

Selection of the best solution in parking infrastructure projects with conflicting criteria from different stakeholders

Selección de la mejor alternativa en proyectos de infraestructuras de aparcamientos con criterios en conflicto de diferentes grupos de interés

B. Muñoz-Medina (*), M. G. Romana (*), J. Ordóñez (**)

ABSTRACT

The paper analyses multicriteria decision making methods as tool that enable both public and private developers and designers to determine the most appropriate alternative(s) in cases where there is uncertainty and economic, social, sustainable and functional criteria in conflict. For this, the paper analyses how the successive application of these methods may help to determine the best solution in parking infrastructure projects and to minimize the subjectivity of the decision makers. The significant criteria in the decision process, and the possible alternatives in terms of locations and typology are analyzed. For the analysis to be complete, all the stakeholders involved in the project must be included, including users because its importance. The proposed methodology covers all this features and includes user perception (user's utility value) expressed in economic terms, criterion had not been included in previous research regarding the selection of alternatives for parking projects.

Keywords: Infraestructure project, parking, multicriteria decision making (MCDM), VIKOR method, AHP method, sensitivity analysis, stakeholders, selection of alternatives.

RESUMEN

El artículo analiza los métodos de decisión multicriterio como herramienta que permite a promotores, públicos o privados, y proyectistas determinar la(s) alternativa(s) más adecuadas en condiciones de incertidumbre y con criterios económicos, sociales, de sostenibilidad y funcionales en conflicto. La aplicación de estos métodos de manera secuencial puede ayudar a determinar la mejor solución y a minimizar la subjetividad del decisor. Se analizan los criterios determinantes en el proceso de decisión y diferentes ubicaciones y tipologías como alternativas. Para que el análisis sea completo, se deben incluir todas las partes interesadas participantes en el proyecto, incluyendo, por su importancia, a los usuarios. La metodología propuesta reúne estas características e incluye como criterio, la percepción del usuario (el valor de utilidad para el usuario), expresado en términos económicos, no incluido en investigaciones previas de selección de alternativas en aparcamientos.

Palabras clave: Proyecto de infraestructuras, aparcamiento, métodos de decisión multicriterio, método VIKOR, método AHP, análisis de sensibilidad, grupos de interés, selección de alternativas.

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Cómo citar este artículo/Citation: Muñoz-Medina, B.; Romana, M. G.; Ordóñez, J. (2019). Selection of the best solution in parking infrastructure projects with conflicting criteria from different stakeholders. *Informes de la Construcción*, 71(556): e312. <https://doi.org/10.3989/ic.63809>.

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Recibido/Received: 09/03/2018
Aceptado/Accepted: 30/01/2019
Publicado on-line/Published on-line: 02/12/2019

1. INTRODUCTION

It is necessary for society and public policies to increase the integration of mobility planning in our cities with economic growth and sustainable development policies, and, it is essential to include in this a more rational and efficient use of vehicles. Within the concept of sustainability is sustainable mobility which can be defined as a transport system that enables movement of people and goods to be carried out under the best conditions at a functional level (this includes travel time, punctuality, comfort, security etc.) and with a more rational use of resources (energy, space etc.) and limited environmental impact (reduction of emissions derived from energy consumptions) (1). Todd Litman says the average vehicle is parked for up to 23 hours and uses several parking locations every week. Parking areas are an essential component of a transport system and are also costly (2). The problems with planning of parking spaces are seen in the most common problems faced by designers, operators, city planners and public developers. These problems often come from the limited supply of available parking spaces to which more should be provided, or these problems are from management of these spaces as available facilities are used in an inefficient manner and should be managed better (2).

The planning of parking is a very significant part of urban transport planning systems and for the sustainable development of cities, at both a local and strategic level. Parking policy may be an appropriate strategy to address congestion problems (3). The policy and supply of parking plays an important role in the management of transport systems in urban and densely populated areas (4). However, parking policies have not received as much attention as have other aspects of transport planning, (5). It is noted that there are studies on parking scheme management and analysis of demand and how price influences the behaviour of users. However, detailed studies have not been carried out to show how a public developer may select the best alternative in locating and defining the typology of parking by considering the economic, functional, social and environmental criteria. This is because it is very important to optimise the financial resources of municipal public budgets.

There is scarce space available in city centres due to large concentrations of commercial centres and high population demographic per square. In Europe, parking space is normally regulated by the area known as the blue zone in which parking space and maximum parking time are dictated. The alternative are public car parks which are regulated by the price and can be in the form of structured parking, underground parking or surface parking (6).

It is common practice to study the economic or environmental indicators—taking into account that there is a great variety of models for economical and environmental assessments, such as Cost-Benefit Analysis, Economic-Impact Analysis and models based on the emission and use of raw materials and energy, amongst others—, in order to assess different options in an infrastructure project, both during the design part and during the management part (7). Also, several authors highlight the need to incorporate the social dimension for selection of alternatives for infrastructures projects, (8), (9), (10). The suggested methodology covers all this and studies other criteria that sometimes also have a major role in the

decision-making process, such as perception of the user or utility value to the user.

