SELECTION BETWEEN SIGNALIZED TRAFFIC LIGHT JUNCTION AND ROUNDABOUT WITH THE USE OF MULTI-CRITERIA DECISION ANALYSIS (MCDA)

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ABSTRACT

The purpose of this paper is the development of selection criteria between a roundabout and a traffic light junction at an urban intersection. Raising the awareness of stakeholders for the prevention of accidents as well as for the improvement of traffic while ensuring environmental criteria is the new approach of implementing sustainable urban mobility plans. "Vision Zero" is a strategy to eliminate all accidents that cause serious injuries and fatalities, while increasing safe and fair mobility for all. "Vision Zero" has proven to be a successful model across Europe and is now being implemented in major North American and Canadian cities. In this frame, the redesign and reconstruction of traffic junctions are integrated with the simultaneous removal of traffic lights at intersections by replacing them with roundabouts. With the literature review of the international literature on roundabouts, the criteria by which we can replace a traffic light junction with a roundabout (single lane) were collected. After thoroughly analyzing the criteria that were collected, their importance was crystallized in the decision-making process for the selection or not for the decision to design a roundabout. The eligibility of the criteria was done by the method of the Analytic Hierarchy Process (AHP). With the SuperDecisions software (version 3), this methodology was effectively applied in a rural area in Waterloo, Ontario, Canada, at the junction of Queen Street and Bleams Road. Conclusions and suggestions were drawn regarding the prospect of applying the methodology developed in the frame of this paper by Local Government Authorities (LGA).

KEYWORDS

Analytic Hierarchy Process (AHP); Roundabout; Traffic light junction; Mobility

1. INTRODUCTION

The present paper is written in the context of modern and sustainable mobility, guided by the global awareness for the prevention and elimination of traffic accidents at road junctions, the improvement of traffic, taking into account operational, environmental, cost, and public acceptance criteria, in the frame of "Vision Zero" strategy [1]. The target is to eliminate road accidents that cause serious injuries and deaths, increasing safe, healthy, and fair transport and mobility for all.

There are many multi-criteria methods applied to urban transport projects [2]. The most common method of multicriteria analysis that is applied in transportation projects is the Analytic Hierarchy Process (AHP) [3]. The AHP method will be used for the decision to replace a traffic lights junction with a roundabout or not [4].

A roundabout, as an optimal alternative, helps to reduce road accidents, due to reduced speed at the junction, increasing, thus, the safety of passengers and pedestrians that cross the junction, to reduce greenhouse gas emissions and noise levels, to improve fuel efficiency, to allow vehicle U-turns, safe entry, and exit to adjacent properties, to traffic improvement, and aesthetic upgrade of the junction.

The selection of the design and installation of a roundabout is made by evaluating and comparing multiple criteria. The installation of roundabouts is problematic when the volume of pedestrians and bicyclists is particularly high, when space is limited, and when traffic volume is large [5].

2. METHODOLOGY

AHP was developed and refined by Thomas Saaty [6][7][8][3] to examine both tangible and intangible factors for optimal decision making, through pairwise comparisons for the optimum choice of criteria [9] to make complex decisions, which include a large number of criteria. AHP is widely used in a variety of decision- making processes. It is perhaps the best documented and recognized multicriteria method, which performs better than other multi-criteria methods since it can be easily adapted to different numbers of characteristics (criteria) and provide alternatives, which can be described both quantitatively and qualitatively [10].

Human judgment, and not just the underlying information, can be used to perform the assessment [7]. The AHP's ability to hierarchically structure a multi-faceted, complex multicriteria problem, and then investigate each hierarchy separately, combining the results as the analysis progresses, is its strong point.

Comparisons are made in pairs of factors, using a scale that shows the strength by which a factor dominates over a higher-level factor [8]. This staggered process can then be expressed with priority weights or scores for the ranking of alternatives.

A model for the decision is developed in sections, prioritizing the objectives, criteria, and alternatives [8]. Four basic planned and coordinated processes produce a specific result as follows [3]:

- A hierarchical analysis of the problem is made to decide on structured decision elements.
- The preferences of the decision-maker regarding the elements of the decision are collected.
- The data are processed, and the individual priorities for the elements of the decision are taken into account.
- The individual priorities are collected, synthesized, and grouped into general priorities of alternatives.

The weight of each criterion is developed. The importance of the criteria in pairs in a table is compared, concerning the desired goal, according to the weight of each criterion.

