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Evaluation of Sustainable Mobility Measures Using Fuzzy COPRAS Method

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The process of decision making in a complex system such as transport is often conducted in the presence of a large number of criteria that are often conflicting and whose values are expressed in different units. This paper presents a multi-criteria decision making (MCDM) approach for evaluating sustainable mobility measures based on qualitative information. The usage of both types of criteria (or only qualitative) in the process of evaluation of sustainable mobility measures is possible thanks to the fuzzy expansion of the multi-criteria decision making methods. The proposed procedure for the evaluation of sustainable mobility measures encompasses selection of measures, criteria and ranking selected measures using the fuzzy COPRAS method. The aim of the proposed method is ranking sustainable mobility measures on the basis of previous experiences. The method enables cities that have not yet implemented these measures to gain an insight into what to expect and establish priorities. The paper demonstrates the potentials and suitability of fuzzy COPRAS in making decisions on mobility measures. Accordingly, twenty six measures are evaluated and the most promising ones have been obtained.

Keywords: evaluation, fuzzy COPRAS, measure, rank, sustainable mobility

1. Introduction

Today, almost every city in the world is faced with growing transportation related problems. Therefore, the ongoing challenge is to find a way to improve urban mobility (the ability for movement of people and goods) and at the same time to reduce congestion and pollution. This brings the concept of sustainable urban mobility to the forefront. Sustainable mobility is defined as providing mobility, i.e., access to goods, services and locations with minimal negative effects (WBCSD, 2001).

Sustainable mobility is an important instrument of transport policy whose aim is to facilitate mobility and also to simultaneously reduce negative economic, environmental and social impacts of transport. A sustainable mobility concept includes a set of different strategies and measures which are reflecting on the usage of private cars, creating a favorable environment for public and non-motorized traffic in order to improve efficiency and sustainable development of transport systems.

A general classification of mobility management measures is based on the so-called “soft measures“ (e.g., campaigns) and “hard measures” - related to the physical improvements of infrastructure, but also increased costs of car use, for example congestion charging or control of road space (Gärling and Schuitema, 2007). Implementation of a single mobility management measure is unlikely to achieve sustainable mobility so a whole set of measures is needed (Basarić, 2015).

In order to promote and support sustainable mobility concept, the European Commission launched a number of initiatives with the aim to provide EU cities with specific sources of knowledge and experience (e.g. CIVITAS, EPOMM, KonSult, etc). The key topic in these initiatives/projects is the evaluation of sustainable mobility measures, i.e., quantification of their contribution to sustainability objectives. Particularly important is the CIVITAS WIKI[1] - a framework for evaluating measures defined within the CIVITAS II initiative, as well as projects MAESTRO[2] and CIVITAS MODERN[3], which are focused on a detailed evaluation of already implemented measures in the so-called experimental cities. A comprehensive overview of measures and the quantification of their effects can be found in the JRC[4] study *Quantifying the Effects of Sustainable Urban Mobility Plans*[5].

There is a number of studies dealing with the concept of sustainable urban mobility from different perspectives - devising conceptual frameworks (e.g., Marx et al., 2015; da Silva et al., 2008; Gakenheimer, 1999), determining sustainable mobility indicators and indexes (e.g., Shiau, 2012; Shiau et al., 2015; Awasthi and Chauhan, 2011), analyzing the influence of specific factors or policy instruments (e.g., Mrkajic and Anguelovski, 2016; Hysing, Frandberg and Vilhelmson, 2015; de Andrade et al, 2015) or conducting market segmentation survey (e.g., Hinkeldein et al., 2015).

There is a special line of research papers dealing with the evaluation of measures of sustainable urban mobility. Their principal aim is to depict measures with highest contribution in achieving sustainable urban mobility goals. One of the main challenges in these studies is to come up with appropriate analytical tool to deal with a variety of measures often in conflict by nature and expressed in accordance with both qualitative and quantitative criteria. One recent study was done by Curiel-Esparza et al. (2016) who integrated the Delphi technique with the Analytic Hierarchy Process (AHP) and the VIKOR method to select the optimal alternative in terms of sustainable mobility. They arrived with a conclusion that the best solution according to their hybrid model is the enhancement of the cycle network. Macário and Marques (2008) studied 200 urban mobility measures in 19 European cities and investigated the preconditions for transferability of these measures. Schmale, Schneidemesser and Dörrie (2015) relied on multi-criteria approach to evaluate the contribution of 75 measures clustered in six categories (public relations, motorized private transport, public transport, walking, biking, miscellaneous) and ended with establishing four groups of measures based on their priority.

