An Approach for Environmental Impact Assessment

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Abstract: - In the environment impacts assessment context, several methods are proposed in literature, such as life cycle analysis, multi criteria analysis and cost benefit analysis etc. Recently, others methods combining MCDA (Multi Criteria Decision Analysis) and AI (Artificial Intelligence) have been explored to develop enhanced methodologies for knowledge based decision support. In this paper, a new approach is presented for environmental assessment of urban mobility. Various criteria should be evaluated using complex data obtained from several information sources. Therefore, the measure evaluation related to urban mobility is a hard task that does not always lead to efficient results. The problem treated in this paper, is complex with insufficient, fuzzy and uncertain data. A hybrid approach based on multi criteria analysis and various information sources has been proposed. The methodology uses fuzzy set theory for modeling criteria and belief theory (Dempster-Shafer Theory (DST)) for evaluations fusion and it is able to handle uncertainty and vagueness.

Key-Words: - Multi-criteria analysis, decision support systems, environmental, impact assessment.

1 Introduction

In many urban areas, rapidly increasing traffic volumes, lower vehicle operating speeds, type of fuel used and the aging of vehicles have resulted in excessive gas emissions, generation of noise pollution and deterioration in living conditions of citizens. In response, the decision makers associated to traffic engineers and urban specialists elaborated various measures for decreasing negative consequences of urban traffic (massive development of the public transport, introduction of fleets with clean vehicles, parking policy in the downtowns, etc). At the same time, any new measure is prone to financial risks and its implementation must not affect the quality of the accessibility for people and goods. In these contexts, the local authorities and transportation community are strongly interested in methods to be able to evaluate impacts of any measure to be carried out in the urban traffic. Several approaches are frequently used for the impacts evaluation like the air quality: Life Cycle Analysis (LCA) [4], Multi-Criteria Decision Making (MCDM) [1], and Cost Benefit Analysis (CBA) [6] etc.

The traditional approaches are, generally inappropriate, to apprehend the complexity of the systems with their environmental, social, economic and cognitive dimensions. Recently, an Evidential Reasoning (ER) approach has been developed for dealing with a complex decision problem in classification and pattern recognition alike [2][3] and in management [11]. Furthermore, uncertainty and vagueness common in human knowledge cannot be properly catered for in such methods aforementioned.

We concluded that no individual method can give a complete, global or rigorous description of the criteria. The solution could be to adapt different approaches in order to treat many information sources with their uncertainty and reliability degrees. We propose to use a hybrid approach based on multi-criteria analysis and artificial intelligence techniques (fuzzy logic and data fusion), to model the various impacts on the environmental, social and economic domains, combine diverse information and analyse criteria for giving global assessment.

Firstly, we present the proposed new approach and the framework of our studies. Secondly an application is used to validate the proposed approach. Finally, the conclusion underlines the benefit of the proposed approach and a description of the potential for further research in this area.

2 General Framework

This study is carried out in the framework of SUCCESS (Smaller Urban Communities in CIVITAS for Environmentally Sustainable Solutions) [9]. The aim of this project is to adapt innovative methods and techniques to estimate the environmental impacts of transport activities and their components. There are 26 measures to test at La Rochelle-France, like the introduction of the hybrid buses, the installation of Park & Ride, the bike sharing etc.

The evaluation takes into account different categories, sub-categories and their corresponding impacts. The impacts are distributed in 5 categories: economy, energy, environment, society and transport system. Each impact is characterized by one or more criteria to evaluate the measures of the project. A list of 28 criteria was established e.g. vehicles/km to illustrate the congestion, NO_x level for the air quality or acceptance degree for safety, etc. Each criterion can be measured by one or several adequate information sources (experts, models, sensors, questionnaires, etc.) and each source allow us a certain type of data alike quantitative or qualitative with uncertain, fuzzy even incomplete data.

2 Proposed Approach

2.1 Multi-criteria and multi-information sources analysis

The proposed approach presents a hybrid methodology based on multi-criteria analysis and fusion multi sources under the framework of belief theory. This type of approach was already used in several applications [2][3], but it was not extensively applied to achieve an evaluation for environmental impact in transport field.

