EVALUATION OF SENSOR TECHNOLOGIES FOR INTELLIGENT TRANSPORT SYSTEMS

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ABSTRACT

The paper presents a new approach to sensor technology evaluation in Optimal Decision Making Process. The sensors have the function of collecting traffic flow information, which allows the automatic traffic management systems to perform control depending on the real-time traffic demand. In order to be able to compare the sensors within a particular selected type set, the multi-criteria evaluation model was used to perform the synthesis of evaluation process. The Analytic Hierarchy Process (AHP) method was used for the synthesis procedure. The proposed model was tested on characteristic example in the Zagreb Metropolitan Traffic Area.

Key words:
Intelligent Transport System, Evaluation of Sensor Technologies, Analytic Hierarchy Process

1. INTRODUCTION

Advanced Traffic Control Applications, as a part of Intelligent Transport System (ITS) rely on real-time data from the traffic system [2]. The most important sources of real-time information for traffic management are the traffic flow sensors (detectors). Naturally, there are technological potentials for information integration from other sources of information such as video-surveillance, satellite and aircraft recording, sensors onboard traffic entities, application of positioning technologies, meteorological sensors as well as reports from special services and traffic participants. The efficiency of ITS applications regarding the collection of data will depend to a large extent on the traffic flow sensors.

There are 350 intersections in Zagreb equipped by traffic signals [8]. The condition in Zagreb regarding traffic management equipment is characterized by the diversity of technological generations, manufacturers and types of devices. Concretely, even 14 different types of controllers by six different manufacturers make the upgrade to advanced control strategies very difficult. A part of signalized intersections is equipped by inductive loops that function as part of local control system. Their role is the detection of the presence of vehicles and/or passage of vehicles. The past experience in Zagreb regarding the application of sensor technologies is related to inductive loop. Thus, the inductive loop is a well-known technology. The main objections are the malfunctions caused by breaking or fracture of the loop conductor or the connecting cable. The number of loop malfunctions due to these causes over the last five years is about 50 a year which, regarding the total number of 300 loops makes about 16% annually. However, it should be mentioned that as much as 60% of malfunctions are caused by the works on the communal infrastructure. At places with no works and where the traffic surface is in good condition, some loops have been functioning for more than 15 years without failure.

There are some characteristic advantages and disadvantages of used sensor technologies [3]. There are, of course, traffic flow sensors that combine the technologies. The comparison according to different criteria related to high-quality information, exploitation, costs and other criteria, yields different results. Therefore, there is the problem of evaluating the traffic flow sensors regarding the concrete selection for different ITS applications.A number of papers and publications contain evaluations of sensor technologies for the ITS application. Here, special use is made of [10], [11] and [13] for the systematization of evaluation criteria and for the evaluation of sensors per individual criteria. The publication [10] presents the requests for ITS data, as well as the applicability of sensors for ITS applications. Furthermore, the paper [13] gives a procedure for selecting adequate detector technology, i.e. concrete detector, based on elimination (Procedure of Detector Technology Selection). However, practice has shown that regarding the today's quality of individual technologies and types of sensors, the majority of traffic flow sensors (detectors) meet the selection procedure. The selection procedure could be improved if the importance of individual criteria is determined.

This paper presents the methodology based on the usage of multi-criteria evaluation model, which, apart from the very single criteria evaluation, will take into consideration also the importance of the individual criteria. Evaluation here understands the assignment of a unique grade to a certain type of traffic flow sensor. It will reflect its adequacy for certain ITS applications. The first part gives a proposal of the multi-criteria evaluation model, whereas in the second part of the paper the model is applied to a real case taking into consideration the concrete problem and feasibility of the traffic control system in Zagreb.

