TITLE

Consensuated prioritization of enhancements for sustainable mobility in urban areas

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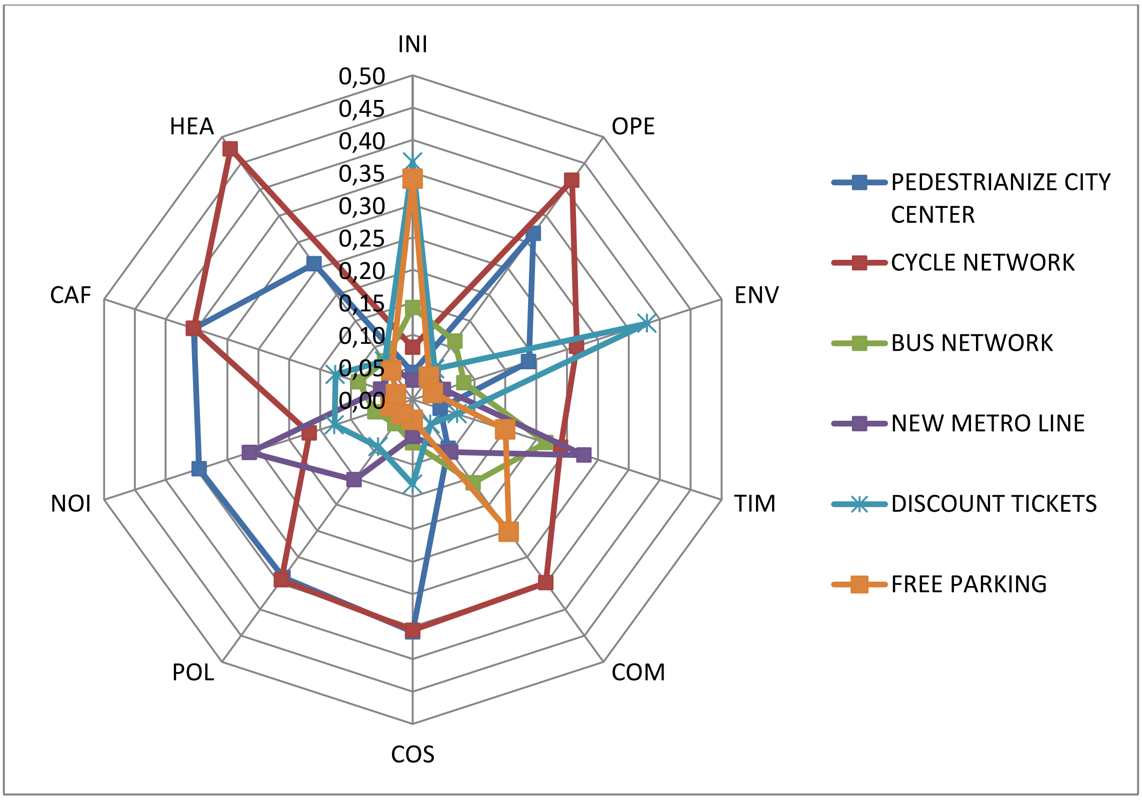
ABSTRACT

Nowadays the European cities usually present important problems at economic, social and environmental levels. The European Union has published policies to ease this issue, and several European cities are creating sustainable mobility urban plans with the measures which can be taken to improve the mobility system. Transport decisions have direct impact on transit times, urban connectivity, and have also effects in the environment, public health and society. Choosing the best enhancement to implement is a complex decision, depending on tangible and intangible criteria, which have to be taken into account together. A compromise solution that weighs travel quality, cost and sustainability inputs has to be achieved. This research work presents a decision support system to select the optimal sustainability enhancement integrating the Delphi technique with the Analytic Hierarchy Process and the VIKOR method.

GRAPHICAL ABSTRACT



HIGHLIGHTS

Select optimal strategies in achieving sustainable mobility.

Analytic Hierarchy Process combined with a Delphi technique and the VIKOR method.

Framework to achieve consensus decision-making in urban mobility.

Applying tangible and intangible criteria in sustainable urban transport.

KEYWORDS

Sustainable mobility, Transport, Multicriteria decision making, AHP, Delphi method, VIKOR technique

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research work.

CONFICTS OF INTEREST

The authors declare no conflict of interest

1. **Introduction**

During the last decades the European cities have been suffering an important transformation. They have evolved from a multifunctional compact city center to a broad physiognomy center with uses aggregated in specialized zones. This transformation has produced important problems at economic, social and environmental levels (Matthews, 2013). This new morphology increases mobility operations (Schauer, 2011). The cities have become hotspots of activities, becoming the main drivers of greenhouse gas emissions. Ground transportation is a key factor in the energy consumed, 19% of the global energy demand and 23% of the CO_2 emissions (Gosse and Clarens, 2013). Therefore, any transport enhancement is a crucial political decision as it has direct impact on urban society, changing transit times and urban connectivity. In addition, urban sprawl is not only determinant in traffic, but has also effects in the environment, public health and society (Creutzig et al., 2012). The cities grow at a frantic level (Matthews, 2013), which implies traffic-related delays in almost all of the world's urban centers, while the carbon emissions from ground transportation are growing more and more.

In this context, the European Union approved in 2007 a Green Paper on Urban Mobility 'Towards a new culture for urban mobility' (CEC, 2007). This document establishes strategies to fight these issues in five different areas that are: against congestion proposes walking and cycling and optimizing the use of private cars; against environmental issues, such as air pollutant emissions and noise suggests the use of new technologies, green procurement, and new ways of driving, also known as eco driving; for improving the efficiency of the transport system gives ideas about the use of intelligent transport systems; to enhance the accessibility to the urban transport infrastructure suggest that the collective transport meets citizen needs, the use of innovative solutions, and the coordination of land use and an integrated approach; and finally, enhancing safety and security of the transport proposing safer behavior, safer and secure infrastructures and safer vehicles. These European Directives have generated national laws. The Spanish Strategy of Sustainable Mobility (Spanish Government, 2009) establishes the most important actions to be accomplished in order to develop the transport system. This policy introduces the concept of the Sustainable Mobility Urban Plan, a tool which points out all the measures which can be developed to improve the mobility system. These mobility plans take into account all the means of transport simultaneously, considering also the sustainable component which adds the value of the triple bottom line that includes economic, social and environmental factors (Canto-Perello et al., 2015, Cunha et al., 2015).