Since several information sources are used during assessment, the new decision matrix is given according to Fig. 1.

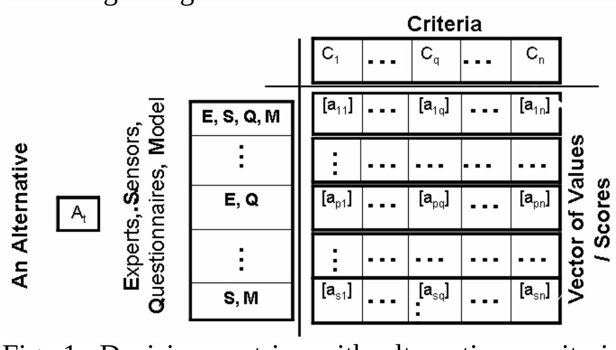

Fig. 1: Decision matrix, with alternatives, criteria and multi-information sources.

This choice of using several sources is justified because in practice, each criterion is measured, at the same time, by one or several adequate sources (see Fig 2). For example, sensors and models measure quantitative criteria (eg. Noise, air pollution etc.). Besides, experts and questionnaires estimate qualitative criteria (eg. accessibility and security etc.).

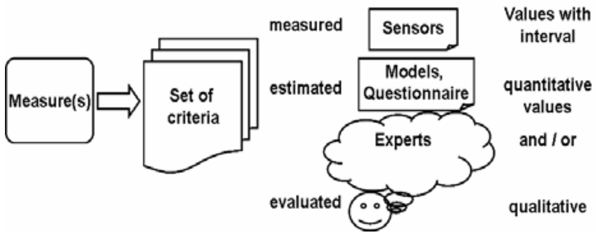

Fig. 2: Information sources and data variety

2.2 Approach steps

The approach steps and their Theoretical frameworks are presented in Table 1.

Table 1: Approach steps and theoretical framework

Steps	Theoretical frameworks
Choice of pertinent criteria	Grid repertory theory & fuzzy logic
Mass assignment	Fuzzy logic & belief theory
Fusion of evaluations	Belief theory
Assessment of a measure:	Utility theory
Effectiveness estimation:	

- **Step1: Choice of pertinent criteria**

The manager of project selects pertinent criteria (C_k for $k = 1,\ldots,n$) and by applying the Grid Repertory Theory (GRT), we find the dependency between criteria [5]. In practice the decision makers find less difficulty in evaluating the impacts related to urban mobility by using qualitative variables (for example “Less” impact) than to quantify them numerically. Consequently, we present a new version of GRT with fuzzy numbers, relative to qualitative variables which enables us to establish a tree of dependence between criteria. The evaluation of the criteria is done using linguistic terms which are defined by fuzzy numbers on the interval [0,1].

Let $\tilde{A}_1$ and $\tilde{A}_2$ be two fuzzy numbers where $\tilde{A}_1 = (l_1, m_1, r_1)$ and $\tilde{A}_2 = (l_2, m_2, r_2)$. The similarity between two criteria is given by:

$$\begin{cases} s\left(C_i, C_j\right) = \dfrac{1}{1 + d\left(C_i, C_j\right)} = \dfrac{1}{1 + \sum_{k=1}^{9} \left| E\left(C_i\right) - E\left(C_j\right) \right|} \\ s\left(\left\{C_i, C_j\right\}, C_k\right) = \max\left(s\left(C_i, C_k\right), s\left(C_j, C_k\right)\right) \end{cases} \quad (1)$$

with $E(C_i)$ is a fuzzy evaluation related to the criteria C_k and the distance between C_i and C_j valuated respectively with $\tilde{A}_1$ and $\tilde{A}_2$ is based on:

$$d\left(C_i, C_j\right) = \frac{1}{2}\left[\left|m_1 - m_2\right| + \max\left(\left|l_1 - l_2\right|, \left|r_1 - r_2\right|\right)\right] \quad (2)$$

For each obtained group, the chef manager selects a criterion for evaluation and gives arbitrary a weight (ω_k denote the importance related to the criteria C_k with $k = 1,\dots,n$).

