Multiple-Criteria Decision-Making Tool for LocalGovernments to Evaluate the Global and LocalSustainability of Transportation Systems in Urban Areas: Case Study

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Abstract: Efficient management of urban transportation systems is a challenge for any local government that wishes to improve public wellbeing and comfort. With that end in mind, this paper proposes a tool for decision making and policy guidance based on multiple-criteriadecision-making methods for the sustainability evaluation of urban transportation. The mathematical model is applied to certain metropolitan areas of Donostia-San Sebastian and validated in a practical case study. It is used to assess the overall urban transportation system of the areaand is applied in further detail to various subzones, yielding a global sustainability index for the urban transportation network and identifyingareas for improvement. It is also applied within the urban area to detect the weaknesses of various subzones and to evaluate specific objectivesfor their resolution. DOI:

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Introduction

The need to address environmental concerns, an important public issue, has led international institutions and developed countries tohighlight the complex relations between environmental and intersectoral policies, in which transportation is of significant importance. One consequence of this approach is that environmental variables and their monitoring are seen as key factors for sustainable development and their integration in a horizontal, intersectoralpolicy. The Brundtland Report marked the beginning of a new erain which respect for the environment, rational use of resources, anda focus on quality of life are—or at least should be—the frameworkof national economic and sectoral policies (World Commission onEnvironment and Development 1987). Transportation in general and urban transportation in particular represent one of the key sectors in sustainable development because transportation causes a significant number of environmental, economic, and social costs ornegative externalities (Browne and Ryan 2011), despite its multiplebenefits. The mitigation of these externalities requires moving toward sustainable transportation systems (Qureshi and Lu 2007).In this regard, the European Commission has adopted a roadmap of40 concrete initiatives that includes a section referring to urban transportation, with the aim of building a competitive transportation system over the next decade (European Commission 2011a, b).

Focusing on urban transportation systems, the development of sustainable city transportation (improving accessibility, minimizing travel times, and facilitating equal mobility options to all while reducing environmental impacts) has become a key challenge anda priority in urban transportation planning (Camargo Perez et al. 2015; Kenworthy 2006). Decision making in the context of urban transportation design and planning is a complex task because of the wide range of variables and impacts that must be taken into account. Assuming that the sustainability of urban transportation iseither directly or indirectly related to a wide range of factors, thereis no true optimal solution. Conversely, a single criterion that mightyield such a solution would never be sufficient for reliable decision making. In this context, multiple-criteria decision making (MCDM), a tool for modeling complex problems with a wide range of criteria and multiple stakeholders, can assist decision makers andis an appropriate methodology for the type of problem proposed in this paper (Brucker et al. 2004; Camargo Perez et al. 2015; Kahraman 2008). Camargo Perez et al. (2015) found that 58 different MCDM techniques were applied to urban passenger transportation systems between 1982 and 2014. They concluded that MCDM techniques were very helpful for the evaluation of transportation systems and subsequent decision making in recent decades (Camargo Perez et al. 2015). Furthermore, Mardani et al. (2016) demonstrated the possibility of combining decision-makingand transportation systems areas in the MCDM procedure.

Consequently, the final decision will involve multiple criteria relating to different (economic, environmental, or sociopolitical) aspects. In recent years, different groups of indicators for monitoring the development of transportation sustainability have been proposed. For example, sustainable transportation indicators for comparative global studies of cities have been introduced (Haghshenas and Vaziri 2012). Considering the common urban transportation development features, Browne and Ryan (2011) compared the ecological footprint of travel-commuting patterns in an Irish city-region in 1996 and 2002. The objective was to estimate the impact of different policy choices for 2010 and to propose an optimal policy mix for sustainable travel (Browne and Ryan 2011).

Marsden and Rye (2010) examined the prospects of deep cuts in CO2 emissions from transportation through an examination of the key policy levers for change, considering relevant governance issues.

This paper conducts an integrated study of urban transportationsystem sustainability, taking into account the characteristics of theurban environment in which it functions, as well as the basic characteristics required in all urban transportation systems, following the guidelines set by the European Conference of Ministers of Transport on improving tools to support decision making that havebeen followed since the Prague Council in 2000, which introduceda new political emphasis on integrated policy, fundamental in driving change in transportation projects and policy screening procedures (European Conference of Ministers of Transport 2004). Theresult is a tool to assess the initial sustainability of the transportation system in an urban area using a MCDM approach, with no need for specific studies to gather the input data that are publicly available from local government statistical summaries. Future investigations will focus on improvements to sustainability through different policies and actions to identify areas with pressing needsin order to reap the maximum benefits of sustainability.

Literature Review

In recent years, numerous MCDM and fuzzy multiple-criteriadecision-making (FMCDM) approaches have been suggested in order to select the best compromises. These approaches have beenapplied to different real-world problems that decision makers present as multicriteria methods for improvements in various fields of mathematical optimization, computer science, and computer technology (Wiecek et al. 2008). Furthermore, FMCDM and MCDM techniques have been classified in some works for use in several areas (Mardani et al. 2015a, b).

Multiple-criteria decision-making methods are very powerful tools that have been applied using different approaches to decision making. Decision makers can therefore prioritize the important criteria, reduce uncertainty, and increase the quality of decisions. Various MCDM techniques have been proposed for solving realworld problems, some of which are shown in Table 1.