The ground transportation means, from walking to motor vehicles, have usually been studied in isolation. Few examples of integrated multi-criteria analysis have been published (Berrittella et al., 2008). It is necessary to make an aggregate study of all the means of transport. The focus of this study is not the traffic, it is the mobility. But, mobility is a challenge with interlinked factors such as economic, technologic, social and cultural ones. As stated in the United Nations Conference on Environment and Development (UNCED, 1992), the issues should be studied in local, regional and global scales. An important element of the challenge is the need to achieve consensus among different forms of knowledge and different stakeholders from science and policy. The point of view must be multiple, considering the motor vehicles drivers as well as the public transport passengers, cyclists and pedestrians, all of them with different necessities and interests (Katoshevski, Arentze & Timmermans, 2010; Orecchini et al., 2010).

The sustainable mobility is a complex problem which has to be considered as a whole. Decisions should integrate simultaneously all the relevant stakeholders, with different interests, some of them opposed to each other, and with different criteria which have to be consensuated. Moreover, some of these criteria are tangible, such as cost and time of travel, whereas some of them are intangible, such as comfort and health. A structured decision-making procedure able to deal with tangible and intangible criteria must be developed in order to reach a consensus in selecting which project is most suitable (Martin-Utrillas et al., 2014; Vermote et al, 2014). This research work presents a decision support system to select the optimal alternative in terms of sustainable mobility. The hybrid model proposed is an integration of the Delphi technique, the Analytic Hierarchy Process (AHP) and the VIKOR method.

2. Methodology

The Delphi method is an experts' foresight process (Hsu and Sandord, 2007; Ma, et Al, 2011; Marchais-Roubelat and Roubelat, 2011). It is suitable for building consensus using a series of questionnaires. The method gathers data from a panel of selected experts as the information will be more credible than that of a single expert (Roubelat, 2011). This technique improves the efficiency of the dynamic process of the panel of experts.

The AHP method is based on paired comparison judgments of knowledgeable experts (Saaty, 2012). The goal is assessed through a hierarchical structure of several levels. The measurement of the intangibles is the key factor for choosing this method. The use of the AHP methodology in a wide variety of decision-making areas (Canto-Perello et al., 2013; Curiel-Esparza and Canto-Perello, 2013; Martin-Utrillas et al., 2015a) suggests the suitability of this method for structuring relevant knowledge concerning consensus in complex multicriteria problems (Syamsuddin and Hwang, 2010). These comparisons are used to obtain the relative priority of the different criteria in terms of sustainable mobility and to assess the alternatives. In addition, AHP analyzes the consistency of the experts' judgments.

The VIKOR method helps to obtain consensus solutions in compromised problems which involve conflicting criteria. Two parameters will be found for each of the enhancements: utility of the majority, and individual reject. These parameters will be merged in a consensus basis, obtaining the best solution according to this method. The best enhancement is the one which provides maximum utility and minimum regret. This method has been tested in different fields with good results. (Martin-Utrillas et al., 2015b; Curiel-Esparza et al., 2014).

3. First Questionnaire and decision hierarchy structure

The first step in the process is the analysis of the criteria and the mobility enhancements. An anonymous questionnaire is sent to the panel of experts, who answer it adding new alternatives or criteria they think are pertinent to the problem. This information is aggregated and resend to the experts, who reconsider their answers and the ones provided by their colleagues. The criteria and alternatives which are considered less important are removed. This feedback process defines the hierarchy structure, generated by consensus among the panelists. The panel of experts chose as the main criteria the cost of the enhancement, travel quality and sustainability. These criteria are also divided into subcriteria layered in the hierarchy, so that it is meaningful to compare them among themselves in relation to the element of the upper level (Saaty and Sagir, 2012). The criteria and subcriteria considered when determining the best solution in terms of sustainable mobility are:

- Economy (E). The amount of investment required for the implementation of the enhancement is considered as an inexcusable criterion (Martin-Utrillas et al., 2015c). Can be divided in three subcategories.
    - Initial costs (INI). The initial investment needed to develop the solution.
    - Operation (OPE). The amount of money needed to operate and maintain the solution.
    - Environmental (ENV). This subcriterion takes into account the life-cycle costs of the enhancement. Its importance has been shown before (Chester and Horvath, 2012).
- Travel quality (Q). This criterion engulfs the parameters associated with the means of transport. It is divided in three categories:
    - Time (TIM). Time is a key factor in the mobility, and can be critical to certain stakeholders. According to this criterion, the best solution is the fastest one.
    - Comfort (COM). An intangible criterion, the comfort is dependent of the traveller; it is usually associated with the quality of the travel.
    - Trip cost (COS). Another key factor is the cost of the trip for the user, because the movements are usually recurrent (repeated many times), so a small difference can

become important at the end. According to this criterion, the best solution is the cheapest one.

- Sustainability (S). Engulfs a series of inputs which are becoming more and more important in developed countries. It is divided into:

  - Pollution (POL). The pollution has been a classic vector of the environment (Armah, et al., 2010). It is a recurrent problem in nowadays cities. (Chiesa et al., 2014; Yang et al., 2015; Berrittella et al., 2008).
  - Noise (NOI). The importance of this factor is broadly considered. It is an important problem of the actual cities, heavily studied (Sheng and Wa, 2011; Urban and Vojtech, 2013), with specific Laws at European level (European Commision, 2002).
  - Carbon footprint (CAF). This factor has become more important in the last years. It indicates the impact on the environment of a certain activity (Minx et al., 2013; Creutzig et al., 2012).
  - Health (HEA). Certain means of transport have health advantages among others (De Hartog et al., 2010; Rojas Rueda et al., 2011).