2. MULTI-CRITERIA DECISION MAKING

The analysis being made is focused in discrete multiple-criteria decision making methods, in which there are a finite number of criteria and of alternatives (11). In a decision-making problem there are always several elements: Decision criteria $C = \{C_1, C_2, \dots, C_n\}$, conditions which allow us to differentiate alternatives and to establish the preferences of the decision-maker; Weight or measurements of the importance of the criteria for the decision-maker, being each criteria vector associated to a weight vector $[w] = (w_1, \dots, w_n)$, weight can be established by direct allocation methods or by the eigenvector method; Alternatives, different solutions to be adopted in a decision-making problem, which are assigned as, $A = \{A_1, A_2, \dots, A_m\}$ ($i=1, 2, \dots, m$) are the possible alternatives; And last, the assessment or decision matrix, by which, for all of the criteria taken into account and for each alternative of the choice ensemble, the decision-maker is able to give a numeric or symbolic a_{ij} value that expresses an assessment or opinion of the alternative A_i regarding criteria C_j (12). The construction of the decision matrix is the most essential element in any decision making problem, and it is the element on which all the decision making methods are based on, from the most simple ones to the most complex ones (13).

The use of decision making methods for resolving Engineering problems, constitutes a very efficient tool for reducing the subjectivity and systematizing the decision-making process. Multicriteria Decision Making Methods (MCDM) are frequently used for selection alternatives of engineering projects, including parking projects, (14), (15), (16), (17).

Also, they can be used in different stages of the process, in order to decide the importance of the criteria for each alternative or in order to select the most fitting alternative (18). In spite of all these important benefits, we must not forget that they also have limitations and that this process has a subjective element and is influenced by the decision-maker's preferences (19). To reduce subjectivity it is recommended to not use direct allocation methods to measure the criteria but instead indirect methods like the eigenvector method of weights. In this method the weights related to each of the criteria are the components for the eigenvector related to the dominant eigenvalue of a paired comparison matrix between the criteria. The methodology developed in this article applies this method of weight allocation to the Analytical Hierarchy Process method (AHP). There are other methods of weight allocation that are indirect and which include, amongst others, the Simos method and the centralized weights method (20).

Two main groups or families can be distinguished in Multicriteria Decision Making Analysis. One of these groups is based on methods from Multi-attribute Utility Theory (MAUT) which is derived from the American School and the other method is called Outranking and is derived from the European School (known until recently as the Franco-Belgian School). It should be noted that in 1983 Despoint et al. had already recorded at least one hundred different techniques of decision making (21).

In the MAUT methods the different criteria are added to one function so that a decision making problem can be mod-

elled on real assessed functions that may be maximised or minimised for different (12). The Analytical Hierarchy Process method (or the AHP method) falls within the MAUT method and was developed in the seventies of the twentieth century by the mathematician Thomas L. Saaty (22). The methods of multicriteria decision making (grouped under the common name of Outranking Methods) are all those that revolve around the theoretical concept of overcoming relationship, as put forward by a group of French researchers (11) in the mid sixties and which concepts are nowadays widely accepted in the world of Discrete Multicriteria Decision making which is used when there is a limited range of solutions to a decision making problem (12). These methods can frequently be found under the name of the ‘European School of Multicriteria decision making’. The most well-known of these methods are ELECTRE (23) y PROMETHEE (24), However there are other methods that can be considered like Outranking methods as these provide a ranking of alternatives which are better classified as TOPSIS (25), (26), VIKOR (27), (13), and others (28), these are listed below as this is the method applied to the case study in this article.

2.1. Steps of the decision making process

The first priority in a decision making process is to know who should make the decision and who are those affected by the decision i.e. the stakeholders. This limits disagreement over definition of the problem, requirements, objectives and criteria (29). In the table 1, the steps of the decision making process are described (29)

2.2. Multi-criteria decision making methods

A methodology for resolving the problem has been set out of selection of the best alternative, combining two multiple-criteria decision-making methods, the Analytic Hierarchy Process (AHP) and the VIKOR method, this last is focused on trying to find the solution that is closest to

the optimal solution (13). A decision process using a hybrid MCDM makes it possible to optimize the process and *facilitates establishing* preferences between the criteria (30), (31).

By the Analytic Hierarchy Process (AHP) the weight eigenvector is calculated for the criteria that determines which is the most ideal solution, by making a paired comparison of them for each project (32), (33), (34). It must be taken into account that the weight eigenvector is not the same for each project, since certain criteria may have a bigger importance in comparison to the others, depending on the characteristics of the project. It is necessary remember that AHP measures the global inconsistency of the views by the Consistency Proportion, calculated by dividing the Consistency Index and the Random Index, and it should be of less than 10%. The Consistency Index measures the consistency of the comparison matrix (22).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad [1]$$

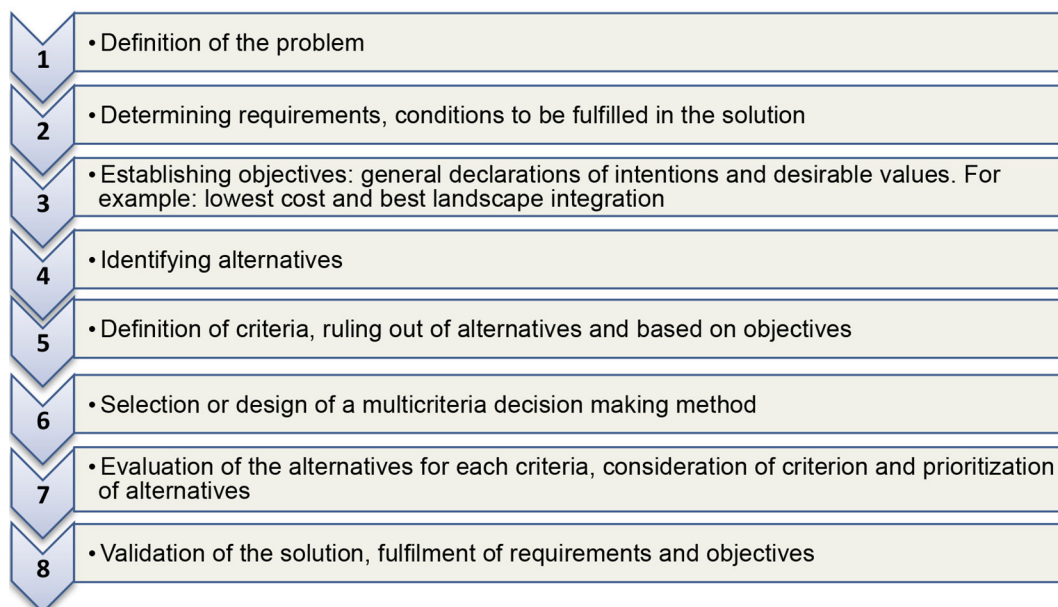
Where, λ_{max} is the biggest value of the transposed matrix of the paired comparison matrix, and n is the matrix range. The Random Index is an index which measures a random matrix according to the matrix range (see Table 2) (22).