2. MULTI-CRITERIA EVALUATION OF TRAFFIC FLOW SENSORS

2.1 AHP method

AHP is one of well-known multi-criteria decision-making method. The objective of multi-criteria decision-making is the choice of the best alternative according to the defined set of criteria. If the results of multi-criteria decision-making are the final evaluations of the alternatives, and if these evaluations reflect their place on the scale of priorities, this procedure may be called multi-criteria evaluation. The theoretical basis of the method was given by T.L. Saaty in 1980. Since then this method has been continuously developing, and numerous scientists and experts have contributed to its development. A special characteristic in the application is good adaptability to various problems. There are several software packages on the market today for the use of this method. AHP method is used to break down a complex decision-making problem into simpler elements, which form a hierarchical structure. The main objective is at the top of the hierarchy. Alternatives are at the lowest level of the hierarchy. Inter-levels correspond to various criteria and sub-criteria. The hierarchy structure depends on the complexity of the concrete problem and the approach to the problem. Many papers have been written about the AHP method and its single characteristics, as well as examples of applications. Further in the text a brief consideration of AHP method is given, without strict mathematical description. The AHP procedure can be presented in eight steps:

1. Consideration of the problem. Defining of the objective. Identification of relevant factors;
2. Defining of criteria and sub-criteria;
3. Forming of hierarchical structure and defining of a set of alternatives at the lowest level;
4. Forming of pairwise comparison matrices for every level;
5. Determining of priorities of elements regarding the superior node;
6. Verification of consistency;
7. If consistency has been met, the priority of alternatives is calculated to the main objective and the sensitivity analysis is carried out.
8. Examining and verifying the decision.

After having formed the hierarchy there follows the decision-making about the relative importance among hierarchy elements regarding the superior element. In this way pairwise comparison matrices are formed. From the pairwise comparison matrix the priorities of criteria and alternatives are determined. Saaty proposed a comparative scale for the comparison of relative importance or preferences of two elements [18]. Pairwise comparison matrix is formed by the decision maker through a series of successive comparisons of the importance of criteria (and alternatives) regarding the superior criterion. If $C_1,C_2,C_3, . . . ,C_n$ are elements of a hierarchy level with a certain superior criterion, element a_{ij} of comparison matrix A represents the preference of element C_i to element C_j. Matrix A is consistent if it has the property of reciprocity and transitivity. In concrete cases there is often occurrence of inconsistent matrices. In AHP method a certain measure of inconsistency is allowed. If the inconsistency is within the permitted limits, the results of the AHP method are accepted. The pairwise comparison matrix determines the priorities of the criteria regarding a superior criterion. There are several methods of determining priorities, as e.g. the methods of eigenvector and methods of distance minimization between the inconsistent matrix formed by the decision maker and the nearest consistent matrices [7]. The opinions about the acceptability of single methods are mixed. The original method proposed by Saaty, for matrices that have low consistency, is the method of eigenvectors [17]. The matrix consistence, including the decision consistence according to the original Saaty proposal is checked by means of the consistency index (CI) obtained from maximal eigenvalue and order of square pairwise comaparison matrix.The consistency index (CI) is divided by the random index (RI), obtained as average value for a large number of randomly generated reciprocal matrices of the same order. In this way the consistency ratio (CR) is given. It represents the measure of consistency whose value determines the feasibility of the solution. Generally, the consistency ratio lower than 0.1 is acceptable, except in the case of smaller matrices. For the matrices of the fourth order the limit value is 0.08, and for matrices of the third order the limit value is 0.05. After having obtained the local criteria priorities (according to the superior ones) and the priorities of alternatives (according to the lowest criteria in the hierarchy), the final priorities of alternatives are calculated according to the main goal. In this case their local priorities are pondered with the weights of all their respective nodes (moving from the lowest level to the main goal) and are then summed up. The rank-list of the alternatives is made based on the final priorities of the alternatives.

When several decision-makers are included in the process, the decision of the group may be brought by a consensus or by processing individual judgements. Processing of individual judgements is a less demanding method of obtaining a solution. There are several ways of merging judgements. The most frequent are AIJ (Aggregating Individual Judgements) and AIP (Aggregating Individual Priorities). AIJ is a method which merges individual judgements for each set of pairwise comparisons. The usual arithmetic procedure for merging of individual judgements is the geometric mean. The AIP method is based on the synthesis of individual final priorities and then merging of individual priorities into a final priority, and arithmetic mean or geometric mean may be used as the arithmetic procedure for merging [6]. In final priorities, due to the possible inconsistency of the decision-maker, there may occur also inconsistency of the solution. The sensitivity test (e.g. changing the criterion importance within certain limits) indicates the robustness of the obtained solution.