The policies which achieved more consensus by the panel of experts, focused in the main transport means used in the city of Valencia (Spain) are:

- Pedestrianize the city center (WAL).
  Walking is considered the most employed mode of transportation, as well as being the cheapest and healthiest method. The AHP method has been employed before to evaluate pedestrians' level of satisfaction (Zainol et al., 2014). This solution forbids motor traffic in the center of the city, allowing only public transport, bicycle, pedestrians and freight transport. This promotion of the walkability provides a carbon-free environment, as well as achieving a more friendly landscape.

- Enhance the cycle network (BIC).
  Valencia's morphological and climatological characteristics are optimal for the bicycle displacements. The city has an even surface, with no ramps, and the climatology is mild, with very few rainy days. Each year this means of transportation increases its numbers. Several studies have been conducted related with bicycle mobility (Wahlgren and Schantz 2014; Ragettli et al., 2014). Although the cycle network is well extended in the suburban areas, there is lack of it in the city center and in the main avenues. The enhancement proposed extends the network, primary in the city center and in the main avenues, linking the suburban areas with the city center, which is the main problem of the actual network.

- Enhance the bus network (BUS).
  Bus transport plays a key role in the mobility of the cities (Huang and Liu, 2014). This solution consists in enlarging the bus fleet, with the aim of opening new lines, reducing the time lapse between buses, and providing service during the night time, especially during the weekends.

- Build a new underground line (MET).
  Underground transportation has known advantages in heavily populated cities and its relationship with sustainability has been well studied (Jackson and Holden, 2013; Gong et al, 2014). The enhancement proposed consists in finishing an uncompleted underground line which connects the south east area of Valencia with the city center.

- Subsidize public transport (DIS)
  The enhancement proposed consists in subsidizing the public transport system by making discounts in bus and metro tickets. With this enhancement the public transport will be a more attractive alternative for the citizens. Similar policies related to transport means are developing in other countries (Holtsmark and Skonhoft, 2014)

- First hour free parking in the city center (PAR)
  This enhancement proposes the bonification of the first hour of public parking for the private cars. Its intention is to reduce the number of cars badly parked occupying and collapsing the lanes of the streets.

The analysis is decomposed into a multi-level hierarchy structure shown in Fig. 1. The first level indicates the overall objective, in this case the Sustainable Mobility. The second and the third levels show the subordinate criteria and subcriteria. The fourth level indicates the Enhancements of Mobility.

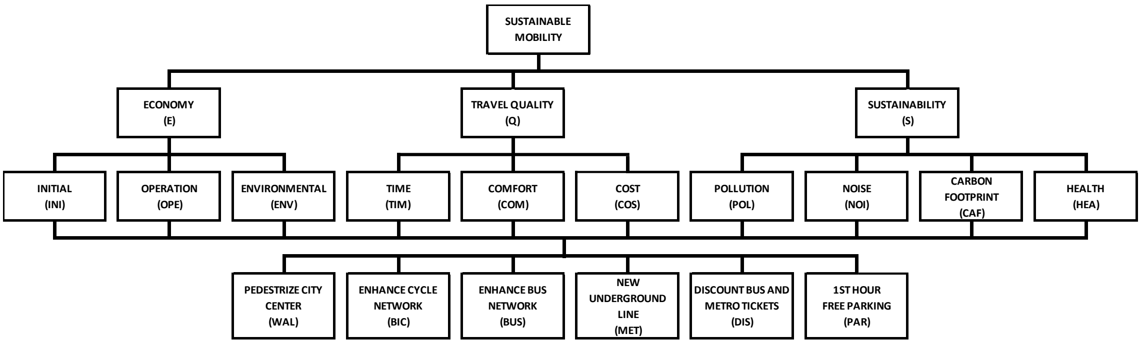


Fig. 1. Hierarchy structure for selecting enhancements for the sustainable mobility.

4. Second questionnaire and construction of pairwise comparison matrix for the criteria

Once the hierarchy structure has been defined, a second questionnaire was send to the panel of experts, who interact with anonymous comments, following the Delphi process. The decision support system acquires data from inquiries, searching for reliable and consistent information. The aim of this questionnaire is to evaluate the criteria using the AHP method. The AHP method is developed in three steps: develop the comparison matrices, calculate the priorities, and analyzing the consistency. The fundament of the AHP method is to obtain a general decision made up from smaller decision components, reducing the complexity of the problem. Only two elements are compared at the same time, by pairwise comparisons, evaluating elements in pairs against a given factor. For this purpose a 9-point scale is used. Higher values correspond with higher preference of one of the options over the other. This scale, developed by Saaty, has been effectively used in many applications (Martin-Utrillas et al., 2014), and compared theoretically with many other scales (Saaty, 2008). If the preferred criteria is the first, the value is the corresponding integer; if the preferred element is the second over the first, the value will be the one of the inverse of the integer indicated.

Each expert performs a pairwise comparison of the criteria with respect to the overall goal. The answers are transformed into values, as described above, which are then reflected in a matrix of pairwise comparisons, also called judgment matrix. The same process is repeated with the subcriteria under the terms of their corresponding criteria. Tables 1 and 2 show the second questionnaire and the answers given by the panel of experts, respectively.