Table 2. Random Index.

Matrix range	2	3	4	5	6	7	8	9	10
Random Index	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

This allows an acceptable level of confidence in that the decision making process has been carried out correctly. On the other hand, through AHP we can establish the ‘behaviour’ of each alternative for each of the qualitative criteria that are part of the decision making processes, with the

Table 1. Steps or stages of the decision making process. Source: Guidebook to Decision-Making Methods, Department of Energy USA. (Baker et al., 2001).



purpose of obtaining a quantitative assessment for qualitative criteria.

Later the VIKOR method will be applied for selecting the most suitable alternative, based on a classification list of alternatives that shall provide us with one or more compromise solutions. The VIKOR method is suitable for solving decision making problems with conflicted and non-commensurable criteria (which means, with different units) or when there is quantitative and qualitative criteria. The compromise solution shall be the one closest to the optimal solution (27), (35).

In order to obtain the compromise solution (or solutions), we shall follow the next steps:

1. We calculate the best, f_i^* , and the worst, f_i^- , values for each criteria:
 $f_i^* = \max_j f_{ij}$; $f_i^- = \min_j f_{ij}$; If function i represents a benefit.
 $f_i^* = \min_j f_{ij}$; $f_i^- = \max_j f_{ij}$; If function i represents a cost.

2. Values S_j , R_j and Q_j are calculated for each alternative:

$$S_j = \sum_{i=1}^n w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \quad [2]$$

$$R_j = \max_i [w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)] \quad [3]$$

$$Q_j = v(S_j - S^*) / (S^- - S^*) + (1 - v)(R_j - R^*) / (R^- - R^*) \quad [4]$$

Where:

$S^* = \min_j S_j$; $S^- = \max_j S_j$; $R^* = \min_j R_j$; $R^- = \max_j R_j$, v and ν is introduced as the weight of the most useful group strategy, where as $(1 - \nu)$, shall be the weight of the individual opposition. In this article we will use the value $\nu = 0,5$, which equals a “consensus” status [20].

3. We organize the alternatives based on values S , R and Q , in descending order. The results will be three classification lists.
4. We identify as compromise solutions the alternative $A(1)$, which is the best ranked based on the value of Q , which means with minimum Q value, if the two following requirements are met:

- a) Requirement 1: Acceptable advantage.
 $Q(A(2)) - Q(A(1)) \geq DQ$, where, $A(2)$ is the second alternative according to the value classification of Q , and $DQ=1/(J-1)$, where J represents the number of alternatives.
- b) Requirement 2: Acceptable stability in the decision-making process.
 Alternative $A(1)$ shall also be the best ranked according to the list of values of S and/or R . This compromise solution is stable within a decision making process.

If one of the requirements is not met, we suggest an ensemble of compromise solutions, which can consist on:

- Alternatives $A(1)$ and $A(2)$ if condition 2 is not met.
- Alternatives $A(1)$, $A(2)$, ... $A(M)$, if condition 1 is not met; $A(M)$ will be established taking into account the

relation $Q(A(M)) - Q(A(1)) < DQ$. These alternatives are considered to be within the ‘closeness’ of the optimal solution.

The VIKOR method is an efficient tool to use as a multiple-criteria decision-making method when the decision-maker is not able to, or doesn't know how to, express their preferences at the beginning of the design process. The obtained compromise-solution may be approved by the decision-maker, given that it provides the biggest group usefulness to the majority, represented by the minimum ‘S’, and an individual minimum opposition represented by the minimum ‘R’ (27).

3. ALTERNATIVES AND CRITERIA OF PARKING SELECTION

In order to determine the best alternative(s) in parking selection, it is necessary to first define the alternatives and criteria or determined attributes in the decision making process. For this reason, it is necessary to first ascertain the desired objective, and to establish that this may be different according to each actor or party involved in the decision making process. For one thing it is necessary to consider the benefits and objectives of the future consumers who need be considered in the decision making process. In order to determine an adequate parking policy as part of the strategy to improve congestion, it is necessary to find out the needs and decisions of motorists (3).

This involves finding the best alternative by considering the economic, functional, sustainable and social criteria. Amongst other things It is necessary to consider the following: the population of the area where parking is wanted (this is for residents and non-residents alike) (36) cost of construction, costs of the land, size of the plot, distance to main roads, distance to entertainment facilities or tourist areas, distance to commercial areas, number or area of local businesses in the surrounding vicinity, number or area of offices, number or area of parking available in the surrounding vicinity (in regulated housing estates and in the public domain), distance to administrative centres and average distance to transport. In some cases, distance to public places (distance from commercial, health, tourism, service, and administrative centers) is the most important criteria in view of the experts, (37). It is also necessary to evaluate the different alternatives according to the criteria of user's perception or utility value to the user. This research considers this perceived value to be the relationship between what the user is willing to pay and the time saved in looking for a parking space with a tariff. It is a relationship in economic terms in which the evaluation is what the user is willing to pay depending on the availability of parking; the time in which it is has taken to park and the time that is needed to arrive at the final destination (these concepts of time can be expressed in economic terms) (3), (38), (39).