2.2 Evaluation criterion of sensor technologies

The selection of criterion for the sensor evaluation is based on the ITS requirements and on the traffic flow sensor characteristics. The evaluation criteria in this paper have been classified in four sets: information quality criteria, exploitation criteria, economic criteria, and other criteria. The information quality criteria refer primarily to the requirements that are set or can be set by various requirements of single ITS applications and services. The selected information quality criteria are presented in Table 2.1. The information quality (particularly accuracy) may be affected by different factors: influence of the setting location, influence of meteorological circumstances, influence of the traffic flow, etc. In this case these influences are taken into consideration in the sense of sub-criteria. The exploitation criteria are related to the life-cycle of sensors, Table 2.2. Economic criteria refer to the costs related to the purchase and costs that are incurred by exploitation, Table 2.3. All the other criteria that may influence the selection of traffic flow sensors are placed into the group of other criteria, Table 2.4.

Table 2.1. Criteria of the quality of traffic flow sensor information

Criteria of sensor information quality	Description of attributes (criteria)
Requested traffic parameters	Capability of traffic flow sensor to collect certain types of data (parameter).
Accuracy of traffic parameters	Matching level between actual values and values obtained through information source.
Precision of measured values	Level of classification up to which the value of the parameter of interest may be presented.
Reliability of information delivery	Refers to the reliability of the traffic flow sensor to send correct data.
Coverage of traffic area	Traffic space from which the traffic flow sensor can send data. The coverage zone.
Resolution within the spatial coverage	How detailed does the sensor present the traffic space by data.
Adaptability of detection zone	Refers to the possibility of spatial adaptation of collecting information.

Table 2.2. Exploitation criteria

Exploitation criteria	Criteria description
Installation	Time of installation, required equipment, and engaged staff in order to install the sensor at a determined location;
Calibration	Calibration time, required equipment and staff for the sensor to provide high-quality information;
Compatibility	Level of functional and technical adaptation to the existing Traffic Control System;
Technological knowledge and experience	Existing knowledge about individual sensors regarding exploitation;
Communication	Required information capacity that needs to be provided in order to use the sensor possibilities;
Supply	Sensor energy consumption;
Maintenance	A number of interventions, time, means and staff necessary to bring the sensor into operation or to keep it in operation;
Durability	Duration of the traffic flow sensor;
Uniformity	The same type of sensor/sensor technologies in a certain area.

Table 2.3. Economic criteria

Economic criteria		Criteria description
Investment costs	Purchase costs	Price of sensor and respective equipment
	Installation costs	Costs of sensor installation in space including work and materials;
	Costs of connecting to the system	Costs of adaptation of the sensor to the system. Price of necessary interfaces and work;
	Calibration costs	Price of work and materials in order to calibrate the sensor;
Maintenance costs	Regular maintenance costs	Price of regular preventive maintenance and test of proper operation;
	Maintenance costs in case of malfunction	Price of sensor repair or replacement;
Life-cycle costs		Other Costs during the sensor life-cycle and including all the costs (reduced to a year).

Table 2.4. Other criteria

Other criteria	Criteria description
Subjective user's satisfaction	Level of subjective user's satisfaction with a certain sensor and/or technology;
Possibility of expanding the application	Application of sensors with minimal intervention for other traffic applications as well, e.g. traffic control, incident detection, repressive measures;
Resistance to damage	Resistance to vandalism, traffic incidents;
Influence on humans	Influence on human health;
Aesthetic criteria	Aesthetic appearance in certain special parts of the city;
Ecological criterion	Quantity and toxicity of waste after the life-cycle.