Table 1. Questionnaire for evaluating the criteria (Q01-Q03) and subcriteria (Q04-Q15)

With respect to the overall goal, the sustainable mobility	
Q01	How important is **economy (E)** when it is compared to **travel quality (Q)**
Q02	How important is **economy (E)** when it is compared to **sustainability (S)**
Q03	How important is **travel quality (Q)** when it is compared to **sustainability (S)**
With respect to the criterion economy	
Q04	How important is **initial costs (INI)** when it is compared to **operation costs (OPE)**
Q05	How important is **initial costs (INI)** when it is compared to **environmental (ENV)**
Q06	How important is **operation costs (OPE)** when it is compared to **environmental (ENV)**
With respect to the criterion travel quality	
Q07	How important is **time (TIM)** when it is compared to **comfort (COM)**
Q08	How important is **time (TIM)** when it is compared to **trip cost (COS)**
Q09	How important is **comfort (COM)** when it is compared to **trip cost (COS)**
With respect to the criterion sustainability	
Q10	How important is **pollution (POL)** when it is compared to **noise (NOI)**
Q11	How important is **pollution (POL)** when it is compared to **carbon footprint (CAF)**
Q12	How important is **pollution (POL)** when it is compared to **health (HEA)**
Q13	How important is **noise (NOI)** when it is compared to **carbon footprint (CAF)**
Q14	How important is **noise (NOI)** when it is compared to **health (HEA)**

Q15	How important is **carbon footprint (CAF)** when it is compared to **health (HEA)**	

Table 2. Evaluation results of each expert using the geometric mean method.

Pairwise overall goal				**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**GM**
Q01	**E**	*vs.*	**Q**	3	1/3	5	/3	1	/5	/3	5	1/3	1/5	**0.719**
Q02	**E**	*vs.*	**S**	1/3	1/5	9	1/7	1/3	1	1/5	3	1/5	1/3	**0.508**
Q03	**Q**	*vs.*	**S**	1/5	1/3	5	1/7	1/5	5	1/3	1	1/3	3	**0.661**
Pairwise criterion Economy														
Q04	**INI**	*vs.*	**OPE**	9	1/7	1/3	1	1/5	1	1/5	1/9	3	5	**0.701**
Q05	**INI**	*vs.*	**ENV**	9	1	1/5	1/9	1/3	5	5	1	9	1/3	**1.175**
Q06	**OPE**	*vs.*	**ENV**	1	7	1/3	1/9	3	5	9	9	9	5	**2.601**
Pairwise criterion Travel Quality														
Q07	**TIM**	*vs.*	**COM**	9	9	5	1	1/3	7	5	3	3	5	**3.410**
Q08	**TIM**	*vs.*	**COS**	5	1/7	7	1/3	1/5	7	5	1/3	3	5	**1.502**
Q09	**COM**	*vs.*	**COS**	1/5	1/9	1	1/5	1/5	1/3	1/3	1/7	1/3	1/3	**0.263**
Pairwise criterion Sustainability														
Q10	**POL**	*vs.*	**NOI**	9	1/5	5	3	1/5	1/7	1/5	3	1/3	1	**0.830**
Q11	**POL**	*vs.*	**CAF**	9	9	9	9	5	1	5	1/3	5	5	**4.107**
Q12	**POL**	*vs.*	**HEA**	9	1	1	3	1/3	1/5	1/5	5	1/5	7	**1.097**
Q13	**NOI**	*vs.*	**CAF**	5	9	5	9	9	9	9	1/5	5	7	**5.028**
Q14	**NOI**	*vs.*	**HEA**	1	5	1/5	5	3	5	1	3	1/5	9	**1.823**
Q15	**CAF**	*vs.*	**HEA**	1/5	1/9	1/9	1/5	1/5	1/5	1/9	7	1/9	1/5	**0.226**

In the analytic hierarchy process (AHP), multiplicative preference relations are called judgment matrices, and are adopted to express the decision makers' preferences. In order to aggregate the panel's answers, several methods can be used. In this paper, the chosen method is the aggregation of individual judgments (AIJ). This method treats the group as a new individual using the geometric mean method (GM), because it preserves the symmetric structure of the judgment matrices. Using the geometric mean method the individual judgment matrices are aggregated into a collective judgment matrix.

Table 3. Priority vector and consistency analysis of the pairwise comparison matrix for criteria and subcriteria for the collective judgment.

	E	**Q**	**S**	**Priority Vector**
E	1.0000	0.7192	0.5079	0.2287
Q	1.3904	1.0000	0.6608	0.3110
S	1.9688	1.5133	1.0000	0.4603
λ_{max} = 3.0005, CI = 0.0002, CR = 0.0005 < 0.05 OK				
	INI	**OPE**	**ENV**	**Priority Vector**
INI	1.0000	0.7008	1.1746	0.2952
OPE	1.4269	1.0000	2.6011	0.4877
ENV	0.8513	0.3845	1.0000	0.2171
λ_{max} = 3.0215, CI = 0.0108, CR = 0.0207 < 0.05 OK				
	TIM	**COM**	**COS**	**Priority Vector**
TIM	1.0000	3.4101	1.5017	0.4907
COM	0.2933	1.0000	0.2627	0.1211
COS	0.6659	3.8060	1.0000	0.3881
λ_{max} = 3.0298, CI = 0.0149, CR = 0.0286 < 0.05 OK				

	POL	**NOI**	**CAF**	**HEA**	**Priority Vector**
POL	1.0000	0.8295	4.1075	1.0968	0.2910
NOI	1.2055	1.0000	5.0283	1.8228	0.3841
CAF	0.2435	0.1989	1.0000	0.2256	0.0679

HEA	0.9117	0.5486	4.4327	1.0000	0.2571
λ_{max} = 4.0224, CI = 0.0075, CR = 0.0084 < 0.09 OK					

5. Priority weighting of the criteria and subcriteria. Consistency ratio

Being established the matrices of the criteria and subcriteria, it is time to determine the relative priority of each of these elements. These weights are obtained by finding the principal eigenvector of the matrices, which, according to Saaty, is the priority vector (Saaty, 2012). In order to find the priority vector ω, the linear system Aω = λ ω must be solved, so det[A − λ•I] = 0 must be calculated. Once the eigenvalues of the criteria matrix and the three subcriteria matrices have been found, the criteria vector can be built. The weights of the subcriteria are multiplied by the weight of the correspondent criterion in the hierarchy.

