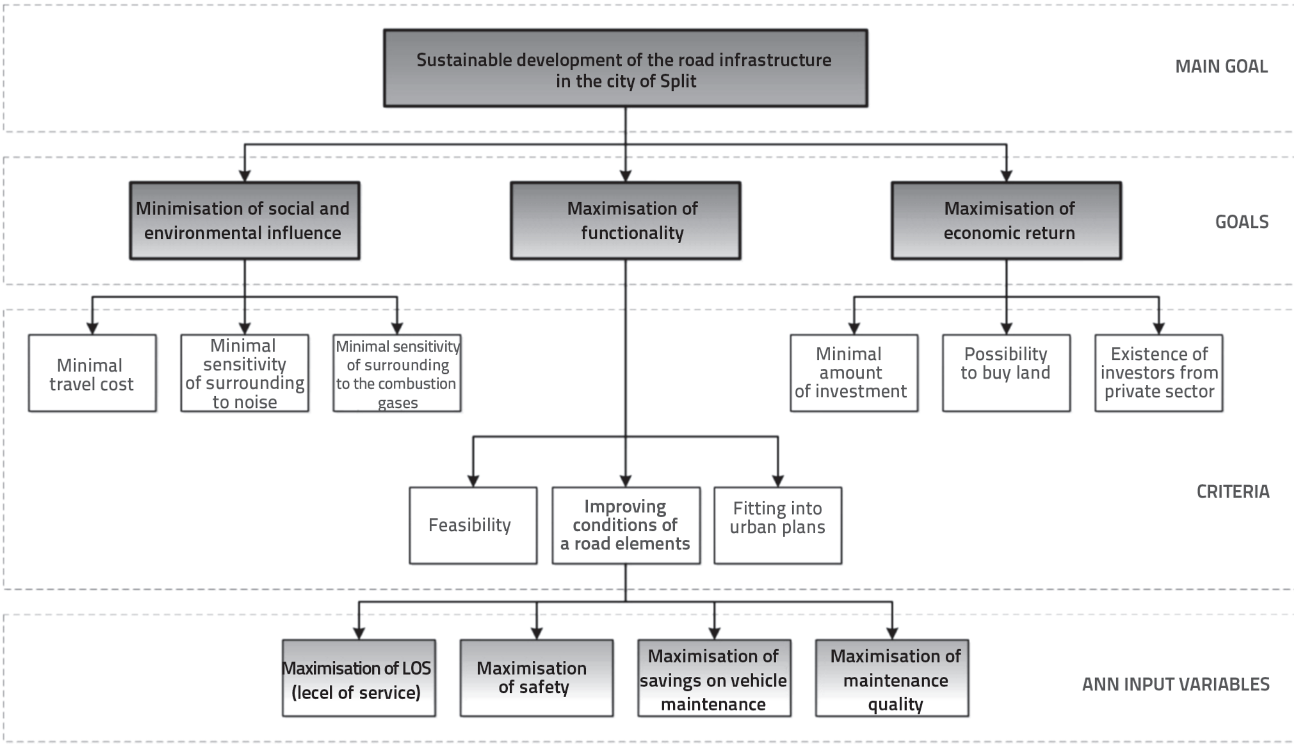

Figure 3. Hierarchical structure of goals and criteria for solving infrastructure planning problem in the city of Split

