USE OF AHP MULTI-CRITERIA METHOD FOR TRANSPORTATION INFRASTRUCTURE PLANNING

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Abstract

Planning, design and implementation of traffic infrastructure is a complex task especially when it is done for infrastructure located in urban areas because it depends on different factors and interests. This is why the solutions have to be evaluated by different type of criteria (traffic, economic, environmental and social). For this purpose during last decades multi-criteria methods came into use and numerous methods have been developed which are classified as multi-criteria analysis methods (e.g. PROMETHEE, ELECTRE, AHP). In this paper the overview of how the multi-criteria analysis method AHP - Analytic Hierarchy Process is used as decision making tool in the process of transportation planning is given. AHP has been used for analysing different types of problems in the field of transportation engineering: selection of routes for railways, roads, bicycle, metro-lines, and selection of priorities of construction for transportation objects. In the paper the case study in which AHP is used for defining priorities in planning multi-store garages is described. In this case five different locations using four main criteria and eight sub-criteria were evaluated with AHP method. The results show that AHP can be used for evaluation of location for transport facilities and that the AHP methodology can be easily implemented in transportation infrastructure planning. It gives the possibility to make decisions using a larger number of criteria, enables the pair-wise comparison of alternatives and enables the involvement of all interested parties.

Key words

AHP; garage-parking facilities; multi-criteria; planning; transportation infrastructure.

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1 INTRODUCTION

The reasons for trying to improve the planning process of transportation infrastructure are different. Expansion and restructuring of modern cities, modernization of present transportation systems, sustainability and concern for environmental impact of transportation infrastructure are probably the most important ones. In the process of planning, designing and reconstruction of transportation infrastructure, the traditional concept of choosing the best solution or the defined problem was based on the use of the cost-benefit (CB) method. That is, choosing those of the proposed alternatives that have resulted to produce more "benefits" than "costs", expressed in monetary terms [1,2]. In recent decades, however, cost-benefit method has shown some limitations because of the fact that all criteria have to be measured through the same value – money. That is sometimes very complex or even impossible to do because of the context in which transportation projects are implemented [3, 4, 5].

In the case of transportation planning (and other phases before implementation) the criteria are very wide: from those regarding construction costs that can be simply expressed in monetary value to the social and environmental criteria that are usually unfavourable for expressing in this way. The methods that have been used during last decades to analyse and solve infrastructural problems in different fields, such as water supply, water management, risk management etc., as well as in the transportation planning and design are the multi-criteria analysis methods. Their advantage is providing analyses of problems using different criteria, expressed in different measures and not only monetary ones. The possibility to compare more alternative solutions to the same problem and the possibility to make objective choices by including different parties in the process (experts and public) are among the most important reasons to use these methods in estimating different infrastructural solutions as well as those in the field of transportation engineering [6, 2]. Incorporating other aspects, aside from economic ones, in decision making process may sometimes be necessary. The public opinion should be taken into consideration explicitly, especially when authorities can provide precise and appropriate information regarding those projects [7].

Multi-criteria analyses for selecting the solutions for transportation infrastructural problems are widely applied. For example: planning of transportation corridors, routes or public transport lines [8, 9, 10, 11, 12, 13, 14, 15, 16], selection of port location, location of terminals or garage-parking facilities [17, 18, 19], their concept or shape [20, 21], planning of airports [2], defining the order for infrastructure construction [22], planning of investment in transport infrastructure [4, 14, 23, 24], selection of priorities in selecting traffic infrastructure maintenance [25], assessment of impact of transportation objects and systems to the environment [5, 26], estimation of traffic safety on routes/roads [27], selection of transportation mode [28], road maintenance in general [29, 30, 31] etc. After analysing the above sources, it can be stressed that the AHP (Analytic Hierarchy Process) method is the mostly used multi-criteria method for solving transportation infrastructural problems [2, 4, 10, 13, 14, 7, 18, 20, 21, 24, 25, 27, 28, 29, 30, 32]. This paper provides a brief overview of how AHP is used as a decision-making tool in the process of transportation planning. It describes few specific problems and presents a case-study in which AHP was used for defining priorities in planning multi-store garages [18].