In order to obtain suitable results in decision-making problems, the answers given by the panel of experts must be consistent. The adequacy of the assessments will be analyzed by a test of consistency. One of the main perks of the AHP method is that it allows the evaluation of the consistency of the answers by an index called consistency ratio (CR). The maximum values of the CR depend on the order of the matrix. The CR is the ratio between the consistency index (CI) and the random consistency index (RCI) as follows:

$$CR = \frac{CI}{RCI} \qquad (1)$$

The consistency index (CI) is obtained from the equation:

$$CI = \frac{\lambda_{max} - 1}{n - 1} \qquad (2)$$

Where:

- λ_{max} is the maximum eigenvalue of the matrix
- n is the order of the matrix.

If the value of the CR exceeds 0.05 for order of the matrix (3), 0.09 for order of the matrix (4) and 0.10, for order of the matrix (n) upper than four, the expert opinions may not be trustworthy, and the answers given need re-examination. Once the consistency values are within the tolerance limits, the process to determine the relative preference of the criteria is finished.

6. Third questionnaire and evaluation of mobility enhancements according to criteria and subcriteria

The weight of the criteria and subcriteria has been evaluated. Now it is time to calculate the priority of each enhancement with respect to each subcriteria. A third questionnaire is send to the panel of experts, who indicate their preference via pairwise comparisons. The same process employed to create the vector of criteria is repeated. A pairwise comparison matrix for each subcriterion is generated from the experts' answers, using the geometric mean value. The priority vector of each matrix is obtained, using the eigenvector method, and a consistency analysis is performed.

Table 4. Assessment enhancements' questionnaire for subcriterion "initial costs" (INI)

Q01	How preferred is **pedestrianize city center (WAL)** when it is compared to **cycle network (BIC)**
Q02	How preferred is **pedestrianize city center (WAL)** when it is compared to **bus network (BUS)**
Q03	How preferred is **pedestrianize city center (WAL)** when it is compared to **new underground line (MET)**
Q04	How preferred is **pedestrianize city center (WAL)** when it is compared to **discount tickets (DIS)**
Q05	How preferred is **pedestrianize city center (WAL)** when it is compared to **free parking (PAR)**
Q06	How preferred is **cycle network (BIC)** when it is compared to **bus network (BUS)**
Q07	How preferred is **cycle network (BIC)** when it is compared to **new underground line (MET)**
Q08	How preferred is **cycle network (BIC)** when it is compared to **discount tickets (DIS)**

Q09	How preferred is **cycle network (BIC)** when it is compared to **free parking (PAR)**
Q10	How preferred is **bus network (BUS)** when it is compared to **new underground line (MET)**
Q11	How preferred is **bus network (BUS)** when it is compared to **discount tickets (DIS)**
Q12	How preferred is **bus network (BUS)** when it is compared to **free parking (PAR)**
Q13	How preferred is **new underground line (MET)** when it is compared to **discount tickets (DIS)**
Q14	How preferred is **new underground line (MET)** when it is compared to **free parking (PAR)**
Q15	How preferred is **discount tickets (DIS)** when it is compared to **free parking (PAR)**

Table 5. Priority vector and consistency analysis of the judgment comparison matrix of the enhancements with respect to each of the subcriteria.

INI	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.4077	0.2071	1.9184	0.1348	0.1417	0.0417
BIC	2.4526	1.0000	0.4789	3.2402	0.1809	0.2497	0.0804
BUS	4.8287	2.0880	1.0000	6.2691	0.2497	0.2627	0.1418
MET	0.5213	0.3086	0.1595	1.0000	0.1239	0.1208	0.0299
DIS	7.4207	5.5265	4.0055	8.0702	1.0000	1.0000	0.3659
PAR	7.0569	4.0055	3.8060	8.2756	1.0000	1.0000	0.3402
λ_{max} = 6.2057, CI = 0.0411, CR = 0.0329 < 0.10 OK							
OPE	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.5774	3.8060	5.2004	5.6602	7.7403	0.3165
BIC	1.7321	1.0000	4.7050	6.3175	6.8178	7.2306	0.4173
BUS	0.2627	0.2125	1.0000	2.6468	2.1411	2.8809	0.1109
MET	0.1923	0.1583	0.3778	1.0000	0.9029	1.1746	0.0536
DIS	0.1767	0.1467	0.4670	1.1076	1.0000	1.5399	0.0581
PAR	0.1292	0.1383	0.3471	0.8513	0.6494	1.0000	0.0434
λ_{max} = 6.0784, CI = 0.0157, CR = 0.0125 < 0.10 OK							
ENV	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.5486	3.0553	4.2515	0.4915	5.0325	0.1880
BIC	1.8228	1.0000	4.0398	4.7819	0.6123	6.4783	0.2657
BUS	0.3273	0.2475	1.0000	2.2708	0.1735	3.6831	0.0834
MET	0.2352	0.2091	0.4404	1.0000	0.1348	2.1247	0.0501
DIS	2.0345	1.6332	5.7645	7.4207	1.0000	8.5588	0.3798
PAR	0.1987	0.1544	0.2715	0.4707	0.1168	1.0000	0.0329
λ_{max} = 6.1390, CI = 0.0278, CR = 0.0222 < 0.10 OK							
TIM	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.1888	0.2433	0.1692	0.5173	0.2882	0.0447
BIC	5.2962	1.0000	1.3797	0.8448	3.1598	1.3904	0.2395
BUS	4.1108	0.7248	1.0000	0.8960	3.1598	1.6747	0.2157
MET	5.9112	1.1837	1.1161	1.0000	4.2154	2.0345	0.2777
DIS	1.9332	0.3165	0.3165	0.2372	1.0000	0.4404	0.0720
PAR	3.4700	0.7192	0.5971	0.4915	2.2708	1.0000	0.1503
λ_{max} = 6.0339, CI = 0.0068, CR = 0.0054 < 0.10 OK							
COM	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.2372	0.6170	1.0077	2.3485	0.3086	0.0931
BIC	4.2154	1.0000	2.3126	3.2154	5.7156	1.6332	0.3493
BUS	1.6207	0.4324	1.0000	1.8089	3.6519	0.5818	0.1588
MET	0.9923	0.3110	0.5528	1.0000	2.2533	0.4438	0.1003
DIS	0.4258	0.1750	0.2738	0.4438	1.0000	0.1823	0.0466
PAR	3.2402	0.6123	1.7188	2.2533	5.4842	1.0000	0.2520
λ_{max} = 6.0391, CI = 0.0078, CR = 0.0063 < 0.10 OK							
COS	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	1.0000	5.8659	6.4889	3.3511	8.4862	0.3581
BIC	1.0000	1.0000	5.6718	6.0666	3.5267	8.4862	0.3557
BUS	0.1705	0.1763	1.0000	1.3904	0.4152	2.6673	0.0670
MET	0.1541	0.1648	0.7192	1.0000	0.3749	2.5344	0.0571
DIS	0.2984	0.2835	2.4082	2.6673	1.0000	4.5882	0.1307