Table 1. Different MCDM Techniques

MCDM technique	Reference
Simple additive weighting (SAW)	MacCrimmon (1968)
Multiattribute utility analysis (MAUA)	Keeney and Raiffa (1976)
Order of preference by similarity to ideal solution (TOPSIS)	Hwang et al. (1979)
VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR)	Opricovic and Tzeng (2004)
Weighted aggregated sum product assessment (WASPAS)	Zavadskas et al. (2012)
Complex proportional assessment method (COPRAS)	Zavadskas et al. (1994)
Multiobjective optimization by ratio analysis (MOORA)	Brauers and Zavadskas (2006)
MULTIMOORA (MOORA plus the full multiplicative form)	Brauers and Zavadskas (2010)
ARAS grey (ARAS-G)	Turskis and Zavadskas (2010)
COPRAS grey (COPRAS-G) Zavadskas and Turskis (2008)	Zavadskas and Turskis (2008)
Kemeny median indicator ranks accordance (KEMIRA)	Krylovas et al. (2014)
ARAS	Zavadskas and Turskis (2010)
Stepwise weight assessment ratio analysis (SWARA)	Kersuliene et al. (2010)
Analytic hierarchy process (AHP)	Saaty and Vargas (2013) and Saaty (1988, 2004, 2008)
Elimination and choice expressing reality (ELECTRE)	Roy (1996)
Novel approach to imprecise assessment and decision environments (NAIADE)	Munda (1995)
Preference ranking organization method for enrichment evaluations (PROMETHEE)	Brans and Mareschal (1992)

Transportation systems are designed to provide users secure, comfortable, and safe trips. As a result, policy makers may discusswhether to build a new transportation system or to extend an existing one, or consider the most appropriate transportation technologies, local preferences for any one alternative, and which transportation systems should be implemented. Their objective will be to evaluate the most desirable transportation system in terms of needsand purposes and to recommend a system that satisfies diverse viewpoints and multiple goals. In contrast, researchers consider transportation systems as large-scale systems characterized bymany elements that interact with each other. Planning these systems becomes complicated, because they have to satisfy different groupsof people with a wide range of views on the need for the chosen option, its benefits, and its financing. Often, the planning cannot beadvanced because there is no consensus.

Furthermore, traditional approaches to decision making in transportation systems are basedon a series of assumptions

- The decision problem is assumed to be well structured;
- The evaluation objectives are assumed to be independent;
- The evaluation criteria are assumed to be quantifiable;
- The decision makers are assumed to be from clearly definedgroups of stakeholders;
- All possible alternatives are assumed to be clearly defined;
- The decision makers are assumed to possess full knowledgeof the information needed to analyze transportation alternatives;and
- The alternative that yields the maximum utility is assumed to bethe optimal solution.

However, some decisions are in reality based on uncertainty, and the validity of the decision is related to how uncertainty is treated and how the participants understand the uncertainties and theambiguities that arise.

Several MCDM methods have been suggested to incorporate the needs of different stakeholders involved in decision-making processes of a transportation system, using a numerical or analytical model to find the alternative that would best meet a wide variety of criteria.

The analytic hierarchy process (AHP) has been used for different purposes in various studies, such as the assessment of sustainable transportation strategies in Taiwan (Shiau and Liu 2013),the improvement of an original two-phase multicriteria model in the Serbian railways (Mandic et al. 2014), the identification and evaluation of a potential market for electrified vehicles in Europe (Zubaryeva et al. 2012), the analysis and evaluation of development in multiairport systems (Zietsman and Vanderschuren 2014), the impact assessment of including various qualitative criteria for the selection of alternative transportation options in Delhi (Yedla and Shrestha 2003), and suggestions for a new framework to screennew urban transportation-based projects on the basis of sustainability criteria (Jones et al. 2013). Fuzzy AHP has been used to proposea new methodology based on an extension of SERVQUAL for theanalysis of performance in the public transportation (PT) service (Lupo 2013); to improve a new model for increasing customer service levels while decreasing logistical costs (He et al. 2012); to present a multidimensional framework for evaluating, monitoring,and comparing the development of public transportation systems toward Transit Metropolis status in different cities in China (Liet al. 2016); and to identify significant criteria for the selectionof a transhipment port (Lirn et al. 2003). In addition to the aforementioned studies, other works have used hybrid MCDM and FMCDM-based techniques to evaluate sustainable developmentin highway transportation (Li et al. 2014), to examine and to improve project selection and evaluation with the collaboration of a state-level transportation agency (Ramani et al. 2010), to develop an evaluation model of systems in airport connection services (Liuet al. 2013), and to select a strategic cargo alliance and to evaluate it in the airline industry (Chao and Kao 2015). Studies proposing a new framework for evaluating performance in public transportationservices (Hawas et al. 2016) and an evaluation of service quality in metro transportation (Awasthi et al. 2011), among others, have used approaches based on the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and fuzzy TOPSIS. Otherapproaches based on variants of MCDM and FMCDM may be mentioned; for example, a study assessing the role of cost-benefit analysis for spatial-infrastructure projects (Mouter et al. 2013) or the investigation of sustainability impacts for future lower CO_2 emissions in the transportation sector (Hickman et al. 2012). Liouet al. (2011) studied the enhancement of service quality among domestic airlines in Taiwan by applying the visekriterijumska optimizacija i kompromisno resenje (VIKOR) multicriteria optimizationand compromise solution and gray relational analysis (GRA), Johnet al. (2014) integrated fuzzy TOPSIS and fuzzy AHP for the selection of an appropriate model to evaluate performance efficiencyin seaports, Lupo (2015) evaluated service quality in internationalairports employing fuzzy ELECTRE III, and Policani Freitas (2013) pointed out the consequences of public transportation having to compete with other means of transportation and the need toassess road transportation quality for passengers.

Among the types of problems studied in the literature, researchers have distinguished between urban passenger transportation systems and urban freight transportation systems, almost always focusing on urban passenger transportation systems. In this regard, they have mainly focused on studying infrastructural investment, the definition of policies for efficient and accurate decision making, the choice of technologies (including clean technologies for vehicles), and the performance evaluation of freight companies.