2 THE AHP METHOD

There are numerous multiple-criteria decision making methods developed today: dominant, maxmin, minmax, conjunctive method, disjunctive method, lexicographic method, elimination by aspects, permutation method, linear assignment method, simple additive weighting (SAW), hierarchical additive weighting, MAUT (Multi-Attribute Utility Theory), ELECTRE (ELimination and (Et) Choice Translating REality), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), LINMAP (Linear Programming Techniques for Multidimensional Analysis of Preference), PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations), AHP and others [33,34,35].

AHP is a priority method addressing problems that can be represented by a hierarchical structure [36, 37]. The top of the hierarchy is the goal, one level beneath are criteria and there is the possibility of having more criteria levels (sub-criteria). The lowest level is represented by alternatives that are possible solutions for the defined problem. AHP method is based on estimating relative priorities (weights) of criteria and alternatives on which pair-wise comparison matrix for criteria and pair-wise comparison matrices for alternatives (one matrix for each criterion) are generated. These matrices are formed by pair-wise comparison of alternatives regarding their importance with respect to each criterion and pair-wise comparison of criteria respect to the goal using a pair-wise comparison scale shown in Tab. 1.

Tab.1: The AHP pair-wise comparison scale [37]

Intensity of importance	**Definition**
1	Equal importance (no preference)
3	Moderate importance (moderate preference)
5	Strong importance (strong preference)
7	Very strong importance (very strong preference)
9	Extreme importance (extreme preference)
2, 4, 6, 8	Intermediate values

The columns in matrices are normalized in order to calculate the priority vector for criteria and the priority vectors for alternatives regarding each criterion. As a result, the overall priority matrix of alternatives is formed in such a way that columns are priority vectors of alternatives for each criterion. The overall priority vector of alternatives is calculated by multiplying this matrix with the priority vector of criteria. The overall priority vector defines the priority (weight) of each alternative in respect to the goal so that the ranking of alternatives can be made. The advantage of the multi-criteria method is that it can be used when just the pair-wise comparison of alternatives according to each criterion and the pair-wise comparison of criteria towards the goal are known. Therefore, this method enables the ranking of alternatives which are not exactly valued under each criteria separately, that is, if the importance of every single criterion is not exactly defined.

In the case of pair-wise comparison of alternatives or criteria the consistency of pair-wise comparison matrices of alternatives, criteria and also of overall priority matrix is analysed by calculating the inconsistency index. The inconsistency index should be lower than 0.1 to assure what the judgments made are consistent. If the inconsistency index is higher, then the re-evaluation of pair-wise comparison of alternatives and criteria is required. For ranking alternatives using the multi-criteria method AHP the following procedure should be followed:

- Define the problem (the goal, the criteria, the alternatives),
- Define the hierarchy,
- Perform pair-wise comparison of alternatives in respect to each criterion,
- Perform pair-wise comparison of criteria in respect to the goal,
- Apply the AHP method to estimate the overall priority vector of alternatives in respect to the goal,

- Form the rank-list of alternatives,
- Perform the sensitivity analysis,
- Make the final decision.

AHP method can address a wide range of problems. However, its application is specially stressed if it is applied on different levels of strategic or tactical traffic planning where often there are no precisely quantified data (which, as a rule, is the case in operational planning). Unlike the usual multi-criteria assessment of every alternative regarding each criterion separately, the possibility of pair-wise comparison of alternatives in relation to a specific criterion, which is enabled by the AHP method, significantly simplifies, i.e. helps the strategic planning.

3 USE OF AHP METHOD FOR TRANSPORTATION INFRASTRUCTURE PLANNING

The analyses of different multi-criteria methods pointed out that AHP method alone or combined with other methods has been used more often than other methods. Some of the most interesting papers in which application of AHP methodology is described for selection of priorities in the process of planning, design, or reconstruction of traffic infrastructure will be discussed [7, 20, 21, 28]. In these papers, solutions for different types of transportation infrastructural problems were selected by using AHP methodology: selection of overall transport system, selection of public transport line, selection of a transportation facility on the defined location (in this case garage parking facility) and finally, selected solution in the case of reconstructed pedestrian crossing. Those cases can be used as valid examples for resolving similar problems in the urban context.

In all of the analyzed cases more than one solution was evaluated and the selected criteria were very different. If we analyse papers which dealt with selection of urban traffic system than the case of selection of the traffic system in Delhi, India is very interesting. In [28] the authors presented a study that attempted to prioritize the alternative transport options by analysing three alternatives (4-stroke 2-wheelers, CNG cars and CNG buses) with respect to six criteria, both quantitative and qualitative. The quantitative criteria were: energy, environment and cost and the qualitative were: technological availability, adaptability and barriers to implementation. The conclusions pointed out the importance of including different factors to ensure success of plan's implementation and also stated that inclusion of qualitative criteria in prioritization process changed the priorities considerably.