In every case study, the determined criteria in the process of decision making will be different but it is almost always shared amongst multiple parties. Therefore, in the evaluation of alternatives sometimes it is necessary for the decision making process to include the zero alternative or the alternative of not doing anything. In the case of this occurring it would be necessary to consider the environmental criteria as congestion problems may arise from scarce supply of parking in relation to its demand and as such the following may occur: higher fuel consumption, inconvenience from traffic noise, CO2 emissions etc. (40).

Table 3. Types of parking facilities. Source: Parking Management Comprehensive Implementation Guide. Todd Litman Victoria Transport Policy Institute.

Type	Cost and Density	Role
On-Street (or Curb) Designated parking spaces located within a road right-of-way, usually in the curb lane	Moderate construction costs and high density (relatively little land used per space) because they require no driveway.	Convenient to use, and can serve multiple destinations. On-street parking should be managed for maximum efficiency.
Surface Parking A parking lot directly on the ground (either paved or unpaved).	Low to moderate construction costs. Low density (they require lots of land per space, including driveways and circulation lanes).	Inefficient if they serve a single destination. Should be minimized and managed for efficiency.
Structured or Underground Any multi-story parking structure (often called a parking garage, parkade or ramp), including parking facilities within or under a building.	High construction costs but relatively low land costs and high densities.	Supports compact development but must be efficiently managed to justify their high construction costs.
Priced (or Metered) Any parking facility where motorists are charged directly for use, including on-street metered parking, and off-street lots where motorists pay by the hour, day, week, month or year.	Varies. Can be applied to any type of parking structure.	Pricing, particularly congestion pricing (fees are higher at times and places with high demand) tends to encourage efficient use of parking facilities.
Commercial Parking A for-profit parking lot available to any motorist and serves multiple destinations	Varies. Can be applied to any type of parking structure.	Tends to be efficient because it is priced and usually serves multiple destinations.

In addition to different possible parking locations, it is also necessary to consider different parking typologies as an alternative like a constructive approach of parking management. These typologies are described in Table 3, (2).

4. CASE STUDY

The methodology of decision making will be applied to a selection of three alternatives of parking typology and different locations in the city of Córdoba, Spain. Córdoba is a city situated in Andalucía in the South of Spain and has a renowned patrimonial and cultural heritage. Its strategic location near the river Guadalquivir (previously navigable) and its inheritance of towns settled on rich earth, has meant that the city has come to be located in a privileged area. In 1994 UNESCO recognized the universal importance of the historical worth of Córdoba by extending the city's title of World Heritage Site from only the site of the Cathedral Mosque to include all the urban area that surrounds it. In 2016, Córdoba had a population of 326,609 inhabitants and in the same year received 991,100 tourists according to data facilitated by the Spanish Government's National Institute of Statistics (41).

In a city that has neighborhoods with protected status and a high level of pedestrian street in the historic centre, there are significant problems in accessibility and traffic congestion. Like in other cities, over time Córdoba has evolved into a sparse city in terms of its land space and is governed by market impulses for housing developments, availability of facilities, industrial quarters, residential areas and second homes in the outskirts. As in other cities, the growth in Córdoba's outskirts has not always coincided with the installation of operating services and necessary public facilities which means that the population remains dispersed and reliant on private vehicle travel (42).

As a result, in the Action Plan of Sustainable Mobility in the city of Córdoba (April 2011), the problem of parking is indicated in the historical district and its peripheral area (42). In the historical district there are different types of parking used for different purposes such as private residents parking, blue

zone regulated parking and loading bays. On the other hand, in the urban centre periphery the installation of regulated parking areas or blue zones are insufficient for the appropriate management of parking and therefore it is necessary to limit traffic and manage mobility better.

The following locations and type of parking alternatives are proposed in response to the situation described above, (43), (44), in order to determine the classification of best-ranked solutions as a consequence of the decision making process.

Alternative 1: Underground parking on Gran Vía Park Avenue on the corner adjoining Manolete Avenue. The car park is built on a plot of land with a surface area of 5,494.39 m² and this terrain is classified as urban ground and is assigned for public parking in the Urban Planning Scheme (45). The car park consists of one floor on top of an open-landscaped slope and two floors for parking below this. The total area of car park is 7,371.45 m². As the total area of the car park is more than 6,000 m² it needs to contain two bidirectional accesses to different streets.

Alternative 2: Surface parking on Gran Vía Park Avenue on the corner adjoining Manolete Avenue. This is to be in the same location and same conditions as Alternative 1 but instead is to be built for surface parking. In this case the total area of parking is 5,494.39 m², which is less than 6,000 m² and so it offers one bidirectional access point from Manolete Avenue.

Alternative 3: Surface parking on Pintor Racionero Road. The parking space is built on land with an area of 5,078.65 m². This land is classified as Urban Land Use (45). A series of archaeological digs that resulted in the appearance of important remains impedes the execution of any type of building below ground. The car park offers bidirectional access.

In all cases the following premises must be respected: minimal possible alteration of current road management and optimization of the surface space for each vehicle.

The present article discusses the theoretical selection process between these three alternatives as a specific case of prior-

itization of investment in infrastructures to reduce financial budgets. In the figure 1 map of the location of the different alternatives is represented.