For table $A = [a_{ij}]$ is considered a table A^r, i.e., the multiplicationtable of A (reciprocal matrix) when for each element of a_{ij} it is valid that $a_{ijr} = \frac{1}{a_{ii}}$. The consequence of a positively defined A^r array is equivalent to the requirement that the maximum eigenvalue λ_{max} must be equal to n. Small deviances in the values of the table A of a_{ij} imply small deviances in the capital eigenvalue λ_{max}. The relationship $(\lambda_{max} - n)$ is the measure of consistency. If it is normalized according to the size of the table, the term Consistency Index (CI) appears, which indicates the deviation of the consistency

$$CI = \frac{(\lambda_{max} - n)}{n - 1}$$ [11].

To determine the CI, a Random Index (RI) has been calculated using a large sample of randomly generated positive arrays (reciprocal matrices) of ascending order [11]. Each table calculates the Consistency Ratio (CR), which compares the inconsistency of all judgments. The ratio of the CI to the corresponding class RI is

$$CR = \frac{CI}{RI}$$ [7]. The inconsistency measurement identifies possible errors in decisions. CR should be less than 0.1 to be considered reasonably consistent [12], while if it is higher, it is necessary to review the judgments.

Regardless of the number of factors, the AHP method requires only the comparison of a pair of criteria, at any given time, allowing the inclusion of tangible and measurable variables as well as intangibles as criteria in the decision [13].

With the approximate method, the total priorities or weights of the criteria are calculated [13].

The alternative that has the highest overall priority is the best option. Sensitivity analysis may be performed on how the weights of the criteria change and how this affects the result.

The final decision is based on the results of the composition and the sensitivity analysis.

3. APPLICATION

For this study, a critical decision was considered using AHP, for the urban provincial junction, in Ontario, Canada, Regional Municipality of Waterloo, Township of Wilmot, at the intersection of Bleams Road (Regional Road 4) & Queen Street (2358-2320 Regional Road 12 (Google coordinates: 43.392536, -80.582405) [14].

The following model was built in the SuperDecisions software, version 3 [12]:

- Goal:

1. Selection between a roundabout and traffic lights [junction].

- Criteria:

1. Operational.
2. Cost.
3. Environmental.
4. Opinion of residents.

- Alternatives:

1. Roundabout.
2. Traffic lights [junction].

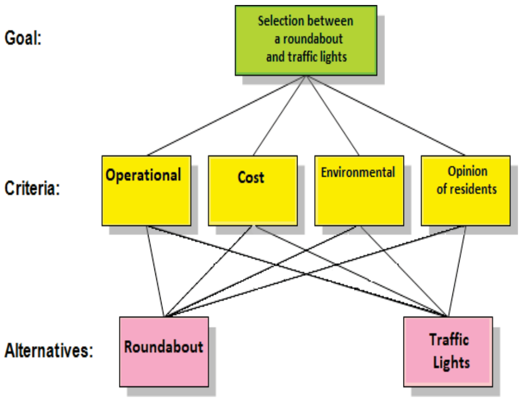

Figure 1. AHP model.

At the top of the hierarchy is the goal: decision making with two (2) alternatives. The intended goal is broken down into sub-targets (decision criteria). The decision criteria are specified for the comparison of alternatives.

Finally, the two (2) alternative solutions are placed in which the comparisons between them are led based on the criteria of the 2nd stage (Fig. 1) [15].

The answers to the questionnaires, where the preferences are expressed, were entered through pairwise comparisons.

The elements of each stage of the hierarchical structure are compared in pairs in terms of the degree of preference concerning the element of the immediately higher stage. Essentially, as many tables as the number of nodes are created. All the elements of one stage are compared with each other, in a pairwise manner. The process ends when the alternatives of the last stage of the hierarchy are compared.

Table 1. The Saaty numerical scale for pairwise comparisons [6].

Price	*Definition*	*Explanation*
1	Equal importance	The comparable data are of equal importance
3	Moderate importance	One element is slightly more important than the other
5	Strong importance	One element is more important than the other
7	Very strong importance	One element is much more important than the other
9	Absolute importance	One element is absolutely more important than the other
2,4,6,8	No relationship at all	These values can be used to express intermediate states of preference

To express the preferences when conducting the pairwise comparisons, a numerical scale is used, through a system of discrete values, from 1 to 9, which expresses the equivalence of preferences, weak preference, and strong preference, absolute preference. The use of intermediate values 2, 4, 6, and 8 express intermediate states and intermediate situations (Table 1) [6].

Both the alternatives, i.e., a roundabout and a traffic lights junction, passed the conventional criteria (Table 2), and, thus, the AHP method was applied, with the following AHP criteria:

1. Operational: road category, geometric features, traffic volumes, speeds, etc.
2. Cost: construction and maintenance costs.
3. Environmental: noise levels, gas emissions, land uses, etc.
4. Opinion of residents: public opinion.