In [7] the authors analyse 18 alternatives for urban railway network development in Isfahan (Iran). Two groups of criteria were used: primary - ensuring the preservation of (ancient) monuments (all alternatives that were a threat to the monuments were eliminated), which is in this case the criteria motivated by special request for the preservation of World Heritage Sites. Other criteria were based on experts' opinions on urban transport infrastructure and other experts (environmental criteria, fuel consumption, construction, operation and maintenance of infrastructure, travel-time, the degree of "coverage" of the population network). An analysis using the CB and AHP methods was done and the results were compared. AHP and CB suggested different prioritization for study scenarios. There were 5 common scenarios among the first 10 selected but in different order. It is interesting that the best graded scenario by CB was not on the list of AHP priorities. The final solution chosen was the one selected as the best by the AHP method. The study showed that the use of more wide range of non-economic criteria in decision making process results in more reasonable outcomes.

The use of AHP was tested in [20], in the case of selecting the best type of garage parking facility. The solution for the floating garage in Rijeka (Croatia) was previously selected on the basis of only two criteria: the number of parking places and the complexity of the reconstruction. The interested parties were local community representatives. Afterwards, 3 main criteria (traffic, economic and environmental) and 9 sub-criteria were introduced through AHP methodology. The results of these two selections were different. It was concluded that the introduction of a range of criteria and objective evaluation carried out by the authors (considered independent experts), in which interested groups were not included, led to the selection of a different alternative.

The next example deals with the possibility to use the AHP method while deciding upon reconstruction of existing infrastructure, in this case pedestrian crossing on the existing road [21]. The proposed solutions for the new pedestrian crossing were: marked pedestrian crossing on the existing road without traffic lights or with installation of traffic lights and in the form of pedestrian passages - underpass and overpass. Four groups of criteria were defined for selection of the optimal pedestrian crossing: safety (with three sub-criteria: driving speed, traffic volume, road width), energy (invested by pedestrians to cross the road), price (three sub-criteria: the cost of design, construction and maintenance) and other criteria (including sub-criteria related to the environmental aspect, comfort and acceptability of the proposed solution with respect to persons with disabilities). Peculiarity of the paper is that it analyzes the impact of stakeholders involved in defining the importance of the criteria. The preferences of different stakeholder groups were tested with following results: professionals and people without disability chose pedestrian underpass or overpass whereas investors and people with disabilities opted for level crossings with lights installation. The authors stated that the multi-criteria process used in this case is time-consuming and complex and therefore usually not carried out for this type of problems.

All of the described cases where AHP method was used in the process of prioritization of possible options for infrastructural problem showed the advantages if decision making process is based on objective and transparent methodology and the possibility to include different parties. The criteria used for selecting were different but can be summarized in the following groups: safety and traffic criteria, economic criteria and environmental criteria. In all of the cases elaboration of the criteria (e.g. definition of sub-criteria) depended on the particular problem and location which can be seen as another advantage of multi-criteria method application.

4 CASE STUDY- USE OF AHP METHODOLOGY IN SELECTING THE LOCATION OF A GARAGE-PARKING FACILITY

The possibility of applying the AHP method in the process of traffic planning is examined in the case-study of a town situated on the Adriatic coast in Croatia [18].

The town is a typical European urban development type with the old historic centre inadequate for motorized traffic and has typical traffic problems such as too many cars, inappropriate road network and lack of parking places. The town is an administrative centre of a micro-region with cca. 30.000 inhabitants and the main business and administrative facilities are situated in the historical city centre. Urban development characteristics of the historical part as well as the natural ones (karst terrain, ground water) were taken into consideration when analysing the alternative locations for the garage-parking facility (GPF). In the case-study the multi-criteria analysis with AHP procedure was applied in order to rank the GPF locations and to determine the priority of GPF construction.

4.1 Alternative locations

Two approaches for resolving the parking problem in cities are possible [18]. The first is the construction of garage-parking facilities in the broader zone of the city centre. This solution is favourable for the users in relation to the accessibility of the facility on foot, but it influences the street network traffic load in the city centre in the most unfavourable way. The second is the construction of garage-parking facilities outside the city centre (in outlying districts) providing the appropriate traffic connections between the facility and the city centre (e.g. by introducing public transport service) with smaller, exclusive garage-parking facilities in the city centre.