2.3 Multi-criteria evaluation model

Input data for the proposed model, Figure 2.1., are the functional requirements of ITS regarding strategies and methods of traffic control, possible future applied strategies and other possible ITS applications. Furthermore, the data are also required on the scope of intervention, conditions at the location (condition of the traffic flow, meteorological conditions, intersection geometries, road conditions, condition of the traffic control system, etc.). The results of the multi-criteria evaluation model is the grade assigned to each traffic flow sensor which reflects its quality for a certain application. Based on the analysis of ITS requirements, the criteria are classified into four groups: criteria that may be excluded, evaluation criteria for AHP model, elimination criteria, and criteria of additional consideration. The first group of criteria includes the criteria that may be excluded,. The second group of criteria is used for modelling of the AHP hierarchy, and these criteria determine the respective importance. The elimination criteria set the border values that the sensors have to satisfy in order to remain in further procedure of evaluation. All the criteria, if they are assigned a border value may be also elimination criteria. After having modelled the AHP hierarchy and the respective calculations, the priorities of individual traffic flow sensors are obtained. This is followed by additional study, especially if there is no big difference among the priorities. In that case the study also includes the additional criteria. This group of criteria may include the criteria already used in the AHP hierarchy, as well as some other criteria such as: terms of contract with the supplier, readiness of supplier for education, etc.

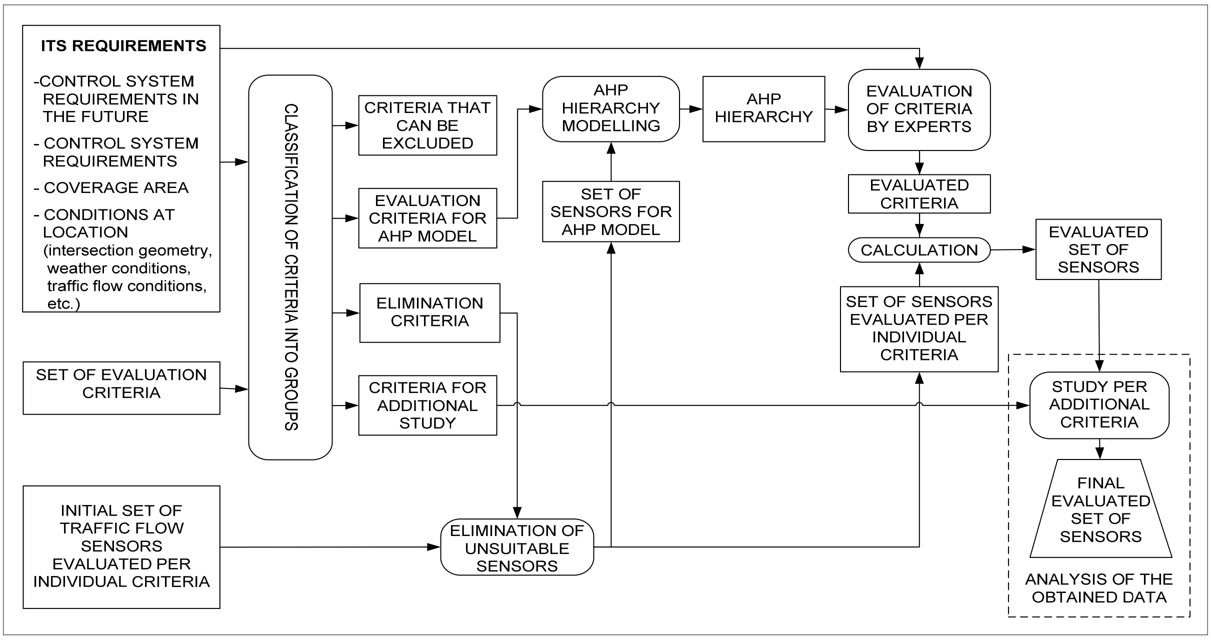

Figure 2.1. Multi-criteria evaluation model

3. CASE STUDY

3.1 Description of the task

The case study refers to the intersection of Heinzlova-Vukovarska (HV-I) in Zagreb Metropolitan Area, one of the major intersections in the city, Figure 3.1. The traffic flow in the morning and in the afternoon is characterized by high density and congestion. During other parts of the day the traffic is of medium density. In order to select the criteria and the evaluation of the traffic flow sensor, the following data have been collected and analysed: the selection of control method, intersection geometry, design characteristics of the intersection, condition of the road surface, condition of the traffic flow, meteorological conditions (number of rainy, foggy, snowy days), presence of gantries and lamp posts, condition of control equipment. The selected control strategy requires a detection zone in front of or after the stop line in order to detect a leaving vehicle, and a detection zone at a distance of 60-70m in front of the stop line in order to detect the vehicle approaching the intersection. The traffic flow parameters needed are only the vehicle detection [1]. Thus, a set of traffic flow sensors has to be evaluated by multi-criteria evaluation.