Furthermore, it is necessary to define the criteria or attributes considered to evaluate the different alternatives. The criteria are categorized into 4 major groups: social, economic, functional and sustainable. Table 4 includes criteria to be considered in the decision making process.

To evaluate the different alternatives in respect to the criteria indicated, the following database and documents have been

used: The Database of the National Institute of Statistics (Ministry of Economy, Government of Spain) (46), Registration Data from the Municipality of Córdoba, (47), Database from the Mobility Area of the Town Council of Córdoba (48) and Action Plan of Sustainable Mobility in the city of Córdoba (42). The data obtained of the surrounding area’s population has been presented in figures 2 and 3. However, the evaluation of different alternatives in the environmental criteria, qualitative criteria, has been obtained through the AHP method and paired comparisons of the behaviour of different alternatives in respect to this criteria. In such a way, the results indicated below were obtained.

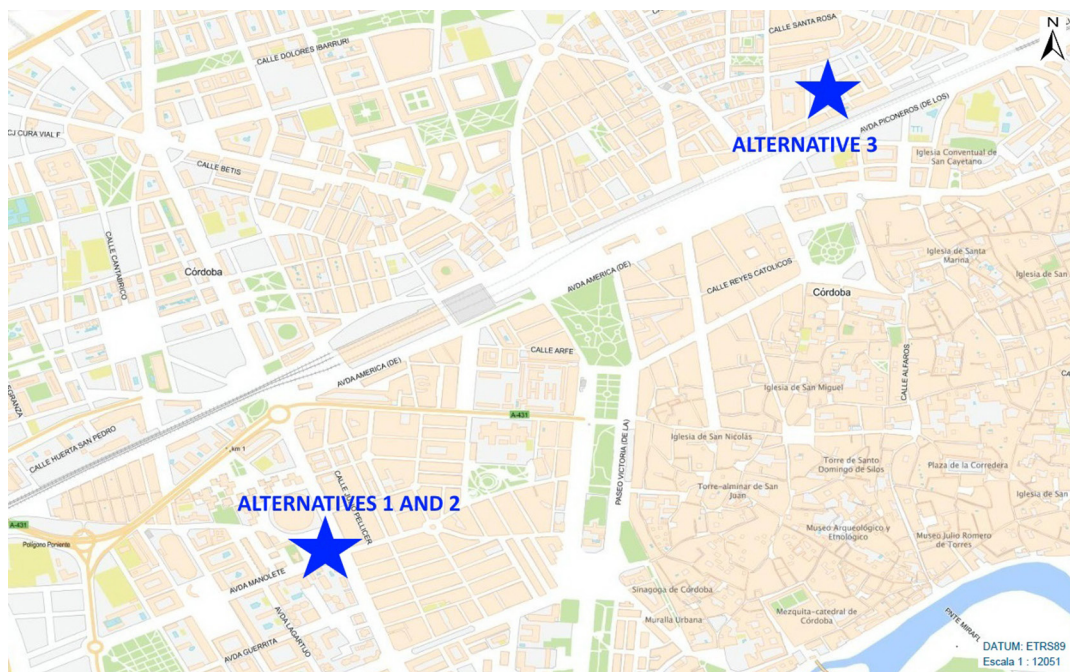


Figure 1. Map of the location of the different alternatives. Source: National Center for Geographic Information. Government of Spain.

Table 4. Criteria to be considered in the decision making process. Source: Author’s own.

Group	Criteria	Description	Measurement Unit	Criterion type
Functional	Number of spaces	Number of available spaces of future parking in each alternative	Number of parking spaces	Maximize
	Utility value to the user	User’s value of the usefulness and the relationship between the willingness of the consumer to pay thus saving time looking for a parking space, arrival at the final destination and the parking tariff	Dimensionless	Maximize
	Number of current parking spaces in rotation in the target area	Existing number of public parking spaces in the area, in regulated on-street parking zones and underground car parks	Number of parking spaces	Minimize
	Ratio of inhabitants in relation to existing residential parking spaces in the area	Ratio of inhabitants in relation to residential parking spaces, in of residential parking, in residential parking, on-street parking and green zones	Dimensionless	Maximize
	Intermodality	Average distance to transport and main roads	Meters	Minimize
Economic	Cost of parking	Cost of construction, licences, land, etc.	€	Minimize
Sustainability	Environmental impact	Impact on the land, noise, cultural heritage, environment	Qualitative criteria	Minimize
Social	Population	Number of residents in the target area of parking space	Number of residents	Maximize
	Proximity to commercial areas	Surface area in commercial use	Meters squared	Maximize
	Proximity to administration areas and offices	Surface area in administrative use	Meters squared	Maximize