Initially, in SuperDecisions, three (3) "clusters" were created with the three (3) levels of hierarchy:

1. Goal: selecting a roundabout or a traffic lights junction.
2. Criteria: operational, cost, environmental, and opinion of the residents.
3. Alternatives: choice between two (2) alternatives, i.e., roundabout or traffic lights junction.

All the criterion nodes were selected, and each was connected separately with the two (2) alternatives: roundabout or traffic lights junction (Fig. 2). Not all criteria have the same weight. Pairs were created to compare the criterion nodes. Ten (10) completed questionnaires were collected, data were compared for comparison, and the pairwise comparison matrix with judgments was compiled (Table 3).

Table 2. Criteria for roundabout and traffic lights junction.

	CATEGORIES	CRITERIA FOR APPLICATION OR NOT IN A CIRCULAR NON-TRAFFIC JOINT NETWORK		ROUNDABOUT	TRAFFIC LIGHTS JUNCTION
1	O	Road category: urban	Yes	Yes	Yes
2		Number of branches (roads) of intersection 3-5	Yes	Yes	Yes
3		Adequate road width	Yes	Yes	Yes
4		Road length sufficient for braking before entering the junction	Yes	Yes	Yes
5		Maximum road slope 1%-2%	Yes	Yes	Yes
6		Ensuring a radius of a 35m-40m roundabout	Yes	Yes	Yes

7		Minimum lane width at the roundabout 12m	Yes	Yes	Yes
8		Average entry speed at the junction < 40km/h	Apply	Yes	Yes
9		Annual Average Daily Traffic (AADT) < 20,000 vehicles/day	Apply	Yes	Yes
10		In 10 years: Annual Average Daily Traffic (AADT) < 20,000 vehicles/day	Apply	Yes	Yes
11		Traffic flow (vehicles / hour) < 1,800 vehicles/hour	Apply	Yes	Yes
12		In 10 years: Traffic flow (vehicles/hour) < 1,800 vehicles/hour	Apply	Yes	Yes
13	Cost	Installation cost: Use	Guaranteed Financing	Yes	Yes
14	Environmental	Noise levels	Reduction	Yes	Yes
15		Emissions levels	Reduction	Yes	Yes
16		Land use	Without change	Yes	Yes
17	Opinion	Opinion of locals (residents – professionals)	Positive	Yes	Yes

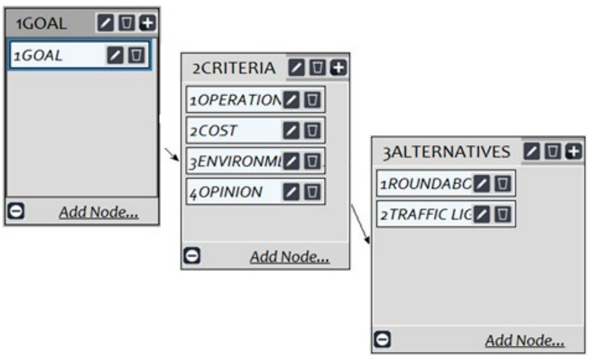

Figure 2. AHP criteria and alternatives to SuperDecisions.

When the significance of a criterion is compared to itself, the numerical value of the table is 1, which corresponds to the weight of the criterion of equal importance on the Saaty scale [13]. The comparison table (Table 3) shows the relevant priorities by pairs with judgment severity calibration. The overall priorities or the weights of the criteria are then calculated [13].

Table 3. Comparison table by pairs with crises.

	OPERATIONAL	***COST***	***ENVIRONMENT***	***OPINION***
OPERATIONAL	1	6	4	3
COST	1/6	1	1/2	1/4
ENVIRONMENT	1/4	2	1	1
OPINION	1/3	4	1	1

Intensity judgments correspond to each of the six (6) pairwise comparisons of the answered questionnaires, one (1) questionnaire at a time in the software as judgments. In all the questionnaires, the CR value was less than 0.10. In Fig. 3, they are presented grouped in a single questionnaire, which is the average of the answers to the questionnaires' questions.

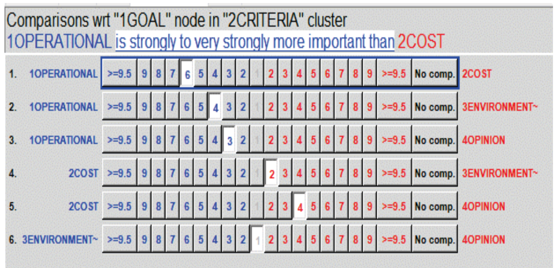

Figure 3. Grouped questionnaire responses in SuperDecisions.