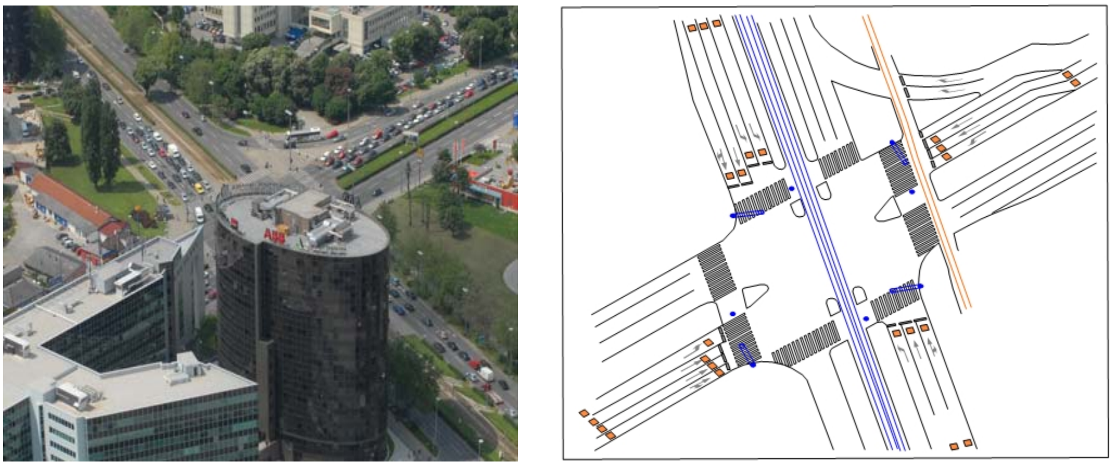

Figure 3.1. The intersection of Heinzlova-Vukovarska (HV-I) in Zagreb

3.2 AHP hierarchy for the selected example

Based on the set of initial criteria, management requirements and conditions at the location, the criteria for AHP hierarchy have been selected, as well as the elimination criteria, [9] presented in Table 3.1.

Table 3.1. Criteria for the HV-I

ELIMINATION CRITERIA	REQUESTED TRAFFIC PARAMETERS Detection of passing vehicle
EVALUATION CRITERIA FOR AHP HIERARCHY	ACCURACY- Accuracy in conditions of no special disturbances - Accuracy in poor weather conditions - Accuracy in conditions of high density traffic flow RELIABILITY INSTALATION CALIBRATION EXPERIENCE WITH SENSOR TECHNOLOGY DURABILITY MAINTENANCE INVESTMENT COSTS (purchase price)

Based on the selected evaluation criteria the AHP hierarchy has been formed, Figure 3.2. The costs taken into consideration are only the investment costs, more precisely the purchase price. The costs of installation, maintenance, and the life-cycle cost have been included in the grade within the exploitation criteria.