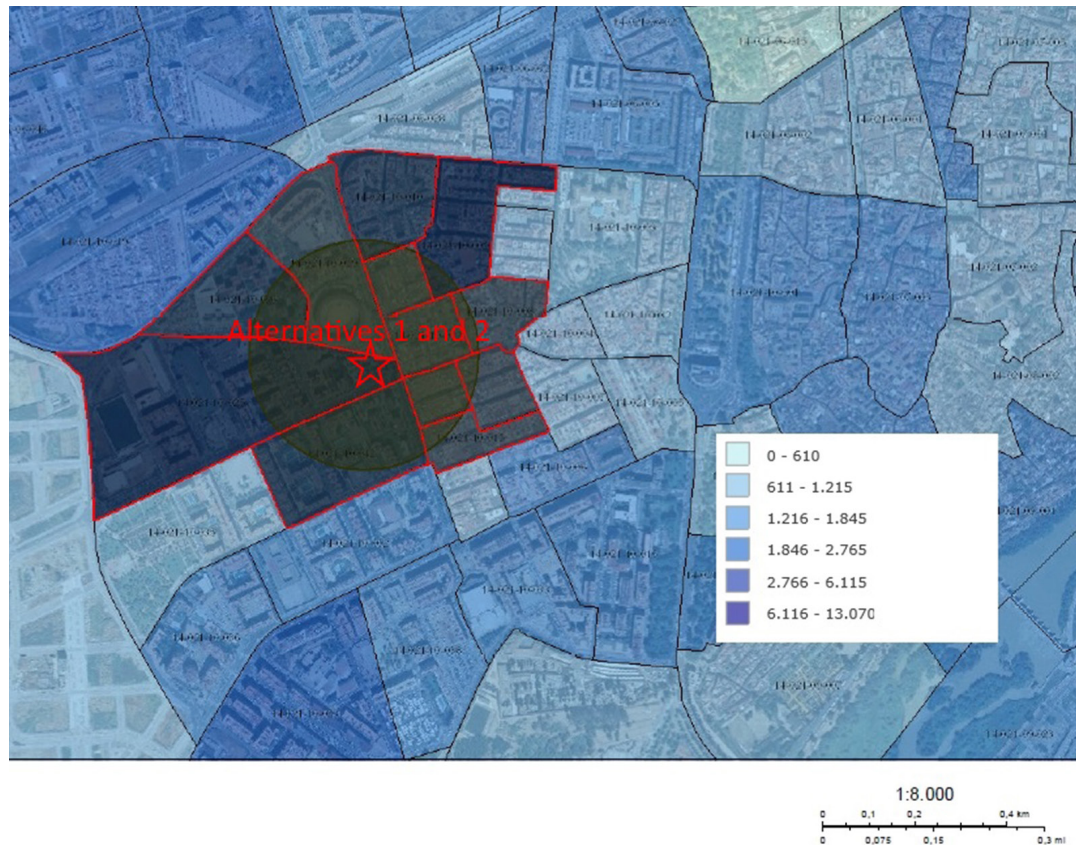


Figure 2. Surrounding area population alternatives 1 and 2. Source: Population and living census. National Institute of Statistics (Ministry of Economics, Government of Spain), 2011.

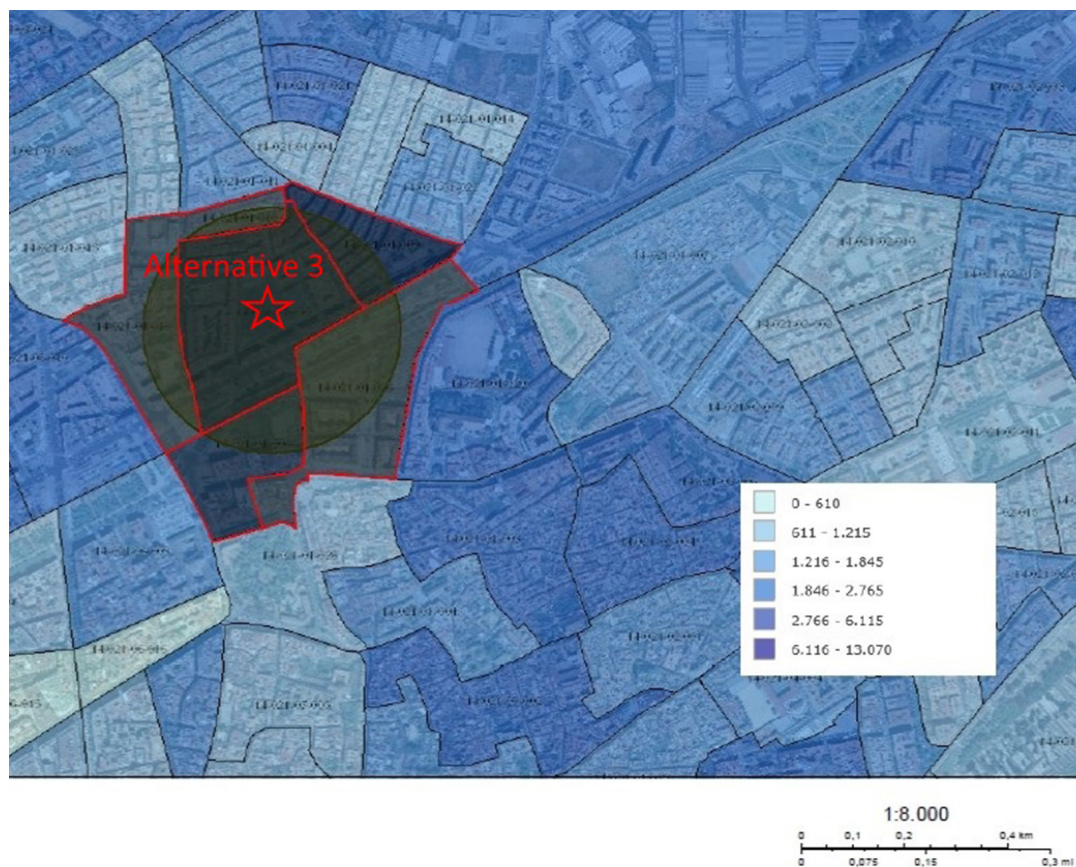


Figure 3. Surrounding population alternative 3. Source: Population and living census. National Institute of Statistics (Ministry of Economics, Government of Spain), 2011.

In table 5 the evaluation of each alternative is included in respect to the different criteria:

As well as the values f_i^* and f_i^- , being the best and worst values of each criteria function, described in table 6.