However, the majority of these studies focus on quantitative reflection of urban mobility measures and thus neglect certain measures that must be evaluated qualitatively as public acceptance or decision maker preferences. Our study fills this gap by using fuzzy COPRAS (hereinafter: COPRAS-F) method which takes into account a great number of possible measures, involve multiple stakeholders, qualitatively data as well as a suitable weight of criteria depending on the strategy of the city.

The aim of the proposed method is ranking sustainable mobility measures through the evaluation of measures, good practices, results and methods included in the EU sustainable transport projects. There have been only a few attempts to apply COPRAS method in the field of transport (e.g., Zavadskas et al., 2007; Barysienë, 2012). A recent study by Barysienë (2012) uses the COPRAS-G method to evaluate technologies used in container terminals.

The paper is organized as follows. The following section is about COPRAS and COPRAS-F methods. Section tree contains the COPRAS-F based procedure for the evaluation of sustainable urban mobility measures. The proposed evaluation procedure is comprised of three basic steps: selection of measures; selection of evaluation criteria and ranking measures according to the COPRAS-F results. The empirical example is presented in Section 4. The paper ends with concluding remarks and future research directions.

2. Copras Method

Within the decision making theory there are numerous multi-criteria decision making methods that support solving various problems. Each MCDM method is characterised by specific mathematical tool, but basically the problem is formally presented by choosing one out of *m* options alternatives, (A_i, $i=1,2,...,m$), which are estimated and mutually compared based on *n* criteria (X_j, $j=1,2,\dots,n$) whose values are known. The

[1] http://www.civitas.eu/sites/default/files/civitas_wiki_d4_10_evaluation_framework.pdf
[2] http://www.transport-research.info/web/projects
[3] http://www.civitas.eu/sites/default/files/d12.3_-_modern_final_evaluation_report_revised.pdf
[4] https://ec.europa.eu/jrc/
[5] https://ec.europa.eu/jrc/sites/default/files/effects_of_sustainable_urban_mobility_plans.pdf

alternatives are presented by vectors x_{ij}, where x_{ij} is a value of i^{th} alternative according to j^{th} criterion. Considering that the criteria influence alternatives' final estimates to the different extent, a weighting coefficient w_j, $j=1,2,\ldots, n$ (where $\sum_{j=1}^{n} w_j = 1$) is allocated to each criterion and reflects its relative importance in alternative evaluation.

One of the recent methods being increasingly used in the literature is the COPRAS (*COmpressed PRoportional ASsessment*) method developed in 1996 by Lithuanian authors (Zavadskas and Kaklauskas, 1996). The COPRAS method is to a certain extent characterised by a more complex procedure for criterion function value aggregation and a simplified procedure for data normalization (criterion character – min or max is not considered). This method is used by numerous authors (Kaklauskas, Zavadskas and Raslanas, 2005; Kaklauskas et al., 2006; Vilutiene and Zavadskas, 2002; Zavadskas, Kaklauskas and Kvederyte, 2001; Zavadskas, Kaklauskas, Banaitis and Kvederyte, 2004; Zavadskas, Kaklauskas, Turskis and Tamosaitiene, 2008) for solving various problems.

Unlike other multi-criteria decision making methods, this method is characterised by numerous advantages and Fouladgar et al. (2012) emphasize in their paper only those that are most important: (1) a possibility to rank numerous alternatives; (2) a shorter time for getting results (by software) than in AHP and ANP methods; (3) a simplified result presentation; (4) a possibility to interpret results graphically.

2.1. Fuzzy COPRAS Method

Conventional multi-criteria decision making methods are applied when solving various problems in case where the data within them are known and numerically expressed (quantitative). The conventional COPRAS method is applied when specific data are available, while in case numerical data are not available, the fuzzy extensions of the COPRAS method are used (COPRAS-F). The COPRAS-F method can be applied when ranking of criteria and alternatives is being solved by linguistic expressions using fuzzy numbers (commonly triangular).