Along these lines, this paper introduces an index of transportation sustainability in urban environments which is obtained by taking account of a set of general factors associated with urban transportation in the field of sustainability. The paper describes a multicriteria methodology to quantify the transportation sustainability of any city, with the objective of obtaining an initial sustainability index value in order to compare the benefits that will be achieved with different strategies and policies. One main goal of this work is to propose the most appropriate methodologies that would be specific, measurable, and attainable by the largest number of cities. The approach in this paper adds value to this debate, introducing new indicators related to urban freight transportation system planning and management and its sustainability problems.

The first challenge and a key aspect of the research is the selection of a group of criteria to represent the different aspects related to the sustainability of urban transportation systems. The involvement of various stakeholders from academia and elsewherein the research process is recommended in order to integrate the best available knowledge, to reconcile values and preferences, andto seek optional solutions to problems, in order to arrive at a participatory approach to research with appropriate means to meet both the requirements posed by real-world problems and the scientific goals of sustainability seen as a transformational field of scientific knowledge (Lang et al. 2012).

Decision-Making Model for Urban Transportation

The proposed evaluation model was used to assess the sustainability of the transportation system and the absence in different zones of the urban area under study. On the basis of these results, appropriate corrective global or local actions could be established to improve urban sustainable mobility. The model has three hierarchic levels in the urban transportation system: requirements, criteria, and indicators. These three levels are arranged in the requirements treefor urban transportation (Fig. 1).

The definition of the hierarchical analysis tree proposed here isa key point in the integrated value model for sustainability assessment (MIVES) methodology (Reyes et al. 2014; San-José Lombera and Garrucho Aprea 2010). The MIVES method was designed with certain aims (Fig. 2). The decision-making tree presents three different levels. The requirements are a means of grouping measurable aspects, in this case associated with the urban transportation system. These requirements are divided into criteria for greater clarity,which in turn give rise to the indicators that make up the final hierarchical level of the requirements tree for urban transportation. Selection and classification of the levels was agreed in a multidisciplinary group comprising researchers and professionals from theconstruction and city planning sectors, among others.

One of the main keys to successfully completing this process lies in the correct selection of panel members, chosen for their skills, knowledge, and independence. In this case, the members ofthe expert panel were professionals from the construction and planning sectors (municipal and Basque government employees with important roles in planning, mobility, and traffic and transportationinfrastructure in urban and interurban areas; and researchers at technology centers and universities) and the selection was based on theguidelines defined by Hallowell and Gambatese (2010), who suggested that the ideal expert panel is formed of a highly qualified and diverse group of between 8 and 16 people. In this case, a total of 10 experts were selected from a database of 50 professionals from30 different organizations (government, technological centers, anduniversities) in the transportation sector. In the expert selection process, the location of the practical application was considered as oneof the selection criteria, so the professionals were people involvedin and aware of the problems of the area (representatives of the citycouncil, county council, and the Basque government; representatives of a group for innovation in transportation; and a university professor specializing in urban transportation).

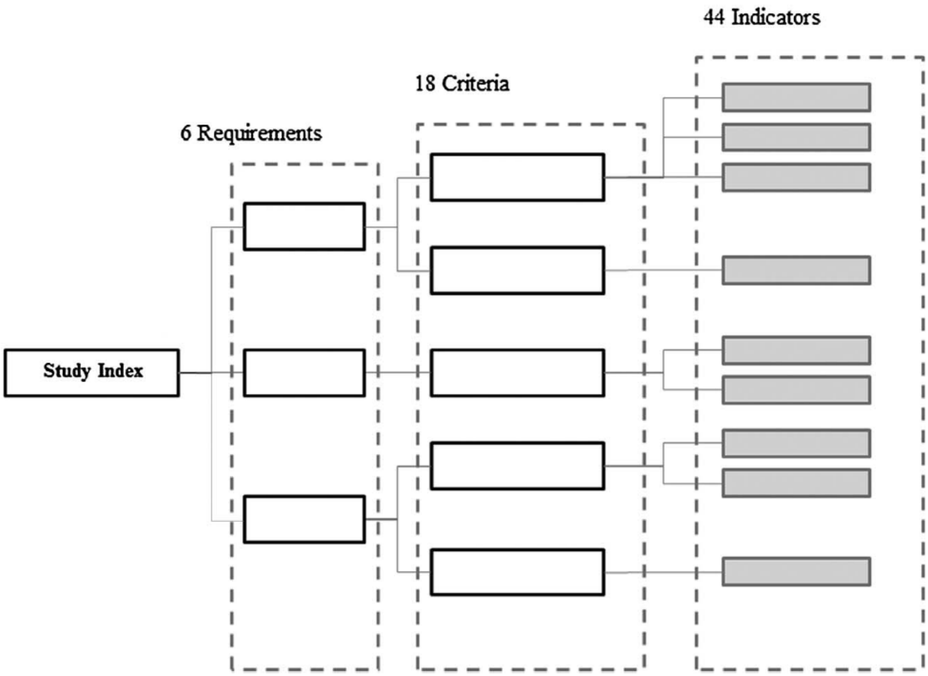


Fig. 1. Requirements tree for urban transportation

The first challenge of this study for the researchers was to obtaina list of sustainable urban transportation indicators. A systematic review to locate relevant existing studies helped to reduce the implicit bias of researchers (Denyer and Tranfield 2009). The searchstrategy consisted of looking for relevant studies within the scientific literature in the form of academic studies published in peerreviewed journals. Online database searches of the Science Directand Scopus databases identified relevant academic articles on the topic of sustainable urban transportation systems and reports on the various foundations for the compilation of statistical data on urban transportation in three provincial capitals in the Basque Country (to select available data for the real problem). The researchers then grouped a set of city-level transportation sustainability indicators related with various aspects of urban transportation inorder to use them in the evaluation of different criteria. The most important criteria were selected with the Delphi method, which is a structured communication technique originally developed as a systematic, interactive forecasting method that relies on a panelof experts (Linstone and Turoff 2002). At an early stage in this systematic process, group members completed a questionnaire to select the sustainability evaluation criteria for an urban transportation system. The questionnaire was checked against the set of criteria presented by the researchers. In a second phase, after the initial collection of criteria, the panel of experts grouped them into different requirements. Having ranked these criteria under the corresponding requirement, a relative weight was assessed to each one. The analytic hierarchy process was used to facilitate the value judgments (criteria weights) of the expert panel, and the key criteria were selected based on their relative weights. In the final phase, results with a relative weight of less than 5% were removed, leaving 18 final evaluation criteria.