PAR	0.1178	0.1178	0.3749	0.3946	0.2180	1.0000	0.0315

λ_{max} = 6.0948, CI = 0.0190, CR = 0.0152 < 0.10 OK

POL	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	1.0000	6.4889	4.2154	3.3511	8.4862	0.3391
BIC	1.0000	1.0000	6.0666	4.4364	3.5267	8.4862	0.3438
BUS	0.1541	0.1648	1.0000	0.1903	0.4152	2.6673	0.0463
MET	0.2372	0.2254	5.2556	1.0000	3.2402	4.6689	0.1528
DIS	0.2984	0.2835	2.4082	0.3086	1.0000	4.5882	0.0901
PAR	0.1178	0.1178	0.3749	0.2142	0.2180	1.0000	0.0279

λ_{max} = 6.3992, CI = 0.0798, CR = 0.0639 < 0.10 OK

NOI	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	2.5150	6.4889	1.0000	3.3511	8.4862	0.3458
BIC	0.3976	1.0000	2.5344	1.1161	1.0000	4.5089	0.1672
BUS	0.1541	0.3946	1.0000	0.1989	0.4152	2.6673	0.0610
MET	1.0000	0.8960	5.0283	1.0000	3.2402	4.6689	0.2639
DIS	0.2984	1.0000	2.4082	0.3086	1.0000	4.5882	0.1266
PAR	0.1178	0.2218	0.3749	0.2142	0.2180	1.0000	0.0354

λ_{max} = 6.221, CI = 0.0442, CR = 0.0354 < 0.10 OK

CAF	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	1.0000	4.7858	6.4889	4.2154	8.7766	0.3545
BIC	1.0000	1.0000	4.7452	6.0666	4.4364	8.7766	0.3549
BUS	0.2090	0.2107	1.0000	2.5150	0.4915	4.5882	0.0876
MET	0.1541	0.1648	0.3976	1.0000	0.2857	3.2972	0.0515
DIS	0.2372	0.2254	2.0345	3.4997	1.0000	5.1648	0.1251
PAR	0.1139	0.1139	0.2180	0.3033	0.1936	1.0000	0.0265

λ_{max} = 6.2771, CI = 0.0554, CR = 0.0443 < 0.10 OK

HEA	**WAL**	**BIC**	**BUS**	**MET**	**DIS**	**PAR**	**Priority Vector**
WAL	1.0000	0.3845	3.9363	4.3597	3.9363	4.8660	0.2584
BIC	2.6011	1.0000	6.2640	6.7600	6.2640	7.1143	0.4775
BUS	0.2540	0.1596	1.0000	1.2457	1.0000	1.3904	0.0734
MET	0.2294	0.1479	0.8027	1.0000	0.8027	1.1161	0.0616
DIS	0.2540	0.1596	1.0000	1.2457	1.0000	1.3904	0.0734
PAR	0.2055	0.1406	0.7192	0.8960	0.7192	1.0000	0.0558

λ_{max} = 6.0354, CI = 0.0071, CR = 0.0057 < 0.10 OK

The last step in the process is to obtain overall priorities. With the priority vectors obtained above, a matrix of priority vectors of enhancements is constructed, as shown in Table 6.

Table 6. Matrix of priority vectors (decision matrix)

	INI	**OPE**	**ENV**	**TIM**	**COM**	**COS**	**POL**	**NOI**	**CAF**	**HEA**
WAL	0.0417	0.3165	0.1880	0.0447	0.0931	0.3581	0.3391	0.3458	0.3545	0.2584
BIC	0.0804	0.4173	0.2657	0.2395	0.3493	0.3557	0.3438	0.1672	0.3549	0.4775
BUS	0.1418	0.1109	0.0834	0.2157	0.1588	0.0670	0.0463	0.0610	0.0876	0.0734
MET	0.0299	0.0536	0.0501	0.2777	0.1003	0.0571	0.1528	0.2639	0.0515	0.0616
DIS	0.3659	0.0581	0.3798	0.0720	0.0466	0.1307	0.0901	0.1266	0.1251	0.0734
PAR	0.3402	0.0434	0.0329	0.1503	0.2520	0.0315	0.0279	0.0354	0.0265	0.0558

7. Stability analysis using VIKOR method

In order to study the resilience of the solution a VIKOR analysis is performed. The VIKOR method classifies the solutions, measuring the closeness of the enhancements with the ideal solution (Opricovic and Tzeng, 2007; Opricovic, 2009). With this method a compromise solution can be found and the stability of the decision can be measured. The method sorts the enhancements by the values of Q_i, calculated from the matrix of the priority vectors. For each subcriterion, the values of f_j^* and f_j^- are obtained. These values are the maximum and the minimum values obtained by the enhancements, and correspond with the best and the worst performance for the given subcriterion as follows:

$$f_j^* = max_i\{x_{ij}\} \quad (3)$$

$$f_j^- = min_i\{x_{ij}\} \quad (4)$$

The values of f_j^* and f_j^- are obtained from the values of Table 7. The best enhancement is obtained using the compromise ranking method. The method measures concordance, with the parameter S, group utility of the majority, and also measures disagreement, with the parameter R, disapproval of the opponent. The values S_i and R_i are given by the following equations:

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (5)$$

$$R_i = max_j \left[w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \right] \quad (6)$$

Where w_j is the priority of each subcriterion.