It is important to highlight that the importance of each criterion depends on the location where the parking is going to be constructed. This is why, for each project, the weight vector is determined, by paired comparisons, and by applying AHP. When using the AHP method for obtaining the weight vector, we obtain the following paired comparison matrix, (see table 7).

The weight vector obtained is $w = (0.1056, 0.2037, 0.0638, 0.0350, 0.0475, 0.1310, 0.2124, 0.1559, 0.0270, 0.0181)$. It is important to remember that the consistency of the comparison matrix must be identified. After determining the consistency following equation [1], we obtain $CI = 0.0953$, which is under 0.1. Therefore the assessments made can be considered as consistent.

Equations [2], [3] and [4] will be applied in order to calculate the S_j , R_j and Q_j values. The alternatives classification list will be established according to the values of S , R and Q , in order to establish the solution or the ensemble of compromise solutions, and ranking of alternatives. Table 8 shows ranking of alternatives.

Table 7. Matrix of paired comparisons relative importance of each criterion. Source: Author's own.

1	1/3	2	2	5	3	1/5	1/2	4	4
3	1	7	6	7	3	2	2	7	7
1/2	1/7	1	2	4	1/3	1/7	1/5	2	2
1/2	1/6	1/2	1	1/3	1/5	1/7	1/5	2	2
1/5	1/7	1/4	3	1	1/5	1/7	1/5	2	2
1/3	1/3	3	5	5	1	1/4	1/3	5	5
5	1/2	7	7	7	4	1	1/5	7	7
2	1/2	5	5	5	3	5	1	5	5
1/4	1/7	1/2	1/2	1/2	1/5	1/7	1/5	1	2
1/4	1/7	1/2	1/2	1/2	1/5	1/7	1/5	1/2	1

Table 8. Ranking of alternatives and values Q, S and R of every alternative. Source: Author's own.

Alternative	Q	S	R
Alternative 3	0.3999	0.5005	0.1559
Alternative 2	0.4230	0.3142	0.2037
Alternative 1	1.0000	0.5471	0.2124

We can see that both requirements of VIKOR method no are met. We must stress that $Q(A(1)) - Q(A(2))$, is lower than 0.50, therefore the requirement 1 of acceptable advantage is not met. Therefore, as a solution to the decision-making

Table 5. Evaluation of the different alternatives in each criterion. Source: Author's own.

Criteria	Alternative 1	Alternative 2	Alternative 3
Number of spaces	508	218	246
Perception of user	0.618	0.618	0.653
Number of existing parking spaces in rotation in the target area	527	527	688
Ratio of inhabitants in relation to existing residential parking spaces in the area	6.18	6.18	3.82
Intermodality	1005	1005	1970
Cost of parking	8525.57	2709.3	2485.16
Environmental impact	0.6753	0.0817	0.2431
Population	15275	15275	7540
Proximity to commercial areas	97532	97532	27139
Proximity to administrative areas and offices	30150	30150	6797

Table 6. Values f_i^* y f_i^- , most and least valued by every alternative in each criteria. Source: Author's own.

Criteria	f_i^*	f_i^-
Number of spaces	508	218
Perception of user	0.618	0.618
Number of existing parking spaces in rotation in the target area	527	527
Ratio of inhabitants in relation to existing residential parking spaces in the area	6.18	6.18
Intermodality	1005	1005
Cost of parking	8525.57	2709.3
Environmental impact	0.6753	0.0817
Population	15275	15275
Proximity to commercial areas	97532	97532
Proximity to administrative areas and offices	30150	30150

problem, we suggest an ensemble of compromise solutions formed by the alternatives 3 and 2. We must remember that the VIKOR method proposes an ensemble of compromise solutions to those alternatives, $A(1), A(2), \dots, A(M)$, that make $Q(A(M)) - Q(A(1)) < DQ$. Therefore, we have a compromise solution for the decision-making problem described here, being the alternative 3 the one most suitable to the determining criteria, Being the best alternative classified according to the ranking S and / or R , requirement 2 of acceptable stability.

5. SENSITIVITY ANALYSIS

Sensitivity analysis measures stability or behavior of the solution to small changes in preferences occurred during the resolution process or to small changes in the values taken for the parameters. Thus, sensitivity analysis is a process of behavioral research of a system, process or method and associated with uncertainty (49). In a context of decision-making, sensitivity analysis has great significance because variations in input to the model may affect the recommendation given by the analyst to the multicriteria decision making. Uncertainty in the data, the proceedings and employed approaches for its resolution all evoked the carrying out of the most complete study possible into behaviour in the decision making process (50). Behaviour analysis must be conducted in three stages that respond, respectively, to the effectiveness and efficiency of the process of decision making and which are: 1. the estimate (validity); 2. the method or mathematical modeling (robustness); and 3. the solution (stability) (50).

The first two are proven to have used multicriteria decision making whose validity has been proven and verified in many cases of location selection in which it has identified optimal solutions. Below the stability of the solution is determined. The impact of the weightings of each criterion in the ranking of solutions is analyzed and for which 30 experiments were carried out, each modifying the weight-

ing of the different criteria. Firstly, we carried out 10 experiments increasing the weight assigned by 10% to one of the 10 criteria used in the previous table, and the rest of the weights we modified in a lineal form so that the total weight remained at 1. Secondly, we carried out 10 experiments increasing the assigned weight by 20% to one of the criteria and the rest of the weights we modified to lineal form so that the weight remained at 1. Thirdly, we carried out 10 experiments increasing the assigned weight by 80% to one of the criteria and the rest of the weights we modified in lineal form so that the amount of weights remained at 1. In order to carry out the simulation and application stated in the VIKOR method, each vector of resulting weight was placed under the programming of an algorithm in the Matlab® which allowed the automation of the calculations.