The proposed methodology is based on the MIVES model, which combines the use of AHP with value functions that allow the homogenization of the study variables, as proposed by Ponset al. (2016). In this sense, with the aim of reducing the uncertaintycaused by the subjective opinions of the panel of experts, some current works enhance AHP methodology. In the field of urban planning, Li et al. (2016) presented a multidimensional framework using an enhanced fuzzy analytical hierarchy process model, in which a nonlinear optimization formulation is proposed to maximize the consistency in pairwise comparison and weight estimation. In other areas, such as the selection of the location of power substation (Kabir and Sumi 2014) or the prioritization of thealternatives for pavement maintenance (Babashamsi et al. 2016), fuzzy AHP models have been also applied for the reduction of theuncertainty.

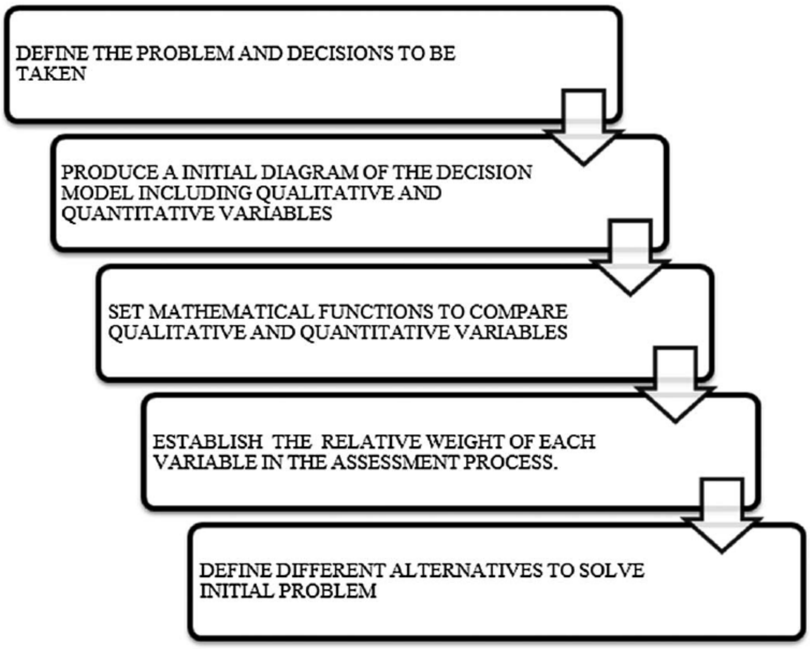


Fig. 2. MIVES goals

Additionally, the content validity ratio (CVR), developed by Lawshe (1975), was calculated for each criterion in order to certifythat the 18 selected criteria were considered essential by all the panel experts. The content validity ratio is used to gauge agreementbetween the experts on the essential nature of a particular item

$$\text{Content Validity Ratio: CVR} = \frac{n_e - \frac{N}{2}}{\frac{N}{2}}$$

where n_e = number of panel experts indicating that an item or indicator is essential; and N = total number of panel experts.

In this case, the ratio reached a value greater than 0.62 for each of the 18 criteria, which, according to Lawshe (1975) and Wilson et al. (2012), certifies the relevance and appropriateness of the 18 criteria in this field of study. Table 2 shows the set of criteria resulting from the consultation, as well as their descriptions

Table 2. Requirements Tree for Urban Transportation

Requirement (%)	Criterion (%)	Indicator
(R1) Environmental (16.7)	(C. 1. 1) Air quality (16)	(I. 1. 1. 1) Air quality index
	(C. 1. 2) GHG emissions (16)	(I. 1. 2. 1) CO_2 emissions
		(I. 1. 2. 2) Motorization
		(I. 1. 2. 3) Evolution of car use
	(C. 1. 3) Modal split (62)	(I. 1. 3. 1) Percentage of car use
		(I. 1. 3. 2) Percentage of public transportation use
		(I. 1. 3. 3) Percentage of nonmotorized mode use
	(C. 1. 4) More-sustainable and nonmotorized modes (7)	(I. 1. 4. 1) Pedestrian offer and demand
		(I. 1. 4. 2) Bicycle offer and demand
		(I. 1. 4. 3) Park and ride, car sharing, and car pooling
(R2) Economic (16.67)	(C. 2. 1) Growth of transportation (16)	(I. 2. 1. 1) Gross added value of transportation
	(C. 2. 2) Energy consumption (25)	(I. 2. 2. 1) Energy type consumption of transportation
		(I. 2. 2. 2) Energy intensity
	(C. 2. 3) Costs of urban transportation (59)	(I. 2. 3. 1) Surcharges on national measures
		(I. 2. 3. 2) Parking fees
		(I. 2. 3. 3) Urban road and congestion pricing
(R3) Social (16.67)	(C. 3. 1) Safety (35)	(I. 3. 1. 1) Vehicle accidents
		(I. 3. 1. 2) Vehicle accidents with victims.
		(I. 3. 1. 3) Vehicle accidents with pedestrians
	(C. 3. 2) Noise (11)	(I. 3. 2. 1) Noise level
		(I. 3. 2. 2) Population range affected by noise
	(C. 3. 3) Comfort of public transportation (35)	(I. 3. 3. 1) Travel time of PT
		(I. 3. 3. 2) Frequency of PT
		(I. 3. 3. 3) Number of transfers of PT
	(C. 3. 4) Accessibility (19)	(I. 3. 4. 1) Adapted PT vehicles
		(I. 3. 4. 2) PT with access to bicycles
		(I. 3. 4. 3) Transportation cards
(R4) Urban model (16.67)	(C. 4. 1) Urban model (25)	(I. 4. 1. 1) Urbanized land
		(I. 4. 1. 2) Intensity use of the residential land
		(I. 4. 1. 3) Urban compactness
	(C. 4. 2) Characteristics of transportation networks (75)	(I. 4. 2. 1) Surface for transportation infrastructure
		(I. 4. 2. 2) Surface for roads
		(I. 4. 2. 3) Cycling network
		(I. 4. 2. 4) Segregated bus network
(R5) Vehicle fleet characteristic (16.67)	(C. 5. 1) Motorization rate (50)	(I. 5. 1. 1) Motorization
		(I. 5. 1. 2) Motorization progression
	(C. 5. 2) Vehicle type (50)	(I. 5. 2. 1) Car registration by section
		(I. 5. 2. 2) Car registration by fuel type
(R6) Freight distribution (16.67)	(C. 6. 1) Supply (43)	(I. 6. 1. 1) Temporal limitation on the loading and unloading areas
		(I. 6. 1. 2) Control on loading and unloading areas
		(I. 6. 1. 3) Access control
	(C. 6. 2) Demand (14)	(I. 6. 2. 1) Activities
	(C. 6. 3) Efficiency (43)	(I. 6. 3. 1) Last mile distribution
		(I. 6. 3. 2) Urban freight distribution center
		(I. 6. 3. 3) Night freight distribution