- **Step 2: Mass assignment**

Data are collected from heterogeneous information sources, so it is necessary to find a common scale for data fusion and evaluation process. Thus, belief theory is used as a theoretical framework [8] which is composed by two steps: mass assignment and data fusion.

For evaluation and fusion steps, we should define firstly, the frame of discernment. Let Ω be the frame of discernment such as: $\Omega = \left\{H_1, H_2, \dots, H_q\right\}$ witch represents the evaluation levels (alike Small, Medium and High) and q fuzzy functions (triangular or trapezoidal) related to the frame of discernment. The initialization methods for the mass function in the belief theory are various and depend on the considered application framework.

We present here, a mean for calculating mass structure for each information source. The interest of such representation can be explained for example, that generally, in practice the human experts find less difficulty to express their opinions in the form of interval or by qualitative term and not only in the form of unit value. In addition, each criterion can be evaluated by a specific information source (experts, sensors, and questionnaire) and each one has its own characteristic. The mass assignment is described as below according to each information source:

- **Experts:** they give their opinions according to a range scale from 0 to 10 (from the worst to the best). Under this scale, fuzzy variables are defined, as shown in Fig. 5 (a), which indicates the perceived measurement related to each criterion (like accessibility etc.). For the mass assignment, we use the theory developed by [7] whose results are given according to Fig. 3 (b). Let Ω be the frame of discernment, witch corresponds to the evaluation levels, where Ω ={VL, L, M, H, VH}= {Very Less, Less, Mean, High, Very High} as given according to Fig. 3 (a).

For example, if an expert gives an evaluation equal to 6.5 among a scale from 0 to 10, then this last value will be transformed into qualitative value alike medium (M) and Large (L) with the appropriatess degrees 0.5 for «Medium» and 1 for «Large» (see Fig. 3 (a)).

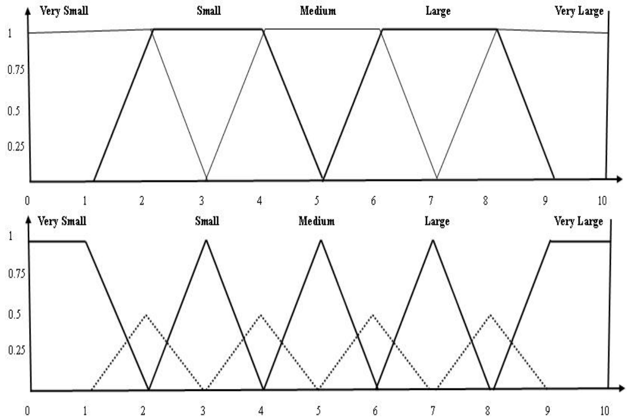

Fig. 3: Fuzzy variables (a), mass assignment (b)

- **Questionnaire:** the mass assignment depends to the appearance frequency of an attribute in the measurement sample.

- **Sensors:** from a data base, classes are defined by applying the "k-means" clustering method. Then a Decision-Rule known by "If-Then" is applied in order to obtain the mass allowed to each evaluation level.

- **Step 3: Fusion of evaluations**

After data collection, evaluation process and mass assignment, we combine the diverse assessment under the framework of belief theory taking into account the reliability of the information sources.

Let $\left\{S_j, j = 1,\dots,p\right\}$ be a set of information sources intervening in the evaluation process with $\left\{\alpha_j, j = 1,\dots,p\right\}$ be respectively their degree of reliability and $A^t = \left\{a^t_{jk}\right\}$ be the matrix of assessment using several information sources. Define $\left(p \times n\right)$ masses according the frame of discernment Ω, such as m^t_{jk} with $j = 1,\dots,p$ and $k = 1,\dots,n$;

When information sources are not full reliable, the mass function (m) is discounted into a new less information denoted $\left(m^\alpha\right)$ and given by:

$$\begin{cases} m^\alpha\left(A\right) = \alpha \cdot m\left(A\right) & \text{for} \quad A \subset \Omega \\ m^\alpha\left(\Omega\right) = 1 - \alpha + \alpha \cdot m\left(\Omega\right) \end{cases} \quad (3)$$

The mass function m^t_k are combined using the fusion operator defined in [8]

$$m^t_k = \bigotimes_{j=1}^{p} m^t_{jk} = m^t_{1k} \otimes \dots \otimes m^t_{pk} \quad (4)$$

- **Step 4: Assessment of a measure**

For decision step, a "pignistic" transformation is done (masses redistribution) related to each

singleton hypothesis by criterion which is noted by $BetP$ [10].
We can determine a global utility related to each criterion by measure, taking into account the utility given for each evaluation level belongs to the frame of discernment schematically represented by Fig. 4.