The results of the sensitivity analysis show an ensemble of compromise solutions can be proposed to solve the problem of decision making, as the alternatives 2 and 3 were demonstrated as the solutions in 100% of the results obtained from the experiments carried out. In 50% of cases alternative 3 was obtained as the best ranked according to the value of Q and R , and in another 50% of cases the alternative 2 was the best ranked. Category 2 is the best ranked when increasing the importance of the criteria of sustainability and population. On the contrary if the perception of the consumer is increased in importance, the alternative 3 is the best ranked and this alternative then considers the expressions of the decision-makers preferences. Additionally, sensitivity analysis shows in no case is the alternative 1 is the best criteria, and except in one of the three experiments, it does not form part of the ensemble of compromise solutions and can therefore be discarded. It is also necessary to discard the evaluation of one of the alternatives of a criterion that has a very different value to the other criteria as this may affect the rankings and see an optimal solution for this particular criterion but not for the other sets of criteria. Figure 4 includes the values of Q obtained in each experiment:

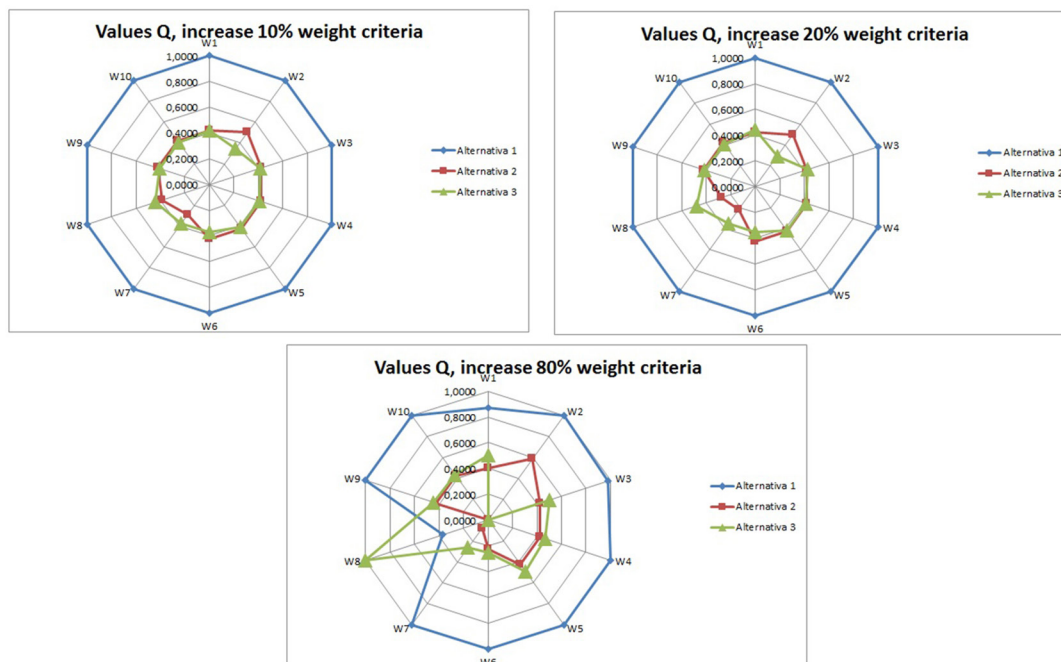


Figure 4. Values Q, sensitivity analysis. Source: Author's own.

6. CONCLUSIONS

The method presented in this paper offers several advantages over existing methods. Perhaps the main strength is the possibility of including an objective systemization of how to identify social, functional, economic, and sustainable criteria in determining the relative importance of each criterion. A second advantage is the consideration of user perception and utility to the user in economic terms, thus making these concepts directly comparable with other variables. Such thing was not possible before in the published decision methods for parking facilities.

The data required to evaluate the different alternatives may be easily obtained from public databases, or by direct measurement. The paper identifies a certain variable set, but the proposed method allows for the inclusion of additional criteria, such as congestion, or the measures set to reduce traffic in downtown areas, due to design or to temporary restrictions triggered by peak pollution periods, to mention some. An additional possibility is to explicitly set priorities regarding the different criteria, if the stakeholders decide so. The stated method allows for the inclusion of user perception in any facility project, and both in the design stage or during the operation of the facility. Furthermore, this method used a two-staged sequential procedure for selecting the best alternative for parking location, using two different decision-making methods. Thus, it is proven that a solid and transparent set of criteria can be taken into account, including the environment impact, user perception and cost. This method allows an objective and transparent process, making clear

which are the expressed preferences and their importance in the process. The proposed decision-making process is based on a reduced and easily available data set, which is easy to obtain, and enables the identification of the criteria and variables that play in the decision making process in a systematic and ordered way.

This method will allow managers, decision-makers and administration officers to reach a solution as a result of a systematic process which is relatively objective, allowing a stable justification of the proposed solution in situations of disagreements amongst different stakeholders and people. It has been proven that the solutions chosen are robust in cases considering very different criteria and in projects in which the precedence of the criteria is clear but the differences not as much.

Finally, this method reduces the role of subjectivity in the decision making process in situations of uncertainty. The performed sensitivity analysis has proven that the solution or solution set obtained are stable (robust) against changes in preferences from decision making actors. The proposed methodology can be used by private and public developers, and by designers willing to find the best alternatives, allowing for the optimization of resources in location selection for parking infrastructure projects.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

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