Following a consensus reached through discussion, the urban model, the characteristics of the vehicle fleets, and aspects of freight distribution were separated from the classic triple line (economic, environmental, and social aspects) as independent requirements in the global tree. The issues that each requirement addresses were as follows:

- Environmental requirement: The group criteria focused on the assessment of policies and actions related to reductions in the emission of pollutants and greenhouse gases (directly related to health, pollution, and environmental problems), seeking to enhance nonmotorized modes of transportation. Table 3 shows the indicators and their assessment objectives.

- Economic requirement: The economic requirement was aimed at assessing the growth of transportation in relation to economic growth. It was also focused on reductions in the energy consumption levels of transportation. Within this overall goal of reduced energy consumption, the objective was to decrease the weighting attached to fossil fuel derivatives. This will be of great interest for the study of different economic policies that may generate sustainable behavior for users, such as fuel and vehicle taxes, road charges, and other financial incentives. Table 4 shows the indicators and their assessment objectives.

- Social requirement: This requirement had a dual assessment objective—the evaluation of the social impact of traffic injuries and fatalities, and of their affordability. Transportation users who travel seek safety, speed, and comfort, although there is nevertheless a direct relationship between the number of deaths on the roads in Spanish cities and the number of trips by car. Focusing on affordability, all citizens should have access to a reasonable level of public transportation and mobility in urban areas without resorting to private vehicles. Nevertheless, schoolchildren, the elderly, those without driving licenses, and the socially underprivileged need public transportation. The social requirement was an attempt to assess these aspects. Table 5 shows the indicators and their assessment objectives.

Table 3. Indicators for Assessing Environmental Requirement with Descriptions and Measurement Systems

Indicator	Description	Measurement
(I. 1. 1. 1) Air quality index	PM_{10}, SO_2, NO_2, CO, and O_3 pollutant emissions	Points system for different AQI values, penalizing high levels of PM_{10}, SO_2, NO_2, CO, and O_3 pollutant emissions
(I. 1. 2. 1) CO_2 emissions (I. 1. 2. 2) Motorization (I. 1. 2. 3) Evolution of car use	Evolution of the percentage of CO_2 emissions from transportation, motorization rate, and percentage of car use (5 years)	Points system penalizing increase of CO_2 emissions from transportation, motorization rate, and percentage of car use
(I. 1. 3. 1) Percentage of car use (I. 1. 3. 2) Percentage of public transportation use (I. 1. 3. 3) Percentage of nonmotorized mode use	Percentage of car use (% value), percentage of public transportation (% value), percentage of nonmotorized mode use (% value)	Points system for the percentage values of the modal split, penalizing use of private vehicles
(I. 1. 4. 1) Pedestrian offer and demand (I. 1. 4. 2) Bicycle offer and demand (I. 1. 4. 3) Park and ride, car sharing, and car pooling	Existence of footpaths between subzones and their quality, segregated network, 30 areas, bicycle parking, public bicycle, park and ride, car sharing, and car pooling	Points system penalizing nonexistence and bad quality of nonmotorized and more-sustainable modes

Table 4. Indicators for Assessing Economic Requirement with Descriptions and Measurement Systems

Indicator	Description	Measurement
(I. 2. 1. 1) Gross added value of transportation	Comparison of annual variation of gross added value of transportation and economy.	Points system penalizing increase of the gross added value of transportation as a function of the total economic turnover
(I. 2. 2. 1) Energy type consumption (I. 2. 2. 2) Energy intensity	Percentage of fossil fuel derivatives. Energy consumption/GDP	Points system penalizing the increase of fossil fuels consumption and energetic intensity
(I. 2. 3. 1) Surcharges on national measures (I. 2. 3. 2) Parking fees (I. 2. 3. 3) Urban road and congestion pricing	Existence or nonexistence of surcharges on national measures, parking fees, and urban road and congestion pricing in each urban area	Points system penalizing nonexistence of surcharges on national measures, parking fees, and urban road and congestion pricing

Table 5. Indicators for Assessing Social Requirement with Descriptions and Measurement Systems