At the strategic planning level in the case-study, five alternative locations were analysed, two of which were allocated in the very centre of the town and three outside the centre. For all of these locations a standard garage-parking facility with semi-circular ramps and approximately 2600 m^2 of plan area was adopted for the analysis. Depending on location parameters, a different numbers of storeys were planned. Alternative A is a GPF with 200 parking places located in the city centre (historical part, built-up area) with assured pedestrian accessibility to destinations of interest, good possibility for commercial use of garage all year round and poor connection with roadway network. The facility has one underground and one semi-embedded storey. For the construction of the GPF an excavation of approximately 17800 m^3 is needed but the garage facility foundations are above ground water level. Alternative B is a GFP with 500 parking places located in the city centre (built-up area) with assured pedestrian accessibility to destinations of interest, good possibility for commercial use of garage all year round but poor connection to roadway network. The facility has 2 underground garage levels that are even below the ground water level and 4 storeys above ground level. The excavated pit propping would be particularly complex and 18600 m^3 would need to be excavated.

Alternative C is a GFP with 500 parking places located outside city centre (the area is partly built-up). The points of interest are out of pedestrian accessibility and therefore not suitable for commercial use off season. It has a good connection to city ring road and roadway network. The facility has one underground garage level that is even below the ground water level and 5 storeys above ground level. The excavated pit propping would be particularly complex because the karstified bedrock is deeply settled. As a result, the foundations would be up to 15 meters deep, with the need for excavation of approximately 15800 m^3. Alternative D is a GFP with 500 parking places located in the suburban part of the city (the area is partly built-up), close to sports' facilities. Implementation of public transportation is necessary in order to reach the center so it is not suitable for commercial use off season but it has a good connection to roadway network. The facility has one underground level and 5 storeys above ground level. The excavated pit propping will be complex because the karstified bedrock is deeply settled with the need for excavation of approximately 15700 m^3. Alternative E is a GFP with 300 parking places located in the suburban part of the city (the area is partly built-up) so the introduction of public transport lines to the centre is required and it is not suitable for commercial use off season. It has good connection to local roadway network. The facility has 3 storeys above ground level and the excavation for foundation is about 3100 m^3.

4.2 Criteria

To rank the GPF locations and determine the priority of GPF construction four groups of criteria (1st level criteria) were defined: traffic criteria (T); economic criteria (E); environmental criteria (EN) and social criteria (S). Three main traffic criteria (2nd level criteria) and several sub-criteria (3rd level criteria) were defined for conducting the multi-criteria analysis [18]:

- T1 – the capacity of the planned GPF (number of parking places)
- T2 – traffic load of the existing road network
  - T21 – capacity of entrances/exits of the GPF
  - T22 – capacity of the surrounding intersections (level of service)
- T3 – traffic importance and accessibility in relation to the existing transportation network
  - T31 – pedestrian accessibility, vicinity of points of interest which can be reached on foot
  - T32 – accessibility to the primary and roadway network (length of approach, potential barriers).

Two economic criteria (2nd level criteria) and several sub-criteria (3rd level criteria) were taken into consideration when analysing the locations in this paper:

- E1 – construction costs
  - E11 – geotechnical characteristics of the terrain and foundation engineering method
  - E12 – the necessary removal of the existing structures from the location
  - E13 – estimated facility construction cost
- E2 – profitability of the facility

The selected environmental criteria (2nd level criteria) and sub-criteria (3rd level criteria) were the following:

EN1 – the influence on the environment during the construction
- EN11 – the influence of the GPF construction on water resources
- EN12 – the harmful influence of GPF construction on the soil (the amount and kind of residual material from previous construction are different on every location)
- EN13 – the harmful influence of GPF construction on the air quality and the increased level of noise during construction

EN2 – the influence on the environment during facility exploitation was analysed in relation to the GPF size and location

EN3 – the influence that the facility has on the existing (and planned) city view

The social criterion (S) is usually assessed through number of people who would benefit from a certain project. In this case, the facilities providing a space for a larger number of vehicles and the facilities which the local inhabitants would benefit from during the whole year (e.g. the facilities situated near the city centre or sports facilities) were favoured over. Possible negative effects for the society were taken into consideration through other criteria (e.g. traffic volume increase in traffic criteria) so they were not discussed as negative social effects. The hierarchy of the garage-parking facility location selection is shown on Fig. 1.