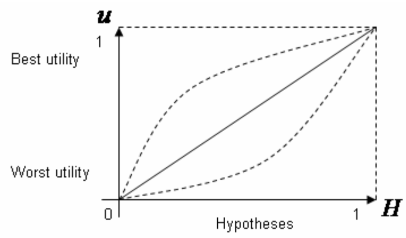

Fig. 4: Utility Functions (linear and exponential)

A global assessment according to all criteria allows us to compute a global utility taking in account the pertinence of each criterion. The crisp utility by criterion u_k^t, is computed as shown in next equation:

$$u_k^t = \sum_{i=1}^{q} u(H_i) \times BetP(H_i) \quad (5)$$

where $u(H_i)$ represents the utility of an evaluation level H_i. $u(H_{i+1}) \geq u(H_i)$ if H_{i+1} is preferred to H_i which represented by ($H_{i+1} \succ H_i$) where the symbol "$\succ$" means a crisp preference. The utilities by criterion can be:
$u(H_1) \leq u(H_2) \leq \cdots \leq u(H_q)$ for positive impacts like safety and $u(H_1) \geq u(H_2) \geq \cdots \geq u(H_q)$ for negative impacts like air pollution and noise.

- **Step 5: Effectiveness estimation:**

The efficiency of a criterion C_k (respectively for a measure M^t) is done by comparison between two implementation phases, noted by ph_1 and ph_2 respectively for before and after implementation. The evaluation index (respectively the measure effectiveness) is equal to the relative deviation $(E.r)$, related to the utilities u_k^{t,ph_1} and u_k^{t,ph_2} (respectively related to $u_{ph_1}^t$ and $u_{ph_2}^t$).

$$E.r_{(C_k)_{ph_1 \to ph_2}} = \frac{\left(u_k^{t,ph_2} - u_k^{t,ph_1}\right)}{u_k^{t,ph_1}} \quad (6)$$

$$E.r_{(M^t)_{ph_1 \to ph_2}} = \frac{\left(u^{t,ph_2} - u^{t,ph_1}\right)}{u^{t,ph_1}} \quad (7)$$

where

$$u^t = \sum_{k=1}^{n} \omega_k \times u_k^t; \quad 1 \leq t \leq m \quad (8)$$

with u_k^t is the utility given for criterion C_k $(k = 1,\ldots,n)$ and ω_k is respectively its weight.
The sign of this evaluation index shows if the implementation of the measure is advantageous or harmful.

3 Application

3.1 Case study

Several measures can carry out to the same objective: for example, to decrease the number of travel made by the car in La Rochelle agglomeration. We chose to study several measures like: the installation of "Bus lines" (M_1), access controlled (M_2), service "Car-Sharing" (M_3), Park & Ride (M_4) and Bike-Sharing (M_5). After selecting measures to be evaluated, the project chief selected the common criteria $(Cr.)$.
The set of criteria is:
$\{C_1,C_2,C_3,C_4,C_5,C_6,C_7,C_8,C_9\}$={Air quality (Aq.), Noise perception (Np.), Fuel consumption (Fc.), Security (Se.), Users number (Un.), Satisfaction (Sa.), Accessibility (Ac.), Congestion (Cg.) and Cost (Co.)}. The various information sources used during evaluation are: experimental measures (data collected from sensors, measurement and counting), opinions citizens or studies and experts opinions. The set of evaluation level is given by: Ω = {H_1, H_2, H_3, H_4, H_5}. The number of levels varies with the information sources. In our case study, their number is the same but it can have different meaning, it depends with the type of data. For example it can be {VS, S, M, L, VL}={Very Small, Small, Medium, Large, Very Large} for the two criteria; visitors number and congestion level.
To find dependency between criteria, a preliminary evaluation is done as follow: in Table 2, we summarize the evaluations made by the project chief for the criteria and measures aforementioned.