Table 2. Criteria names, short description, and evaluation technique

Criteria label	Name of criteria	Short description of criteria, and technique used for evaluating condition of infrastructure elements
C_1	Minimum travel cost	Expert assessment of travel cost savings – rating in EUR
C_2	Minimum sensitivity of the area to noise	Expert assessment of sensitivity taking into account the distance between the element and the place where people (especially children) are staying longer (such as schools, residential buildings and medical centres) – rating from 1 (best) to 10 (worst)
C_3	Minimum sensitivity of the area to combustion gases	Expert assessment of sensitivity taking into account the distance between the element and the place where people (especially children) are staying longer (such as schools, residential buildings and medical centres) – rating from 1 (best) to 10 (worst)
C_4	Feasibility	Expert assessment taking into account expected duration of construction and completion in accordance with the time schedule and bill of quantities – rating from 1 (best) to 5 (worst)
C_5	Improving conditions of a road element	Assessment of conditions for an infrastructure element by the ANN especially trained and tested for this purpose – rating from 0 (best conditions) to 1 (worst conditions) *
C_6	Fitting into urban development plans	It is determined whether or not the element is included in physical development plans (e.g. county development plan, master plan, or urban development plan) – rating as follows: if it is included – 0; if not included – 1
C_7	Minimum funding	The amount includes the cost of preparation of project documentation, cost of construction on the "turnkey" basis, cost of land acquisition, and other costs – rating in EUR
C_8	Land buying possibility	It is determined whether or not it is possible to buy the additional land right next to the element that might be put to good use for reconstruction (or rehabilitation) of the element – rating as follows: if it is possible – 0; if not possible – 1
C_9	Existence of private-sector investors	It is determined whether the interest exists to establish cooperation on the reconstruction (or rehabilitation) project in form of the PPP (Public Private Partnership) – rating as follows: if it is possible – 0; if not possible – 1

* u odjeljku 3.3 opširniji je opis ove tehnike

Table 3. Weights for criteria and scenarios

Criteria label	Name of criteria	Weights for scenario 1	Weights for scenario 2	Weights for scenario 3	Weights for scenario 4	Weights for scenario 4 [%]
$_{1}$	Minimum travel cost	0.111	0.173	0.122	0.136	13.6
$_{2}$	Minimum sensitivity to noise	0.111	0.081	0.101	0.098	9.8
$_{3}$	Minimum sensitivity to combustion gases	0.111	0.079	0.110	0.100	10.0
$_{4}$	Feasibility	0.109	0.034	0.111	0.084	8.4
C_5	Improving conditions of a road element	0.070	0.259	0.111	0.147	14.7
C_6	Fitting into urban plans	0.154	0.04	0.111	0.102	10.2
C_7	Minimum funding	0.231	0.136	0.164	0.177	17.7
C_8	Land buying possibility	0.069	0.172	0.074	0.105	10.5
C_9	Existence of investors from private sector	0.034	0.026	0.096	0.051	5.1
	Total	1.000	1.000	1.000	1.000	100.0

are shown in Table 2 along with their descriptions and the techniques used to evaluate condition of infrastructure elements. The goals at the last (lowest) level of the goal tree are selected as appropriate variables - to be input variables for ANN - within the process of identifying road-infrastructure elements the condition of which can be improved.

Criteria weights were defined using stakeholder preferences and by applying the AHP method to the defined goal tree. Regarding the AHP rules for comparing goals and criteria, all stakeholders compared each criterion with other criteria to determine its relative importance for achieving the direct parent goal, and also its relative importance for achieving (indirectly) the main goal. When applying the AHP method, it is important to take into account the consistency index (CI) (if the CI value is "*S*", i.e. smaller than or equal to 0,1, the weights are calculated properly ($CI_{government}$=0,06; $CI_{experts}$=0,05; $CI_{citizens}$=0,09) meaning the inconsistency is lower than 10% [24]).

According to the importance for achieving the main goal, each stakeholder group defined different sets of weights for the same criteria set. Each set of weights represents a different scenario, and three scenarios required for further analysis are defined (Table 3). Determination of weights by AHP method for all three scenarios was considered appropriate because the CI value smaller than 0,1 was provided for all three scenarios. The first scenario describes preferences of city authorities, the second scenario describes preferences of the transport experts, and the third scenario shows how citizens view the analysed problem.

Different stakeholder groups gave different preferences to the previously defined criteria. Each group prefers the criteria it knows well and feels responsible for. Accordingly, city authorities (Scenario 1) and transport experts (Scenario 2) showed that they prefer criteria associated with the functionality, constructability, and feasibility of the solution, while the citizens group (Scenario 3) showed equal preference toward the defined criteria, and hence toward the solution. The fourth scenario represents a compromise view to the analysed problem.

Further analysis is conducted according to the fourth scenario. The fourth scenario consists of the same criteria set as the three preceding scenarios, but involves a different set of weights. Each criterion weight within this scenario is derived as an average value of weights of that same criterion from the three previously mentioned scenarios. In this way, the preferences of all stakeholders are built into the model, and are manifested in the final solution, i.e., in the priority ranking list.