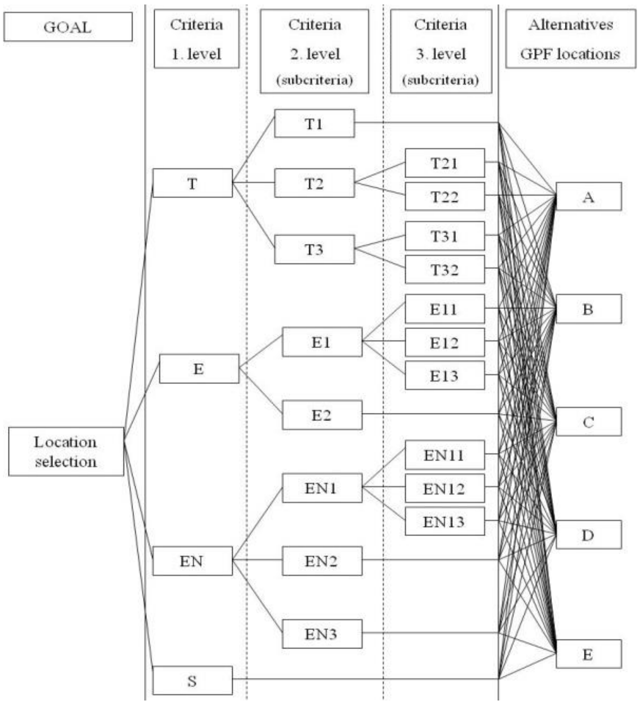
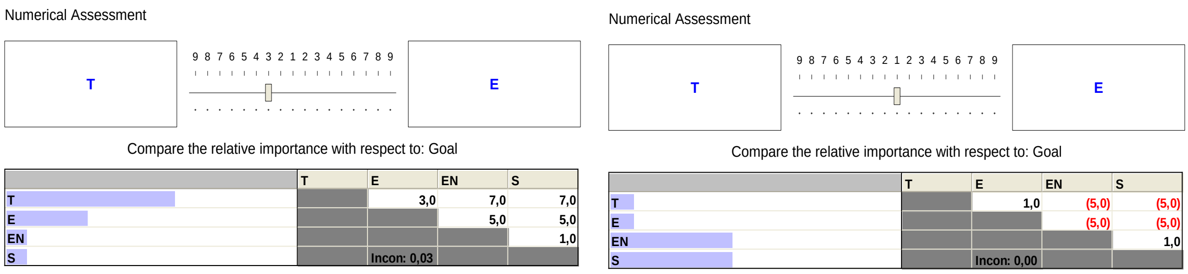


Fig. 1: Hierarchy structure [18]

4.3 Pair-wise comparison of alternatives and criteria importance determination

The AHP method application presumes pair-wise comparison of all alternatives with respect to each defined criterion and sub-criterion of the above hierarchy. The comparison can be conducted based on measurable or estimated importance/preference of one alternative in relation to the other. Based on all defined criteria a pair-wise comparison of all five alternatives was conducted according to every determined criterion, as well as pair-wise comparison of all criteria of a lower lever to the upper level and finally 1st level criteria to the goal. The whole procedure of pair-wise comparison is explained in detail in the paper [18].

The criteria and sub-criteria importance determination is a very important step in the optimal solution selection procedure. When selecting the traffic facility location, the most important criteria are usually the traffic and the economic criteria.



	T	E	EN	S
T		3,0	7,0	7,0
E			5,0	5,0
EN				1,0
S		Incon: 0,03		

	T	E	EN	S
T		1,0	(5,0)	(5,0)
E			(5,0)	(5,0)
EN				1,0
S		Incon: 0,00		

Fig. 2: Pair-wise comparison of criteria in relation to the goal for the first scenario (left) and the second scenario (right) [18]

The specific requirements of a certain environment (in this case, the tourist centre located in the sensitive karstic area) can however impose the environmental and the social criteria as the very important ones. The criteria importance in selecting the most favourable solution depends also on a specific requirement connected with the development strategy of a certain area.

In the case study two scenarios were analysed. The first scenario gives the highest importance to traffic criteria, then economic and lastly to environmental and social criteria (Fig. 2, left side). The second scenario gives higher importance to environmental and social criteria in relation to traffic and economic criteria (Fig. 2, right side). The software used for defining priorities was EXPERT CHOICE 11.5 which has been developed based on the theoretical and mathematical principles of the AHP method.