The steps in the COPRAS-F method application can vary depending on the way in which the weights are estimated, as well as on the defuzzification mode of fuzzy numbers, but basically the steps in this method application are the following (Fouladgar et al., 2012):

Step 1: The decision making process starts with step 1 which refers to the generation of feasible alternatives (*m*) and to the adoption of criteria for defined alternative (*n*) evaluation;
Step 2: The choice of linguistic estimates for evaluating criteria and alternatives – in case where criteria and alternative weights are considered to be linguistic variables. It is very common that the choice of linguistic estimates for criteria and alternatives is made by applying fuzzified Likert scale (Camparo, 2013) shown in Table 1:

Table 1: Linguistic terms for alternative evaluation

Linguistic value	Fuzzy numbers
Very high (VH)	(4.5,5,5)
High (H)	(3.5,4,4.5)
Medium (M)	(2.5,3,3.5)
Low (L)	(1.5,2,2.5)
Very low (VL)	(1,1,1)

Step 3: Determining weight coefficient of the criteria (denoted by w_j) by applying one of the multi-criteria decision making methods (most commonly by AHP, ANP, fuzzy AHP, fuzzy ANP method etc.).
Step 4: Computation of aggregated fuzzy decision making matrix based on initial decision making matrix (*X*). Aggregated values are shown in matrix *D:*

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & & \tilde{x}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{2}$$

The elements of aggregated matrix ($\tilde{x}_{ij}$) are obtained using the equation (3):

where $\tilde{x}_{ijk}$ is a value/estimate of alternative A_i according to criterion Cj, given by k^{th} expert.

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3})$$

$$x_{ij1} = \min\{x_{ijk1}\}, \; x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2} \quad x_{ij3} = \max\{x_{ijk3}\} \tag{3}$$

Step 4: Defuzzification of aggregated fuzzy decision making matrix, obtained in the previous step, and obtaining numerical values of the alternatives according to each criterion. Defuzzificated values are obtained using the equation (4):

$$x_{ij} = \frac{\left[(Ux_{ij} - Lx_{ij}) + (Mx_{ij} - Lx_{ij})\right]}{3} + Lx_{ij} \tag{4}$$

Step 5: Obtaining normalized decision making matrix (denoted by f_{ij}). The aim of criteria value normalization is to transform different criterion values (*benefit* or *cost*) into the values allowing mutual comparison.

Step 6: Obtaining weighted normalized decision making matrix (denoted by $\hat{x}_{ij}$). The values of weighted decision making matrix are obtained by multiplying the elements of normalized decision making matrix by weighted coefficients (w_j):

$$\hat{x}_{ij} = f_{ij} * w_j \tag{5}$$

Step 7: Summing up the weighted valued of the matrix by columns. The values are summed up depending on the group to which the criteria belong (*min* or *max*). The values of *max* criteria (higher value of a criterion is preferred) are obtained by equation (6), while the values of *min* criterion type (lower value of a criterion is preferred) are obtained by equation (7):

$$P_i = \sum_{j=1}^{k} \hat{x}_{ij} \tag{6}$$

$$R_i = \sum_{j=k+1}^{m} \hat{x}_{ij} \tag{7}$$

Step 8: Determining relative weights (importance) of each alternative. Using equation (8) the importance of each considered alternative from the set of the alternatives being compared is determined:

$$Q_i = P_i + \frac{R_{\min}\sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \frac{R_{\min}}{R_i}} = P_i + \frac{\sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \frac{1}{R_i}} \tag{8}$$

Step 9: Ranking of alternatives based on the value of a criterion function N_i which is allocated to each of the considered alternatives. The higher the value of a criterion function is, the better the alternative is. Final values of criterion functions are obtained using the equation (9):

$$N_i = \frac{Q_i}{Q_{\max}} * 100\% \tag{9}$$

where Q_{max} is the maximum relative importance value.

3. Evaluation Procedure

The evaluation procedure of sustainable mobility measures consists of the following phases: (1) Selection of measures to be evaluated; (2) Selection of evaluation criteria and; (3) Evaluation and ranking selected measures using the COPRAS-F method. These are further elaborated below.