3.3. Identification of road infrastructure elements whose condition can be improved

Several different ANN architectures are available for this kind of research. However, one of the most common is the feed-forward network. In this feed-forward network, the neurons of one layer are only connected to the neurons in the next layer. These connections are unidirectional, meaning signals or information being processed can only pass through the network in a single direction, i.e., from the input layer, via the hidden layer(s), to the output layer. Feed-forward networks commonly use the back-propagation supervised-learning algorithm to dynamically alter the weights of connections for each neuron in the network.

Back propagation is the best known training algorithm for neural networks, and is still one of the most useful. It was devised independently by several authors [26-29]. The algorithm works by iteratively altering the connection weight values for neurons based on the error in the network's actual output value when compared to the target output value. The actual modification of weights is carried out after each training example is presented to the network. A multilayer perceptron (MLP) is a special type of feed-forward network employing three or more layers, with nonlinear transfer functions in the hidden layer neurons. MLPs are able to associate training patterns with outputs for nonlinearly separable data. Due originally to [29], this is perhaps the most popular network architecture in use today.

Table 4. Road elements with insufficient conditions in study area

Code of element	Assessment of element's condition	Name of road infrastructure element
A1	0.564	Pojišanska and Zvonimirova (crossroad)
A2	0.628	Sukoišanska (street section)
A3	0.790	Put Stinica (street)
A4	0.584	Meštrovićeva, Sustipanskog P. and Ulica Dražanac (crossroad)
A5	0.836	Spinčićeva, Zajčeva and Put Firula (crossroad)
A6	0.506	Pojišanska_1 (street section)
A7	0.526	Pojišanska_2 (street section)
A8	0.715	Kavanjinova, Manđerova, Svačićeva (crossroad)
A9	0.674	Domovinskog rata (street section)
A10	0.611	Sukoišanska and Starčevićeva (crossroad)
A11	0.754	Vukovarska, Bihaćka, Zagrebačka and Dom. rata (crossroad)
A12	0.688	Mažuranićevo Š., Dom. rata and Gundulićeva (crossroad)
A13	0.623	Ulica slobode (street section)

Road-infrastructure elements in poor conditions that can be improved are identified by adequate and, especially for this purpose, properly trained and tested ANN (network type-Multilayer Perceptron with the following three layer architecture 4:4-3-1:1, and with excellent performance-regression ratio 0,06, correlation 0,999, and error 0,004) with four input variables and only one output variable. The four input variables of this ANN are: level of service (LOS), safety, savings on vehicle maintenance, and maintenance quality.

This specific ANN is trained by the back-propagation algorithm (by STATISTICA Automated Neural Networks–SANN software produced by StatSoft Inc.) using the training set consisting of 200 cases, each case with four values (collected during the first monitoring cycle) for four input variables, and the same number (200) of output variable values, which are provided by experts (expert assessment). The value of the output variable is an assessment of conditions for one infrastructure element. The test data set consists of 36 cases, and it was found that the selected ANN gets the assessment of conditions of the analysed cases with the required accuracy (for this kind of expert assessment).

Input variable values (236 cases) were gathered once again in the same study area one year later. The data gathered during the second monitoring cycle were used to assess condition of all road elements in the study area by the trained ANN. Among all identified elements, only those with the condition evaluated as insufficient were selected for further analysis and priority ranking. The conditions are considered insufficient if the conditions-assessment value is less than 1 within an assessment interval from 0 (worst conditions) to 10 (best conditions). The selected infrastructure elements with insufficient conditions in the study area are shown in Table 4.

Table 4 shows 13 elements with insufficient condition in the study area as defined according to the trained ANN. Based on this analysis, the best infrastructure element is element A6 (street section), while the worst infrastructure element is element A5 (crossroad).