Indicator	Descriptions	Measurement
(I. 3. 1. 1) Accidents (I. 3. 1. 2) Accidents with victims (I. 3. 1. 3) Run over	Evolution in 5-year period Evolution in 5-year period Evolution in 5-year period	Points system penalizing growth of the number of accidents and of accidents with victims and pedestrians run over
(I. 3. 2. 1) Noise level (I. 3. 2. 2) Population range affected by noise	Noise level exposure of the population in each subzone of the urban area Percentage of the population affected by this noise level	Points system penalizing noise level exposure of the population and high percentage of the population affected by this noise level
(I. 3. 3. 1) Travel time of PT (I. 3. 3. 2) Frequency of PT (I. 3. 3. 3) Number of transfers of PT	Comparison of travel time of PT and private car between subzones of the urban area Frequency of PT between subzones of the urban area Number of transfers of PT between subzones of the urban area	Points system penalizing differences in travel time of PT and private car, low frequency of PT, and number of transfers of PT
(I. 3. 4. 1) Adapted PT vehicles (I. 3. 4. 2) PT with access to bicycles (I. 3. 4. 3) Transportation cards	Percentage of adapted PT vehicles Percentage of PT to high areas with access to bicycles without time restrictions Existence of different transportation cards	Points system penalizing low percentage of adapted PT vehicles, and PT to high areas with access to bicycles without time restrictions and nonexistence of different transportation cards

Urban form requirement: The urban form requirement was related to the interdependence between urban form and transportation, and the effect of this interdependence on concerns over the environment and sustainable urban development. These cocerns cover low-density housing, separate urban land usage, the poor accessibility and quality of urban services, increasing car dependence and nonrenewable energy use, pollution, traffic congestion, low public transportation use, and increasing numbers of fatalities and accidents on the roads. Numerous researchers have examined various aspects of the relationship between land use and transportation (Aljoufie 2014; Alqhatani et al. 2012; Colonna et al. 2012; Kenworthy 2006; Yigitcanlar and Kamruzzaman 2014). Therefore, because of this interdependence, policies to enhance sustainable land use will improve the sustainability of the urban transportation system. Each urban environment has a particular urban form, to which the sustainability of its transportation system is directly related. A compact and diverse city in all its aspects is required for efficient and sustainable urban transportation. Table 6 shows the indicators and their assessment objectives.

Table 6. Indicators for Assessing Urban Model Requirement with Descriptions and Measurement Systems

Indicator	Description	Measurement
(I. 4. 1. 1) Urbanized land	Evolution of the percentage of urbanized land (5 years)	Points system penalizing growth of the percentage of urbanized land, decreasing ratio of inhabitants/ha and dwellings/ha
(I. 4. 1. 2) Intensity use of residential land	Inhabitants/ha	
(I. 4. 1. 3) Urban compactness	Dwellings/ha	
(I. 4. 2. 1) Surface for transportation infrastructure	Evolution of the percentage of the surface for transportation infrastructure	Points system penalizing growth of the percentage of the surface for transportation infrastructure, of the percentage of urban surface for roads, of km/10,000 habitants, and decreasing of segregated network
(I. 4. 2. 2) Surface for roads	Evolution of the percentage of surface for roads	
(I. 4. 2. 3) Cycling network	Evolution of km/10,000 inhabitants	
(I. 4. 2. 4) Segregated bus network	Percentage of segregated network	

Requirement relating to the characteristics of the fleet of vehicles: This requirement focused on the evaluation of policies and measures that aim to curtail the progress of motorization and to renew the fleet of vehicles, thereby reducing the use of fossil fuels in favor of more ecological alternatives. Table 7 shows the indicators and their assessment objectives.

Table 7. Indicators for Assessing Characteristics of the Fleet of Vehicles Requirement with Descriptions and Measurement Systems

Indicator	Descriptions	Measurement
(I. 5. 1. 1) Motorization	Motorization value (vehicles/habitant)	Points system penalizing growth of motorization value and its progression
(I. 5. 1. 2) Motorization progression	Evolution of vehicles × km (5 years)	
(I. 5. 2. 1) Car registration by section	Evolution of car registration by sections of pollutants emitted (5 years)	Points system penalizing registration of vehicles with high values for CO_2 emitted and fossil fuel
(I. 5. 2. 2) Car registration by fuel type	Evolution of car registration by fuel type (5 years)	

Freight distribution requirement: Freight transportation has a minor role in transportation planning procedures in most cities, despite its significant contribution to pollution, noise disturbance, traffic congestion, and safety problems in urban areas. Local governments have introduced different policy measures, such as time-access restrictions, the expansion of low-emission zones (LEZ), congestion charging, and so on, based on the results of different studies related with these issues (Akyol and De Koster 2013; Anderson et al. 2005; Filippi et al. 2010; Lindholm 2010; Lindholm and Blinge 2014; Ruesch et al. 2012). In developed societies, excessive and inefficient consumption increases the need and the frequency of supply. Distribution activity over the last mile, in the final stage of supply chain operations, has to negotiate physical barriers (narrow streets, pedestrian zones, congestion of roads, and so on). It is therefore necessary to find the best logistics solutions to ensure the effective daily supply of products to urban areas without compromising the environment and the livelihoods and the quality of life for residents and other users of these areas. Table 8 shows the indicators and their assessment objectives.

When the decision-making model is completed, an MCDM assessment methodology must be selected that takes full account of the characteristics of the problem.