3.1. Selection of Measures

Based on extensive literature on the subject, 26 measures are chosen and classified into 8 categories (Table 2) (Lopez-Ruiz et al., 2013). The first category belongs to public transport services that are an important part of sustainable planning. The measures relate to the improvement of public transport supply mainly for public transit. Cycling and information system are also included. The second category consists of measures that improve city logistics and freight distribution which is one of the major problems accross large cities. A large number of activities within freight distribution leads to the issue of optimization of the associated activities. The major problems relate to low vehicle occupancy, empty rides, limited time delivery, as well as losses in time due to load manipulation operations.

Table 2: Sustainable mobility measures

Category of measure	Measures	Id
Public transport service	Investment in promotion of performance and efficiency of public transit	A_1
	Network and frequency of service improvement	A_2
	Public transport information systems	A_3
	Integrated (interoperable) system of fares	A_4
	Alternative taxi service	A_5
	Investment in infrastructure and cycling systems	A_6
City logistics and freight distribution	Improving the efficiency of city logistics using ICT	A_7
	Freight distribution centers and points of delivery	A_8
	Improvement of energy efficiency and environmental performance of vehicles	A_9
Mobility management	Company school and personal mobility plans	A_{10}
	Carsharing i carpooling schemes	A_{11}
	Telecommuting	A_{12}
Integration of transport modes	Multimodal connection platforms	A_{13}
	Information on multimodal travel choices	A_{14}
	Park and ride areas	A_{15}
Road transport	Reserved bus and HOV lanes	A_{16}
	Parking charging and management	A_{17}
	Dynamic traffic routing	A_{18}
	Low speed zones	A_{19}
Marketing and education	Information and marketing campaigns	A_{20}
	Promotion of eco-driving	A_{21}
Acess restriction	Cordon based charging in cities	A_{22}
	Congestion charging zones	A_{23}
	Low emission zones	A_{24}
Clean technologies and alternative fuel	Investment in alternative fuel supply infrastructure	A_{25}
	Introduction of alternative fuel vehicles	A_{26}

The third category of measures includes measures of mobility management, which are considered as a key element in the development of sustainable forms of transport in the implementation of transport activities. Mobility management measures focus on behaviour change of passengers in order to achieve sustainable practices in everyday transportation activities. Very often these measures are implemented in combination with other measures. The fourth category of measures relates to the integration of transport modes while the fifth category includes the promotion of road transport operations and regulations. The next group of measures includes measures targeted at behavioral change, followed by restriction measures and pricing mechanisms.

3.2. Criteria Selection

The selection of relevant criteria has been performed on the basis of EU sustainable practices within sustainable transport projects as well as data existence (Lopez-Ruiz et al., 2013). The final five criteria are listed in Table 3. All criteria are aimed at maximizing value, which means the higher value of the criterion, the better sustainable mobility performance.

Table 3: Criteria for sustainable mobility measures evaluation

Criteria	Id	Target value
Potential reduce in CO_2 (in kilotonnes)	C_1	*max*
Possibility/rationality of short term applications	C_2	*max*
Availability for users	C_3	*max*
Change in modal split-sustainable mobility	C_4	*max*
Public acceptability	C_5	*max*

3.3. The Evaluation and Ranking of Measures Based on COPRAS-F Method

As the values of selected measures against the following criteria may not be expressed quantitatively the phasy expansion of the chosen method is applied. Accordingly, the third step of the proposed approach involves the distribution of linguistic score for each of the measures/alternatives upon each criterion. For the evaluation of the measures, decision makers, i.e., experts use linguistic expressions that are translated into triangular fuzzy numbers. Thereafter the aggregation of scores for criteria and alternatives is performed.

4. Empirical Example

The selected alternatives (Table 2) and criteria (Table 3) are used as the procedure input. For simplicity reasons the criteria are equally weighted, while the evaluation of the measures has been carried out by a single expert. Table 4 presents the linguistic score for twenty-six measures (alternative) for sustainable mobility. The evaluation of alternatives according to the criteria was done on the basis of empirical knowledge of decision-makers, using a fuzzyficated Likert scale (Table 1).