Table 5. Multicriteria model with rankings

Code of element	Ranking	Score	Weights and labels of criteria								
			13.55	9.78	9.99	8.45	14.68	10.20	17.70	10.48	5.15
				C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A1	2.	72.67	7.40	9.80	10.00	8.40	9.91	10.20	6.46	10.50	0.00
A2	1.	72.82	3.34	8.82	8.89	5.04	11.04	10.20	14.99	10.50	0.00
A3	7.	61.90	3.58	4.90	4.44	5.04	13.89	10.20	4.24	10.50	5.10
A4	10.	47.22	13.60	3.92	4.44	1.68	10.27	0.00	2.80	10.50	0.00
A5	3.	70.16	6.20	6.86	7.78	8.40	14.69	0.00	15.72	10.50	0.00
A6	8.	57.23	4.06	1.96	1.11	8.40	8.89	10.20	17.51	0.00	5.10
A7	11.	39.52	1.19	5.88	5.56	5.04	9.25	0.00	7.50	0.00	5.10
A8	13.	24.73	3.10	2.94	2.22	1.68	12.57	0.00	2.22	0.00	0.00
A9	5.	65.33	1.67	3.92	4.44	5.04	11.85	10.20	17.70	10.50	0.00
A10	4.	66.25	0.00	6.86	6.67	8.40	10.74	10.20	12.88	10.50	0.00
A11	6.	63.52	2.15	8.82	8.89	1.68	13.25	10.20	8.03	10.50	0.00
A12	9.	47.27	10.74	0.98	1.11	1.68	12.09	10.20	10.47	0.00	0.00
A13	12.	35.60	3.82	1.96	1.11	5.04	10.95	0.00	2.22	10.50	0.00