Table 8. Indicators for Assessing Freight Distribution Requirement with Descriptions and Measurement Systems

Indicator	Description	Measurement
(I. 6. 1. 1) Temporal limitation on the loading and unloading areas	Existence of temporal limitation on loading and unloading zones	Points system penalizing nonexistence of temporal limitation on the loading and unloading areas, increased control over the loading and unloading areas, and access control cameras
(I. 6. 1. 2) Control on loading and unloading areas	Existence of control on loading and unloading zones	
(I. 6. 1. 3) Access control	Existence of access control cameras	
(I. 6. 2. 1) Activities	Existence of grouping of economic activities	Points system penalizing nonexistence of grouping of economic activities
(I. 6. 3. 1) Last mile distribution	Existence of ecological distribution in the last mile	Points system penalizing nonexistence of ecological distribution in the last mile, urban freight distribution center, and night freight distribution
(I. 6. 3. 2) Urban freight distribution center	Existence of urban freight distribution center to optimize distribution	
(I. 6. 3. 3) Night freight distribution	Existence of night freight distribution	

Assessment Methodology

There are different analysis methodologies, each with their own approach for decision making. These methodologies can be grouped into four sets (Pardalos et al. 1995) (Table 9):

- Multiattribute utility theory (MAUT) is based on finding a global function from the aggregation of each value function of theindicators;

- Multiobjective mathematical programming (MMP) is applied tocontinuous decision-making problems that are a generalizationof the multiobjective case in linear programming;
- Outranking relation theory (ORT) is based on the systematic comparison of each pair of alternatives in all the aspects under study; and
- Preference disaggregation analysis (PDA) creates a coherent model taking previous decisions into account.

Table 9. Classification of the Multicriteria Decision Making Methods

Approach	Classification of methodology
Multiobjective mathematical programming (MMP)	Restrictions method Weights method Compromise programming Goal programming
Multiattribute utility theory (MAUT)	Weighted addition (MIVES methodology) Weighted product Multiexpert PRES and PRES II methods Analytic hierarchy process (AHP) Analytic network process (ANP)
Outranking relation theory (ORT)	ELECTRE method PROMETHE method
Preference disaggregation analysis (PDA)	UTA method

Multiple-criteria decision analysis (MCDA) methods can therefore assist the decision maker in solving both continuous and discrete problems that involve different aspects and multiple stakeholders with conflicting views. The application of each method yields its own particular selection and classification of alternatives. The decisions made in this paper have the following characteristics:

- No uncertainty: the characteristics of the alternatives aredeterministic;
- Multicriteria: there are many aspects to be studied in an integrated way;
- Discrete: there is a countable and finite value of each alternative; and
- Multiexpert: a group carries out the decision-making process.

The analysis of the different decision-making methodologies and the characteristics of the decisions justifies the use of MIVES methodology for this research. The integrated value model for sustainability assessment is based on multiple-criteria decision making methods, in which selection from a set of continuous or discrete alternatives must be made, taking into account different points of view (Brugha 2004). It has been successfully applied to different fields of sustainability evaluation (Cuadrado et al. 2015a, b, 2016; Hosseini et al. 2016; Pardo-Bosch and Aguado 2016; Pons et al. 2016; Reyes et al. 2014).

In general, policy makers are responsible for urban planning and administration. Their decisions involve problems with numerous elements and environments with complicated relationships. This methodology introduces a tool for evaluating the sustainability of different alternatives for a single transportation system. The sustainability index for the urban transportation system is defined upon the basis of the requirements tree for urban transportation, and the requirements, criteria, and indicators should reflect the problem to be solved and decisions to be made.

When the evaluation tree is complete, the next task is to obtain sustainability priorities or weights from the different assessment or hierarchy levels of the assessment model. The method used to obtain sustainability weights is based on the analytic hierarchy process decision method (Cuadrado 2009; Saaty 2004). The analytic hierarchy process is one of the most widely used multiattribute decision-making (MADM) methods. Applied to many different fields as a multiattribute decision-analysis tool with multiple alternatives and criteria, it uses pairwise comparisons and matrix algebra to weight criteria, and the decision is made by using the derived weights of the evaluative criteria (Saaty 1980). Its principles are (Saaty 1986):

- Reciprocal property: it is basic in making paired comparisons;

Homogeneity: it is characteristic of human capabilities to drawcomparisons that are not too dissimilar with respect to a common property and, hence, the need for arranging them within an order preserving hierarchy;

- Dependence of a lower level on the adjacent higher level: judgments on the priorities of the elements in a hierarchy do not depend on lower-level elements; and
- The idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy. The AHP neither assumes transitivity (or the stronger condition of consistency) nor includes strong assumptions of the usual notions of rationality. A number of facts are derived from these axioms, providing an operational basis for the AHP.

The analytic hierarchy process involves the estimation of priority weights of a set of criteria or alternatives from a square matrix of pairwise comparisons A aij, which is positive, and if the paired comparison judgment is perfectly consistent it is reciprocal. Importance is measured on an integer-valued scale from 1 to 9 (Table 10). The eigenvector associated with the largest eigenvalue of each matrix represents the order of priorities. Moreover, the eigenvalue is a measure of the consistency of the judgment that is made. This offers a way of verifying the successful allocation of preferences.

Table 10. Interpretation of Entities in a Pairwise Comparison Matrix

Value of a_{ij}	Interpretation
1	Objectives *i* and *j* have equal importance
3	Objective *i* is weakly more important than objective *j*
5	Experience and judgment indicate that objective *i* is strongly more important than objective *j*
7	Objective *i* is very strongly or demonstrably more important than objective *j*
9	Objective *i* is absolutely more important than objective *j*
2, 4, 6, 8	Intermediate values

The eigenvector associated with the largest eigenvalue of each matrix represents the order of priorities. Moreover, the eigenvalue is a measure of the consistency of the judgment that is made. This offers a way of verifying the successful allocation of preferences.

Eigenvector and eigenvalue calculations are performed with the following expression:

$$(A - \lambda \cdot I) \cdot \omega = 0$$

where A = reciprocal comparison matrix between pairs or the decision matrix; ω = eigenvector of the A matrix; and λ = maximum eigenvalue. Moreover, the consistency of the matrix must be checked using the consistency relation, which is basically the relation between the consistency index and the random index

$$C.R. = \frac{C.I.}{R.I.} \leq 0,1$$

where *C.R.* = consistency ratio; *C.I.* = consistency index; and *R.I.* =random index. The consistency index (*C.I.*) is defined as

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

where λ_{max} = largest eigenvector; and n = order of the decision matrix.