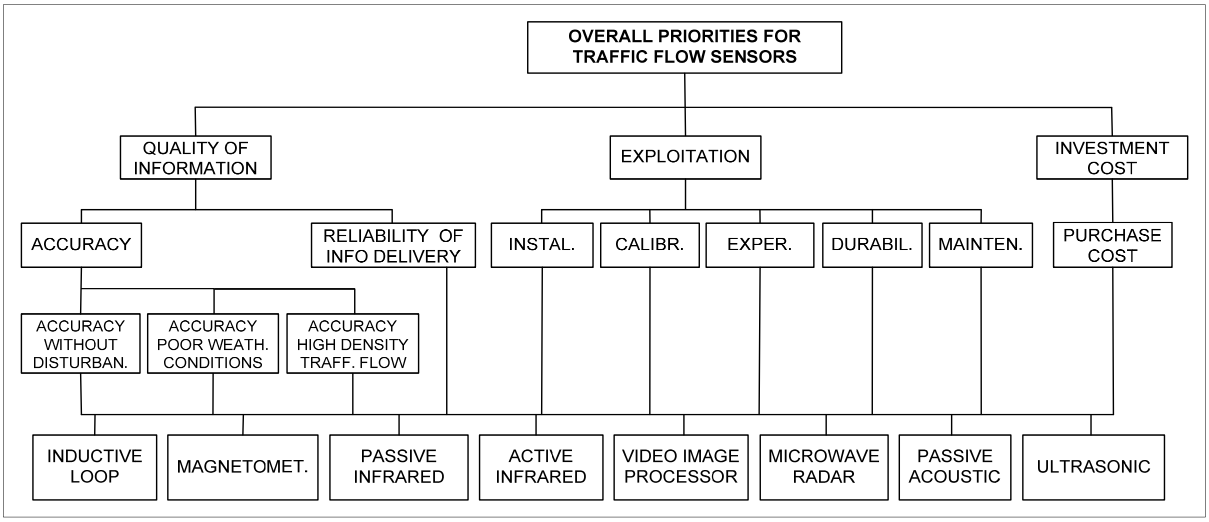

Figure 3.2. AHP hierarchy for HV-I

Based on [10], [11] and [13] and using other sources from the literature, the grades have been given to certain types of traffic flow sensors, Table 3.2. The specific characteristics of Zagreb as well as of the concrete location have been taken into consideration. For instance, the condition of the road surface at the selected location is of special interest (important for the inductive loop, and which affects the evaluation of the inductive loop reliability). For the assessment of reliability the grades taken from [16] have been used. Since the results are based only on testing one representative of the product, these evaluation grades should be taken with reserve.

Table 3.2. Evaluation of traffic flow sensors per individual criteria

EVALUATION CRITERIA	A	B	C	D	E	F	G	H
ACCURACY IN CONDITIONS WITH NO SPECIAL DISTURBANCES	3	2.5	2.5	3	3	2	3	2.5
ACCURACY IN CONDITIONS OF HIGH DENSITY AND LOW SPEEDS	2.5	2	2	3	2.5	1.5	2	1.5
ACCURACY IN POOR WEATHER CONDITIONS	3	2.5	2.5	1	2	1.5	3	2.5
RELIABILITY	3	3	3	2.5	3	3	3	2
INSTALLATION	1	1.5	3	2.5	3	3	3	3
CALIBRATION	3	2	3	3	1.5	3	2.5	2
EXPERIENCE WITH SENSOR TECHNOLOGY	3	1	1	1	1.5	1	1	1
DURABILITY	3	3	2	2.5	2.5	2	2	2
MAINTENANCE	1	2	3	2.5	2	3	2.5	3
PRICE	2.5	2	2.5	0.5	2	2	2.5	2.5
A- Inductive loop B- Magnetometer C- Passive infrared D- Active infrared E- Video imaging processor F- Passive acoustic G- Ultrasonic H- Microwave radar								

For the inductive loop reliability evaluation, the condition of the road surface has been also taken into consideration. In this case, at the selected location, the condition is good (no fractures, no corrugation of the traffic surface and no gradients). For the criterion of the existing experience with a certain sensor technology the condition in Zagreb has been taken into consideration. For the criterion of prices also the number of traffic flow sensors has been taken into consideration in order to cover the detection zones. The grading scale ranged from 1 to 3. Grade 3 represents the best grade and 1 the worst grade, and the allowed increment is 0.5 in order to emphasise more the differences. These grades can be adapted to the used AHP.

3.3 Results

In order to determine the importance of single criteria a survey has been carried out among a group of experts in the area of traffic control. The survey group consisted of respondents such as: public services involved in traffic maintenance, companies that deal with design in traffic and scientists and experts from the University of Zagreb. The experts were requested to compare the relative importance of pairs of criteria according to the AHP hierarchy and Saaty scale. For each of 23 respondents a pairwise comparison matrix was formed and the consistency checked. Here, three respondents were excluded due to extraordinary high inconsistency. In order to form the final pairwise comparison matrices the AIJ (Aggregating Individual Judgements) method was used, which merges individual judgements for every set of pairwise comparisons and geometric mean for the calculation.