And finally, the value of Q_i is given by the equation:

$$Q_i = \upsilon \frac{S_i - S^*}{S^- - S^*} + (1 - \upsilon) \frac{R_i - R^*}{R^- - R^*} \quad (7)$$

where,

$S^* = \min_i S_i$

$S^- = \max_i S_i$

$R^* = \min_i R_i$

$R^- = \max_i R_i$

The parameter υ is the weight of the largest group's utility value. The parameters S_i, R_i and Q_i are calculated considering the consensus value of υ is 0.5. These values are shown in Table 7. The mobility enhancements are ranked by their values of the parameters S, R and Q in ascending order. The best mobility enhancement is the one with the lower value of Q, which is the compromise solution. The enhancements are ranked in Table 8. In addition, this solution satisfies the following two conditions:

Condition 1. Acceptable advantage. The compromise enhancement BIC has a significant distance from the second ranked MET.

$$Q_2 - Q_1 \geq \Delta Q \quad (8)$$

$$\Delta Q = 1/(J - 1) \quad (9)$$

Where J is the number of enhancements evaluated

Condition 2. Acceptable stability. The compromise enhancement BIC is the best ranked in the S and R parameters.

Table 7. S_i, R_i, and Q_i values (υ =0.5) for each mobility enhancement

	WAL	**BIC**	**BUS**	**MET**	**DIS**	**PAR**
S_i	0.3707	0.2013	0.7779	0.6386	0.7312	0.8430
R_i	0.1526	0.1017	0.1622	0.1167	0.1347	0.1768
Q_i	0.4709	0.0000	0.8520	0.4406	0.6328	1.0000

Table 8. Mobility enhancements ranking obtained from VIKOR method

Position	**1**	**2**	**3**	**4**	**5**	**6**
S_i	BIC	WAL	MET	DIS	BUS	PAR
R_i	BIC	MET	DIS	WAL	BUS	PAR
Q_i	BIC	MET	WAL	DIS	BUS	PAR

8. Conclusions

Transport policies play a key role in the development of cities. They have direct impact in the way of life of millions of people and on the surrounding environment. The selection of the best environmental policies has to take into account various stakeholders with different tangible and intangible criteria. Hence, a structured decision-making procedure able to deal with tangible and intangible criteria acquires special relevance. The decision support system applied in this research work is a hybrid model integrating the Delphi technique, the AHP and the VIKOR method. The interaction between the experts is achieved by means of the Delphi method. The automatization of the process, using the anonymous questionnaires is a key factor in order to reach the needed consensus, achieving the conclusions by means of collective work. In our case the mobility cannot be dissociated from sustainability, and therefore the evaluation criteria have to take into account the triple bottom line.

The hierarchy structure of the criteria and subcriteria has been designed by the experts' anonymous answers. This methodology depends on the importance given to each criterion by the panelists. In this case, the most important subcriteria, according to the answers given, are noise, time and pollution, followed by trip costs, health and operation costs as shown in Fig. 2. Among the economic subcriteria, the most relevant, according to the expert, is the operation costs. It outweighs the initial costs, as well as the environmental costs. Among travel quality subcriteria, the two best ranked are time and trip cost, followed at some distance by the comfort criterion. Time is a fundamental concept of the mobility, so it is no surprise the importance given to this criterion. Comfort is relegated to the last place of the travel quality criteria. Among sustainability subcriteria, the most relevant are noise and pollution.