Table 2: Evaluations by the project chief

Cr.	M_1	M_2	M_3	M_4	M_5
C_1	F	M	F	F	TE
C_2	M	F	M	F	E
C_3	M	E	M	F	E
C_4	E	F	F	E	M
C_5	M	E	M	TE	E
C_6	M	E	M	E	P
C_7	E	F	E	E	E
C_8	E	M	E	E	M
C_9	E	E	E	E	F

With the criteria set defined aforementioned, the result from the F-GRT gives us the following tree dependency between criteria (Fig. 5).

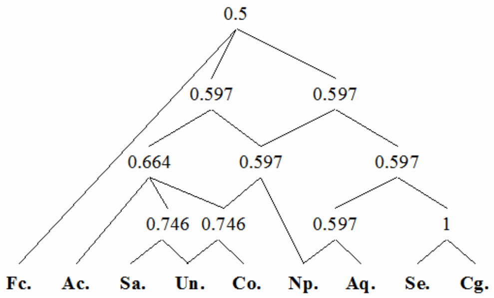

Fig. 5: Dependency tree between criteria

The results of the F-GRT, with fuzzy numbers, enable us to find similarities between criteria and measures as to make a preliminary comparative analysis. The criteria can be grouped according to the dependence degrees. In our case study, it is remarkable that there are four groups of criteria which are: {Fc}, {Ac., Sa., Nu., Co.}, {Np., Aq.} and {Se., Cg.}. However, this approach does not enable us to find the criteria weights and to make the choice of the most reliable measure. For each group of criteria one was selected. The whole selected criteria are: {Aq., Nu., Sa., Cg.}. The vector of weights is given in Table 3.
In this paper, Park & Ride measure is analysed for evaluation in two stages. The first stage is an initial evaluation before implementation and the second stage is a post evaluation after implementation.

Table 3: Criteria weights

Criteria	Criteria weights
C_1 : Air quality (Aq.)	0.15
C_5 : Users number (Nu.)	0.40
C_6 : Satisfaction (Sa.)	0.25
C_8 : Congestion (Cg.)	0.20

The Data used for assessment in this study are given as follow (frame of discernment is different according to the information sources):
- Ω_1: V.L: Very Small, S: Small, M: Medium, L: Large, V.L: Very Large (is used for evaluating users number and congestion levels).
- Ω_2: E: Excellent, G: Good, O: Ordinary, P: Poor, B: Bad (is used for evaluating Air quality).
- Ω_3: A.S: Absolutely Satisfied, P.S: Partly Satisfied, N.S/D.S: Neither Satisfied nor Dissatisfied, P.D: Partly Dissatisfied, A.D: Absolutely Dissatisfied (is used for evaluating satisfaction degree).

Each criterion is evaluated with two information sources and each one has its reliability degree. We suppose here that each source is fully reliable (no discounting)
The set of evaluation level is given by: $\Omega=\{H_1, H_2, H_3, H_4, H_5\}=\{\Omega_1$ or Ω_2 or $\Omega_3\}$ and the vector of utility related to the evaluation level is as follow : $u=\{u(H_1), u(H_2), u(H_3), u(H_4), u(H_5)\}$ such as:
- For a negative effect like the air quality and the noise, the vector utility can be given as follow: $u=\{u(H_1), u(H_2), u(H_3), u(H_4), u(H_5)\}=\{1, 0.8, 0.6, 0.4, 0.2\}$.
- For a positive effect like safety and user acceptance, the vector utility can be given, is this case, as follow: $u=\{u(H_1), u(H_2), u(H_3), u(H_4), u(H_5)\}=\{0.2, 0.4, 0.6, 0.8, 1\}$

3.2. Results

The pollutant NO_2 is measured by a sensor, where data are shown according to Fig. 6 (a) (b) and Fig. 7.