In order to obtain the criteria priorities the software package Expert Choice was used which uses the eigenvector method for the calculation of priorities. The matrices obtained by AIJ method have been used in the project. The software package plans the input according to the Saaty scale which contains integer values, but allows input of numbers with up to two decimals, and the values of the matrix elements were rounded to two decimals. The obtained priority values are presented graphically, Figure 3.3., 3.4., 3.5., 3.6. The importance of criteria here is relative, regarding the superior objective, i.e. criterion. Relative importance of criteria of the lowest level regarding the goal is presented in Figure 3.7. The final traffic flow sensor priorities are presented in Figure 3.8.

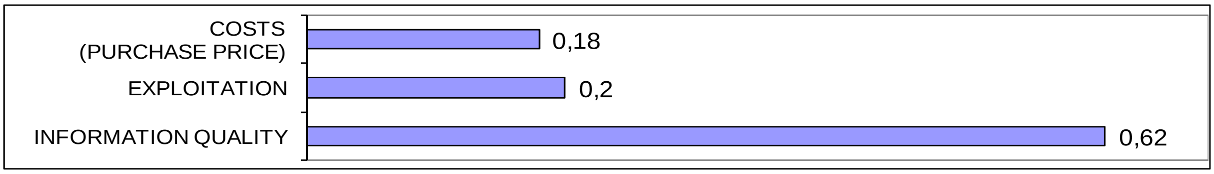

Figure 3.3. Relative importance of the main criteria regarding the main goal

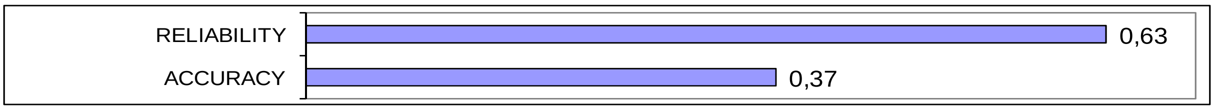

Figure 3.4. Relative importance of sub-criteria of information quality

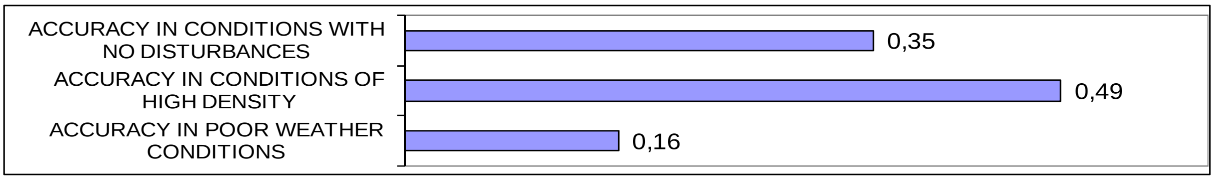

Figure 3.5. Relative importance of sub-criteria of accuracy criteria

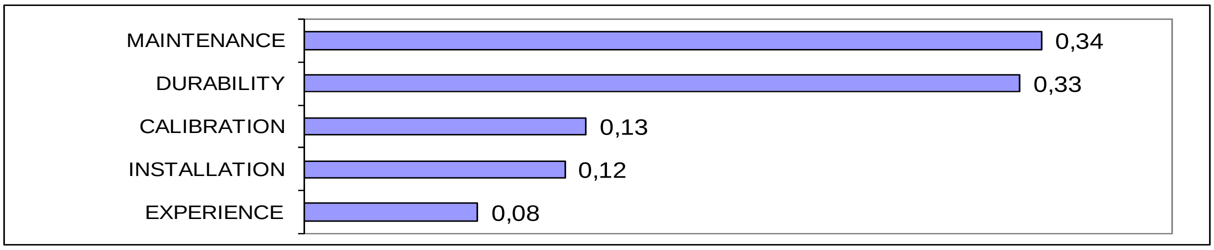

Figure 3.6. Relative importance of sub-criteria of exploitation criteria

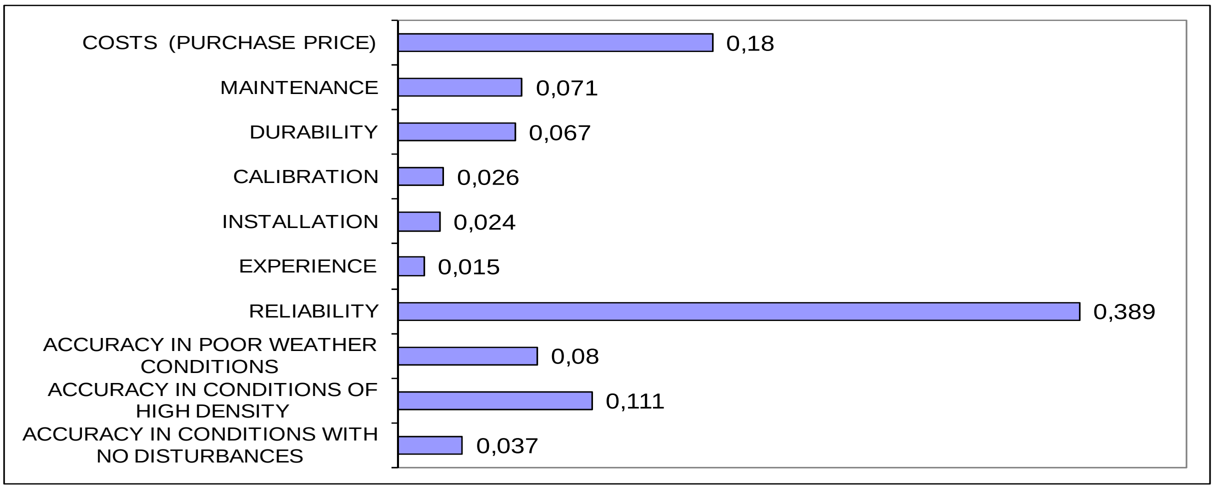

Figure 3.7. Relative importance of criteria of the lowest level regarding the goal

Figure 3.8. Overall priorities of sensor obtained by multi-criteria evaluation model

The difference of priorities between the leading passive infrared and inductive loop is only 0.2%, and the difference of priorities between the leading and the radar is 3.7%. There are relatively small differences between the first groups of priorities. As expected the active infrared has the lowest priority. The sensitivity test has been carried out by means of the application which is part of the Expert Choice software package. When the evaluation procedure is finished, the sensitivity of the solutions have to be analyzed [12]. The sensitivity test shows that changing of the weights of the main criteria within 10% makes almost no change in the order of alternatives. In case of increasing the weight of the information quality criterion by 10% the inductive loop go to the first place, which is the consequence of the assigned good grade regarding reliability due to the good condition of the traffic surface at the location. By changing the weights of the main criteria by 20% the order of alternatives changes slightly, but still no sensor receives a high convincing priority.