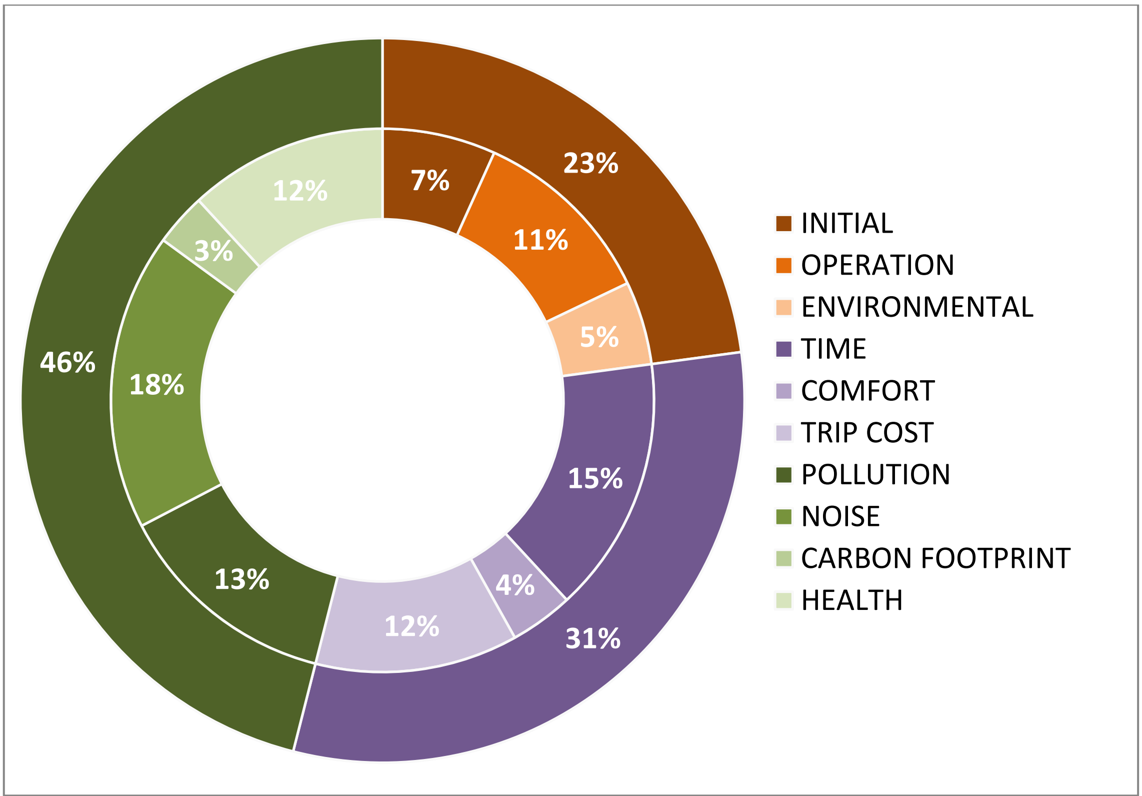


Fig. 2. Weights of each criteria and subcriteria

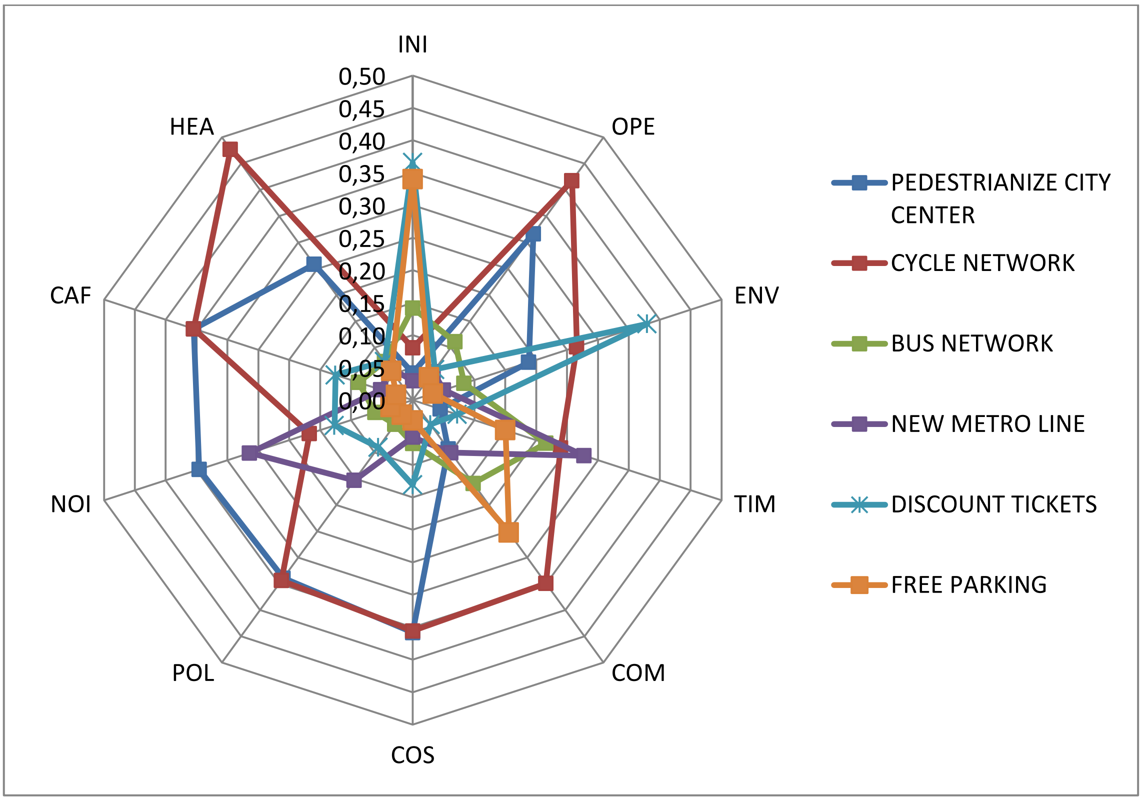


Fig. 3. Weights of each enhancement sorted by subcriteria

The answers of the third questionnaire sent to the panel of experts are embedded in the decision matrix. This matrix gathers the priority of each enhancement with respect to each subcriteria. The graphic presentation of the matrix, shown in Fig. 3, is a powerful tool to compare the enhancements, and to understand the final results of the model. Finally, a VIKOR analysis has been applied to guarantee consensus and stability. The best solution according to the hybrid model is the enhancement of the cycle network. Inspecting the graphic, this enhancement scores the best results in several subcriteria. It is also a very equilibrate solution, because only scores low results in the initial costs. This enhancement is ranked first in the parameter S, utility of the majority, and also in the parameter R, individual reject. The second ranked is the enhancement related to underground transportation. This solution is not so equilibrate as the previous one. It scores well in relevant subcriteria such as time, noise, pollution, but fails in operation costs, travel cost and health. The third in the rank is the pedestrianisation of the center of Valencia. The results are similar as the obtained by the cycle network enhancement, and the pedestrianisation is the second ranked in the parameter S. But, this enhancement is heavily penalized by the time subcriterion. The fourth enhancement is the subsidy of the public transport. This policy scores average results in most of the subcriteria. It has good marks in initial and environmental costs, but these are secondary subcriteria. Its balance allows it to be ranked number 3 in parameter R. The fifth policy is the enhancement of the bus network, with similar results to the previous solution. This solution is heavily penalized by the bad results in the sustainable subcriteria (pollution, noise, carbon footprint and health). The last enhancement is the free public parking for the first hour. It only obtains good marks in secondary subcriteria (initial costs and comfort). As shown, the proposed decision support system establishes a framework which solves mobility decision-making problems in a systematic way, and helps in selecting the optimal policies to achieve sustainable mobility.

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