4.4 Results of AHP method application

Alternatives analysis conducted by AHP method application according to the first scenario, shown in Table 2, singles out the alternative B as the optimal one and with a very similar overall priority vector value to the alternative C. Other alternatives (D, A, E) have a significantly smaller overall priority vector [18]. The result of analysis according to the second scenario, shown in Table 2, singles out also the alternative B as the optimal one. It is followed by alternatives C and A. Other analysed alternatives (D and E) have a significantly lower overall priority vector value which indicates that they should either not be taken into further consideration or, if the execution dynamics is being determined, that they are ranked low on the priority list. The overall inconsistency indexes are adequate for both scenarios. The performance sensitivity graph analysis shown in Fig. 3 gives a better insight in the advantages/disadvantages of every single alternative, the influence of each criterion and its importance on the final ranking of alternatives.

Tab. 2: Result of multi-criteria GPF locations ranking by applying the AHP method for both scenarios

Alternative	**1st scenario**		**2nd scenario**	
	Priority	**Rank**	**Priority**	**Rank**
A	0,171	4	0,219	3
B	0,238	1	0,288	1
C	0,236	2	0,247	2
D	0,189	3	0,124	4
E	0,165	5	0,123	5
Overall Inconsistency	0,02		0,01	

Based on the conducted analysis according to the both scenarios of criteria importance, the best GPF location is the alternative B which is followed by the alternative C. Alternatives A, E and D are ranked as from 3rd to 5th place.

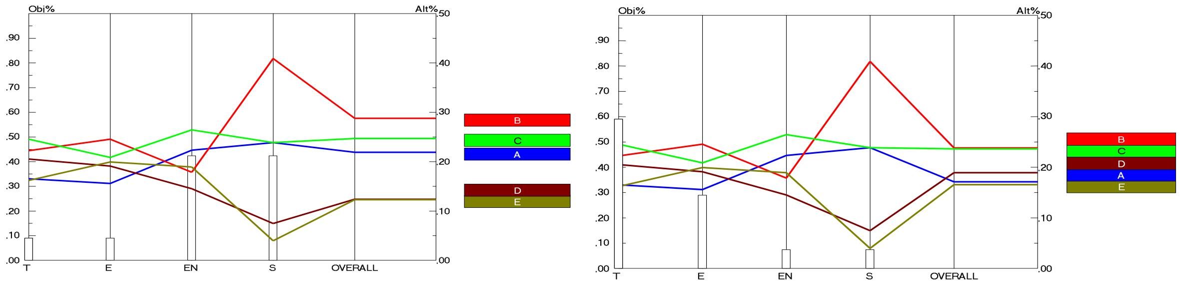


Fig. 3: Performance sensitivity graph for the 1st scenario (left) and for the 2nd (right) [18]

Since the alternative B is less favourable than the alternative C according to the environmental criterion, either the alternative C can be selected from the graphical presentation of sensitivity analysis as the final one or the social criterion can be elaborated in more detail and the ranking should be repeated. The results can also be used to define the order of construction of the proposed garage facilities because they show the need for different GPF from different perspectives.

5 CONCLUSION

This paper presents the use of AHP method for improvement of decision making in transportation infrastructure planning. First, the basics of the multi-criteria AHP method was shortly explained and than 5 examples of AHP use in transportation infrastructure planning were shown. Authors presented one of the examples in more detail: the AHP procedure application for ranking locations for the construction of GPF and determining the priority of GPF construction.

It can be concluded that the use of AHP : enables the involvement all interested parties (experts, local inhabitants, local authorities, etc.), gives the possibility to make decisions using a larger number of criteria that doesn't have to be expressed in monetary values (both quantitative or qualitative measures can be used), enables the pair-wise comparison of alternatives and criteria so it is not necessary to asses exactly each alternative regarding each criterion which is sometimes difficult to accomplish, gives the possibility to analyse the performance sensitivity etc.

The AHP methodology can be easily implemented in transportation infrastructure planning, saves time needed for decision making, especially if a larger number of interested parts need to be involved, and helps in better analysis of possible solutions. Finally, it makes the selection/prioritization of alternatives more objective and transparent. It must be stressed that AHP method is a very useful tool presuming that the goal, criteria and alternatives are well defined.

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