After the formation of the initial decision making matrix (Table 4) the aggregation of its elements is carried out. The elements of the aggregate matrix (Equation 2) are obtained by applying the Equation (3). Subsequent defuzzification of the aggregated decision matrix has to be carried out (Equation 4), thereafter the normalization. By multiplying the elements of the normalized matrix with the criteria weights, the weighted normalized matrix is obtained (Equation 5). In the final step the aggregation of values is conducted for all alternatives (Equations 6-9) according to a set of criteria (minimum or maximum).

Table 4: Evaluation of sustainable mobility measures

Alternatives	Linguistic assessments for the alternatives				
	C_1	C_2	C_3	C_4	C_5
A_1	M	M	H	H	M
A_2	H	H	H	H	H
A_3	M	M	M	H	H
A_4	L	H	M	L	M
A_5	M	L	L	M	M
A_6	H	L	L	M	M
A_7	H	H	M	M	M
A_8	M	M	M	L	L
A_9	M	L	M	M	M
A_{10}	M	L	H	H	M
A_{11}	L	M	H	H	H
A_{12}	VH	M	H	H	M
A_{13}	L	VL	M	H	M
A_{14}	H	M	H	M	H
A_{15}	M	L	H	H	M
A_{16}	VH	H	M	H	L
A_{17}	H	M	M	M	L
A_{18}	L	M	L	L	M
A_{19}	L	M	M	M	VL
A_{20}	M	H	VH	H	H
A_{21}	VL	H	H	M	H
A_{22}	H	H	M	H	VL
A_{23}	VH	H	M	H	VL
A_{24}	H	L	L	M	VL
A_{25}	M	L	L	VL	M
A_{26}	M	L	L	VL	M

Table 5 summarises the alternative values by criteria, the significance (impact) of each of the studied alternatives (Qi), the final criteria functions (Ni), and ranks of the alternatives. According to the final criteria functions alternative - measures for sustainable mobility are ranked.

Table 5: Results of COPRAS-F method

Alternatives	P_i	Q_i	N_i	Rank
A_1	0,233	0,233264	85,68	6
A_2	0,209	0,209088	76,80	10
A_3	0,235	0,234943	86,30	5
A_4	0,155	0,154981	56,93	21
A_5	0,176	0,176493	64,83	16
A_6	0,194	0,194235	71,35	12
A_7	0,240	0,23979	88,08	**3**
A_8	0,176	0,176284	64,75	17
A_9	0,192	0,191661	70,40	13
A_{10}	0,217	0,216658	79,58	8
A_{11}	0,195	0,195307	71,74	11
A_{12}	0,181	0,180985	66,48	15
A_{13}	0,172	0,171845	63,12	18
A_{14}	0,183	0,182952	67,20	14
A_{15}	0,164	0,164379	60,38	19
A_{16}	0,250	0,250166	91,89	**2**
A_{17}	0,139	0,138793	50,98	25
A_{18}	0,157	0,157097	57,70	20
A_{19}	0,127	0,127345	46,78	26
A_{20}	0,272	0,272246	100,00	**1**
A_{21}	0,214	0,213528	78,43	9
A_{22}	0,224	0,223501	82,10	7
A_{23}	0,239	0,238718	87,68	4
A_{24}	0,152	0,152172	55,75	22
A_{25}	0,152	0,152172	55,75	23
A_{26}	0,152	0,152172	55,75	23

The first-ranked is an alternative which has a maximum value of criterion function, which in this case is the aternative A20: information and marketing campaigns. The second is the measure A16: reserved bus and HOV lanes, while the third is the measure A7: improving the efficiency of city logistics using information and communication technologies.

Concluding Remarks

In this paper we used the COPRAS-F method to evaluate and rank 26 sustainable mobility measures implemented in the EU countries/cities. Three measures were identified as the most beneficial – information and marketing campaigns; reserved bus and HOV lanes and improving the efficiency of city logistics with ICT solutions.

The advantage of the proposed approach lies in the ability to use descriptive – linguistic data to evaluate sustainable mobility measures which cannot be evaluated quantitatively. The proposed approach and obtained results can help decision makers to decide what sustainable mobility measures to implement, taking into account the nature and importance of defined criteria for evaluation.

Still, there are a number of different criteria that can be used in the evaluation process. One of the directions for future research can be the development of a proper model for selecting an adequate set of criteria.

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