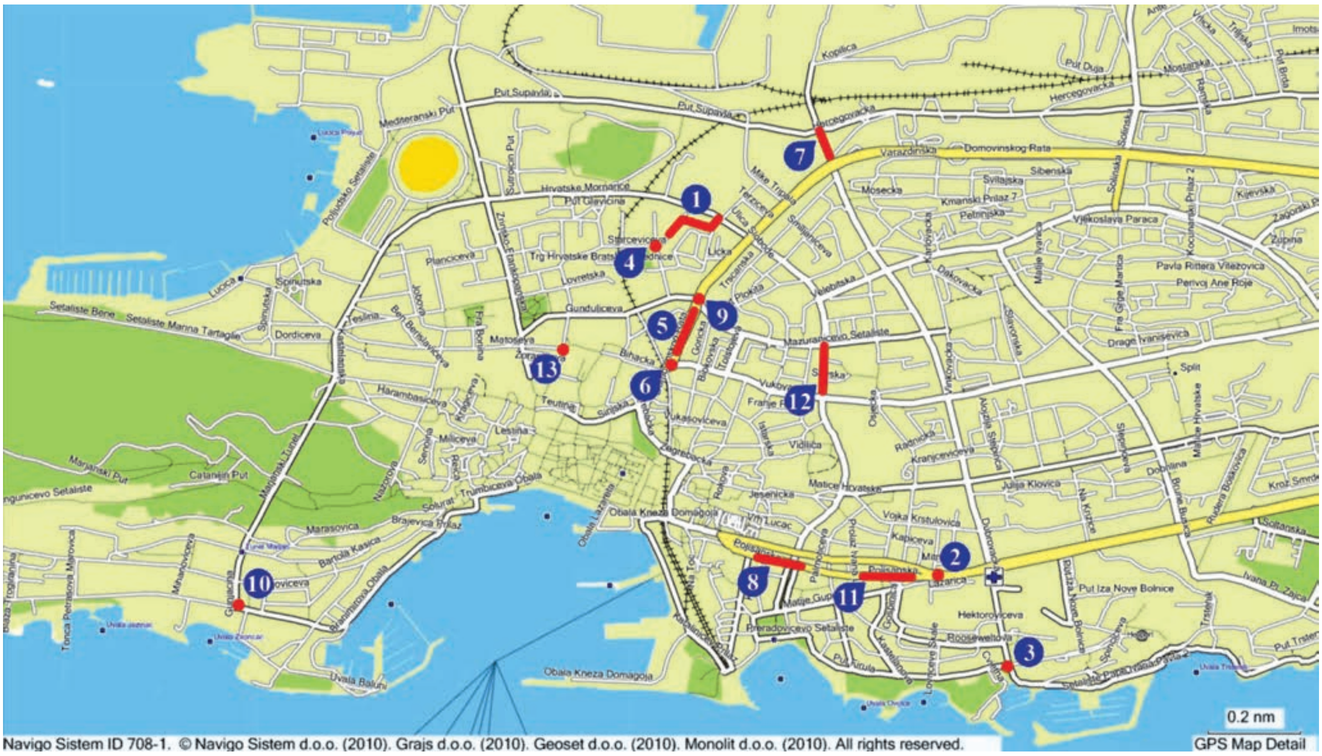

Figure 4. Spatial distribution and ranking of analyzed elements

3.4. Decision making – priority setting

The multicriteria model for priority ranking of road-infrastructure elements in the city centre is shown in Table 5. Considering the conflicts between the scenarios, the fourth scenario weights are calculated as a simple average of the preceding three scenarios weights (Scenarios 1, 2, and 3), thus giving equal importance to all stakeholder groups. The new fourth scenario is formed with weights based on the experts compromise. These weight values are then used in the SAW method. Evaluations of infrastructure element conditions need to be prepared (normalized and transformed) before the SAW method is implemented.

The set of nine data presented in Table 5 (row A1 and columns C_1 to C_9) is determined as nine different products of evaluation of conditions for the infrastructure element A1 (according to all nine criteria) with the corresponding criteria weights. Data in other rows are obtained analogously. The final score of each element is obtained as the pondered sum shown in the third column of Table 5. That column represents the final score of the multicriteria model for each element, while the final ranking of road elements is shown in the second column. If the score resulting from the SAW is greater, it means that the road element is considered prior to the improvement actions, such as reconstructions, that are to be undertaken. Hence, the road-infrastructure element A2 prevails over all other compared elements with the score of 72.82. It is followed by the elements A1 (72.67) and A5 (70.16). The element with the lowest score (24.73) is the element A8. This means that the element A2 is the element with not only the worst conditions among the 13 analyzed, but also the element that will provide the best support to the main goal if the improvement actions are undertaken. The spatial distribution of analyzed road-infrastructure elements, along with the priority-ranking results, is shown in Figure 4.

The priority-ranking list obtained using the proposed decision-support methodology is an overall plan that is useful in road-infrastructure project management. Then local-government representatives assisted by project-management experts (in the field of urban-road infrastructure) selected the most convenient solution (throughout the group decision-making process) which is in accordance with the results of the priority ranking and actual policies. The selected solution represents a plan for improving condition of elements for one investment period only, and must be in compliance with limited resources available in the city budget. Available financial resources for the next investment period are introduced (by local-government representatives) during the solution selection process as the final selection criterion. Finally, local-government representatives accepted six top-ranked elements (according to Table 5 and Figure 4) as an improvement plan for the next annual investment period.

4. Conclusion

The proposed decision-support concept shows that complex and sensitive decision-making processes, such as the ones for planning improvement of urban road infrastructure, can correctly be supported if appropriate methods and data are properly organized and used. The DSS for urban infrastructure management was a good starting point for considering such an approach and for designing the concept. The decision-support concept for road infrastructure planning, as presented in this paper, is a system for setting priority of actions within the urban road-infrastructure management plan. It is conceptualized as a conjunction involving operational and multicriteria methods, and the ANNs. Applied to the road infrastructure of the city of Split, it seems to function well, and it can be used for any other type of urban traffic infrastructure, and for any urbanized community or city. It is shown that the decision-making processes during planning can be supported at all decision-making levels by proper interaction between the decision-support concept modules. A monitoring program can provide relevant, uniform and scheduled data for the ANN analysis, resulting in identification of road-infrastructure elements on which conditions can be improved. It was established that the introduction of the ANN as a knowledge-based tool is appropriate for the substitution of experts' involvement at the operational level. In addition, the application of the multicriteria methodology (AHP and SAW methods) points to several methodological and sociopolitical advantages of this approach in resolving complex problems, such as the road-infrastructure elements priority ranking according to the requirements for improvement of their conditions, regardless of decision level. Thus, stakeholders that are divided into three significantly different groups (local government, experts, and citizens) can be directly involved in the decision-making process. Their opinions are accepted and expressed through criteria weights, thus making the improvement plan selection and implementation much easier, and devoid of mistrust and unfair preferences. Finally, it can be concluded that the presented concept and solution, expressed in form of a list of top-ranked infrastructure elements, can serve as a good basis for improvement of planning processes in the sphere of urban road-infrastructure.

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