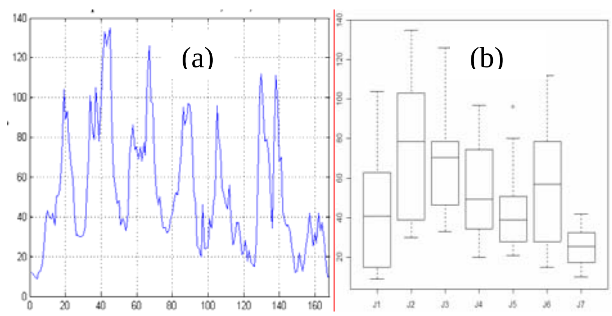

Fig. 6: NO_2 concentration, hour by hour, year: 2004 (a) and mean daily concentration (b) via the sensor of "La Grille, La Rochelle-France"

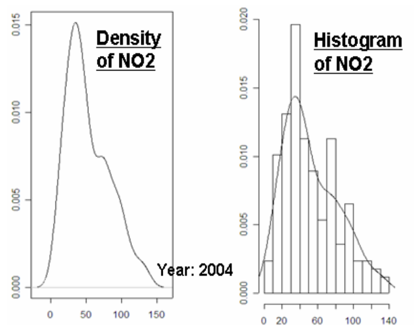

Fig. 7: Density of probability of NO_2

By applying the "K-mean" clustering method, we determine firstly the center of the classes, and then thanks to the Decision Rule known by "If-Then" we assign mass to the levels of evaluation (frame of discernment) as shown in Table 4.

We summarize the whole mass assignment as shown in Table 5. Each criterion can be evaluated in this case study by two information sources having their own reliability degree.

Table 4: Mass assignment of NO_2

Decision Rule	Mass distribution (m)
- if (NO_2 in 9-35) then the level is «Good»	m(Good)= 0.232
- if (NO_2 in 35-69) then the level is « Ordinary »	m(Acceptable)=0.428
- if (NO_2 in 69-135) then the level is «Poor»	m(Poor)= 0.339

Table 5: Mass assignment

Cr	Information sources		
	Experts opinions	Sensor	Questionnaire
Aq	m(G)= 0.3 m(O)=0.7	M(G)= 0.232 m(O)=0.428 m(P)= 0.339	
Nu	m(L)=1	M(S)= 0.293 m(M)= 0.469 m(L)= 0.241	
Sa	m(P.D,A.D) = 0.5 M(Ω)=.05		m(A.S)= 0.314 m(P.S)=0.202 m(N.S/N.D)= 0.219 m(P.D)= 0.233 m(A.D)= 0.31
Cg	m(S)= 0.45 m(M)= 0.55	M(S)= 0.251 m(M)= 0.362 m(L)= 0.387	

An evaluation by criterion is given according a function of utility related to each evaluation level. At last a global evaluation is computed taking into account the weight of each criterion. A similar presentation in Fig. 8 allows interpretation easily the evolution of each criterion before and after Park & Ride implementation.

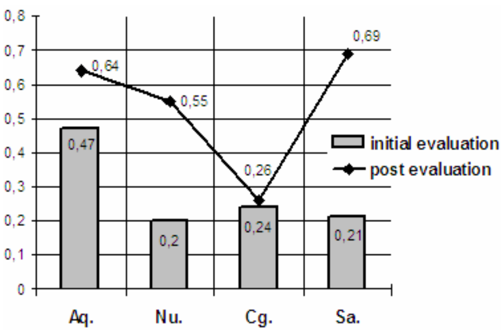

Fig. 8: Criteria evaluation of Park & Ride.

The evolution of all criteria shows advantageous impacts for the Park & Ride implementation. The evaluation index could also be estimated using the equation (7).

4 Conclusion

In this paper we have proposed a methodology for the evaluation of the impacts related to the urban mobility, under the framework of multi criteria analysis, fuzzy logic and belief theory. In order to test the proposed approach, Park & Ride service at La Rochelle-France has been evaluated within the framework of the European Success project for the improvement of urban mobility and the results seem to be conclusive. Its interest deals with its capacity to combine in effective way information resulting from different information sources, even if in the case of the fuzzy data and uncertainty. An interactive Web-tool is under implementation for data collection, information treatment and decision-making aid.

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