SuperDecisions produces statistical results in charts. Roundabout was found to be the 1st, i.e., the best alternative, with a percentage of 75.14%. The alternative of traffic lights junction was found to be the 2nd alternative with a percentage of 24.86% (Fig. 4, Table 4).

55.697% of the respondents consider the "operational" criterion to be the most important. Next are the other criteria, the "opinion" with a percentage of 20.854%, the "environmental" with a percentage of 16.107%, and finally, the criterion "cost" with a percentage of 7.343% (Fig. 5).

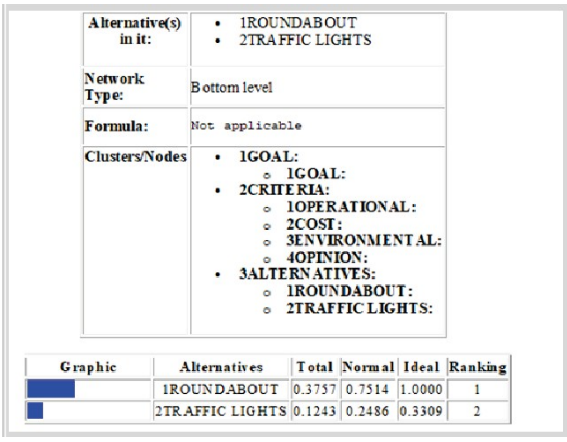

Figure 4. Results of AHP in SuperDecisions.

Table 4. Results of the AHP target.

Alternatives	*Total*	*Normal*	*Ideal*	*Ranking*
1 ROUNDABOUT	0.38	0.75	1.0	1
2 TRAFFIC LIGHTS	0.12	0.25	0.33	2

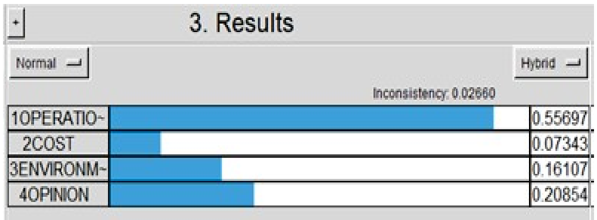

Figure 5. Hybrid table of percentage results.

CR=0.02660 <0.10; therefore the results are acceptable (Table 4).

4. SENSITIVITY ANALYSIS

Overall, priorities are influenced by the weights of the criteria. What if the weights in each criterion were different? This process is called sensitivity analysis [13].

By normalizing each column of Table 5, the "Priorities" column is obtained, which shows the relative importance of each alternative (Fig. 6).

Table 5. Comparison table by pairs with judgments and cumulative results.

	OPERATIONAL	*COST*	*ENVIRONMENT*	*OPINION*
OPERATIONAL	1	6	4	3
COST	0.17	1	0.50	0.25
ENVIRONMENT	0.25	2	1	1
OPINION	0.33	4	1	1
SUM	1.75	13.00	6.50	5.25

Figure 6. Normalized comparison table by pairs with judgment weights' calibration.

5. DISCUSSION

The operational criteria were ranked with the simplified AHP as the most important. Social consensus is needed in local projects. Public opinion is becoming more aware of environmental issues. The choice of the roundabout as a solution at intersections is perfectly in line with the "Vision Zero" strategy.

The cost criterion is the least important probably because it does not directly affect the individual budget of the people, but indirectly. Safe and quality projects are required. AHP helps to extract, scientifically, and accurately, the best choice, based on the safety of the public and the protection of the environment.

The general methodology that was followed was formulated in a flow chart that can be used by the Local Government Authorities (LGA) to make relevant decisions for the conversion of intersections into either roundabouts or traffic light junctions (Fig. 7), in the same was it was applied in the frame of this paper (Fig. 8).

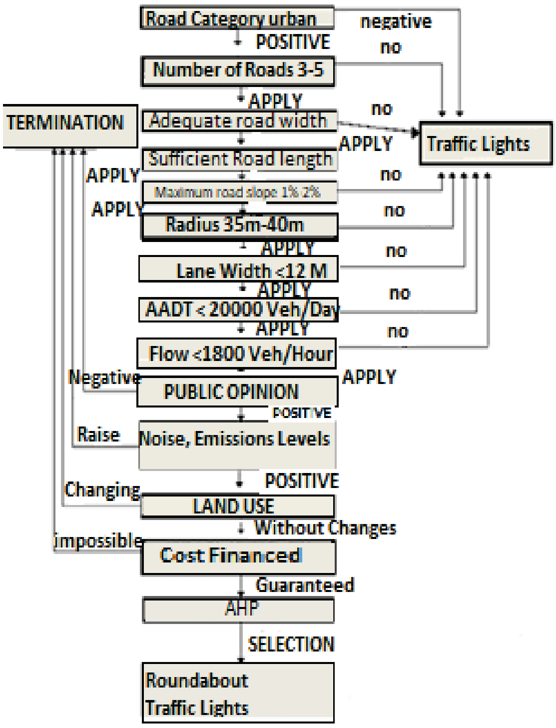

Figure 7. The proposed methodology for LGA.