The obtained results have been presented to selected experts, a total of twelve, and they were asked to give their opinion about the sensor selection. Three of them categorically favoured the inductive loop and gave the following reasons: familiarity with the technology, accuracy and durability (the condition is proper installation). Four placed emphasis on the video image processor regarding the possibility to expand the application. Two of the respondents considered that passive infrared is suitable because of installation and simple replacement in case of malfunctioning. In the opinion of three experts all the sensors, except the active infrared one can be taken into consideration and the attention should be paid to the usage of technology in other European cities.

4. CONCLUSION

Unlike the usual evaluations of traffic flow sensors according to single criteria, this paper takes into consideration also the importance of individual criteria. Based on this, a multi-criteria evaluation model of traffic flow sensors with the application of AHP method has been proposed. The final results of the model are the priorities of the traffic flow sensors regarding the requirements of the defined ITS applications taking into consideration also other relevant factors such as the coverage area, conditions at the location, etc. The results of the model on the carried out example show relatively small differences in the priorities of the selected sensors. The final results are within the expected range. This refers particularly to the relatively small differences in values of their respective priorities. It should be emphasised that the type of sensor technology does not have to be evaluated but rather the concrete product. A better evaluation of the traffic flow sensor according to some criteria assumes independent testing of several equal types. Further studies will apply this method to analyse also more demanding ITS applications (with several more demanding traffic parameters and on a larger coverage area). Several criteria and alternatives need to be taken into consideration. In this case greater differences between final priorities are to be expected.

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