Figure 8. The intersection of the application area in the Township of Wilmot, Regional Municipality of Waterloo, Ontario, Canada.

REFERENCES

[1] Vision Zero Network, n.d., *Webinar recap: Safe systems for safe mobility: a deeper dive webpage.* https://visionzeronetwork.org/webinar- recap-safe-systems-for-safe-mobility-a- deeper-dive/

[2] Bhandari, S. B., Nalmpantis, D., 2018, Application of various multiple criteria analysis methods for the evaluation of rural road projects. *The Open Transportation Journal, 12,* 57–76. https://doi.org/10.2174/18744478018120 10057

[3] Saaty, T. L., 1995, Transport planning with multiple criteria: The analytic hierarchy process applications and progress review. *Journal of Advanced Transportation, 29* (1), 81–126. https://doi.org/10.1002/atr.5670290109

[4] Forman, E. H., Saul, G.I., 2001, The Analytic Hierarchy Process—An exposition. *Operations Research, 49* (4), 469–486. https://doi.org/10.1287/opre.49.4.469.11 231

[5] Spanou, D., 2014, *Roundabouts: geometric design, landscape adaptation, and road safety – case study in Kavala* [Γεωμετρικός σχεδιασμός, προσαρμογή στο τοπίο, και οδική ασφάλεια – Μελέτη περίπτωσης στην πόλη της Καβάλας]. MSc diploma thesis, Aristotle University of Thessaloniki, Thessaloniki, Greece. http://ikee.lib.auth.gr/record/135875/file s/GRI-2015-13817.pdf

[6] Saaty, T. L., 1997, A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15* (3), 234– 281. https://doi.org/10.1016/0022- 2496(77)90033-5

[7] Saaty, T. L., 1980, *The analytic hierarchy process: planning, priority setting, resource allocation.* New York, NY: McGraw-Hill. p. 287. 978-0070543713.

[8] Saaty, T. L., 1990, How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48* (1), 9– 26. https://doi.org/10.1016/0377- 2217(90)90057-I

[9] Sarraf, R., McGuire, M. P., 2020, Integration and comparison of multi- criteria decision making methods in safe route planner. *Expert Systems with Applications, 154,* 113399. https://doi.org/10.1016/j.eswa.2020.1133 99

[10]Nalmpantis, D., Roukouni, A., Genitsaris, E., Stamelou, A., Naniopoulos, A., 2019, Evaluation of innovative ideas for Public Transport proposed by citizens using Multi-Criteria Decision Analysis (MCDA). *European Transport Research Review, 11* (1), 22. https://doi.org/10.1186/s12544-019-0356-6

[11]Kollia, I., 2012, *Analytic Hierarchy Process (AHP): A decision making model in multiple criteria conditions* [Ιεραρχική Ανάλυση Αποφάσεων (AHP): Ένα μοντέλο λήψης αποφάσεων σε συνθήκες πολλαπλών κριτηρίων], MSc diploma thesis, University of Patras, Patras, Greece https://nemertes.lis.upatras.gr/jspui/bitst ream/10889/5465/1/Διπλωματικη-

AHP_Κόλλια_Ηλιάνα_AM256.pdf

[12]Creative Decisions Foundation, n.d., *Homepage*. http://www.superdecisions.com/

[13]Mu, E., Pereyra-Rojas, M., 2018, Practical decision making using Superdecisions v3: An introduction to the Analytic Hierarchy Process. Cham, Switzerland: Springer. P. 155. 978-3-319-68368-3. https://doi.org/10.1007/978-3-319-68369-0

[14]Google, n.d., *Google Maps.* https://www.google.com/maps

[15]Vasileiadis, I., Nalmpantis, D., 2019, Development of a methodology, using Multi-Criteria Decision Analysis (MCDA), to choose between full pedestrianization and traffic calming area (woonerf zone type), In E. Nathanail & I. Karakikes (Eds.), *Advances in Intelligent Systems and Computing* (Vol. 879). Cham, Switzerland: Springer. pp. 315–322. 978-3-030-02304- 1. https://doi.org/10.1007/978-3-030- 02305-8_38