The random index *R.I.* is the maximum value of the consistencyindex *C.I.* for a decision matrix that is randomly generated. Its values depend on the matrix size (Table 11).

Table 11. Random Index of a Matrix of up to 10 Elements

Size of matrix (n)	Random index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

The calculation of the sustainability index for an urban transportation system begins by evaluating each of the indicators that are defined. A mathematical expression was defined to compare the assessments of the indicators with the different units (Alarcon et al. 2011): value functions (v_i). Their values vary from0 to 1 and depend on five parameters, minimum and maximum reference points on the indicator scale under consideration, and the assessed value of the indicator under consideration

$$v_i(X_{\text{ind}}) = A + B \cdot \left[1 - e^{-K_i \cdot \left(\frac{|X_{\text{ind}} - X_{\text{min}}|}{C_i}\right)^{P_i}}\right]$$

where $X_{\min}$ = minimum reference point on the indicator scale underconsideration, with a response to the indicator generating a value equal to 0; $X_{\max}$ = maximum reference point on the indicator scale under consideration, with a response to the indicator generating a value equal to 1; X_{ind} = response to the assessed alternative regarding the indicator under consideration, which is found between the values $X_{\min}$ and $X_{\max}$, with a response to the indicator generating avalue equal to v_i (X_{ind}), which is sought; P_i = form factor defining whether the curve is concave, convex, straight, or S-shaped, where concave curves are obtained for $P < 1$, convex or S-shaped curvesare obtained if $P > 1$, and straight curves are obtained if P 1, and P_i roughly determines the slope of the curve at the inflection point with coordinates (C_i, K_i); C_i = abscissa value where the inflection point is produced on curves with $P_i > 1$; K_i = ordinate value of the inflection point; A = value of response $x_{\min}$, where A 0 or A 1 (generally, A 0); and B = factor enabling maintenance of the value function in the range (0.00, 1.00), and the best response always has a value equal to 1.

$$B = \frac{1}{1 - e^{-K_i \cdot \left(\frac{|X_{\max} - X_{\min}|}{C_i}\right)^{P_i}}}$$

The equation of the value function varies according to the values assigned to the parameters K_i, C_i, $X_{\max}$, $X_{\min}$, and P_i. Table 12 shows the values that each variable needs to adopt in accordance with the different value functions.

Table 12. Parameter Values for Different Value Functions

Form	Concave	Convex	Linear	S curve
P_i	<0.75	>2	1	$2 < P_i < 10$
K_i	>0.9	<0.1	0	$0.1 < K_i < 0.2$

There are four stages involved in determining the satisfaction value: (1) determine the tendency of the value function (increase or decrease); (2) determine the points in order to set minimum andmaximum levels of satisfaction; (3) determine the shape of the function (linear, concave, convex, S curve); and (4) determine the mathematical expression of the value function.

The parameters, tendency, and shape of the value functionsfor each indicator are determined by international guidelines, the scientific literature, national regulations, and the background of each expert.

According to Alarcon et al. (2011), in a concave curve when the value of the indicator starts to increase, satisfaction increases rapidly, so this curve is chosen when most alternatives are close tothe minimum satisfaction. In a convex curve when the value of theindicator starts to increase, satisfaction increases slightly. The convex function is selected when most alternatives are close to the maximum point of satisfaction. A linear function presents a steadyincrease in satisfaction, and the S-curve function is a combinationof concave and convex functions. In this type of function, a considerable increase of satisfaction is obtained in the middle range ofvalues.

This process is applied to all the indicators until the entire sublevel of indicators is defined. Having defined values v_i and weightsλ_i at the sublevel that corresponds to the indicators, the additive value function V_{CR} is applied

$$V_{\text{CR}k} = \sum_{i=1}^{j} \lambda_{i,k} \cdot \nu_{i,k}(x_{\text{alt}})$$

where $V_{\text{CR}k}$ = criterion k value; $\lambda_{i;k}$ = weight of the indicator i, of criterion k; $v_{i;k}$ x_{alt} = indicator value i of criterion k; and j = number of indicators hanging from criterion k. A third assessmentprocess at the criteria level is needed to obtain the sustainable valueof the urban transportation system in relation to the requirement under consideration, V_{REQ}

$$V_{\mathrm{REQ}k} = \sum_{i=1}^{j} \lambda_{\mathrm{CR}_{i,k}} \cdot \nu_{\mathrm{CR}_{i,k}}$$

where $V_{\mathrm{REQ}k}$ = requirement k value; $\lambda_{\mathrm{CR}_{i;k}}$ = weight of criterion i of requirement k; $v_{\mathrm{CR}_{i;k}}$ = value of criterion i of requirement k; and j = number of criteria hanging from requirement k.

Finally, the highest hierarchical level is reached, and the sustainability index of the urban transportation system is generated

$$I_{UT} = \sum_{i=1}^{j} \lambda_{\mathrm{REQ}_i} \cdot \nu_{\mathrm{REQ}_i}$$

where I_{UT} = sustainability Index of the urban transportation system; λ_{REQ_i} = weight of study requirement i; v_{REQ_i} = value of study requirement i; and j = total number of requirements

Sustainability weights were obtained using the analytic hierarchy process (Cuadrado 2009; Saaty 2004). The approach used in this methodology organizes all factors in a systematic way, providing simple structured solutions to decision-making problems. Furthermore, both the macrolevel and microlevel of a single problem can be analyzed, due to the tree structure of AHP. This methodology is a numerical assessment of alternatives based on a systematicassessment of a set of decision alternatives

Validation of Methodology: Case of Donostia-San Sebastian

This model was validated through its application to an urban transportation system, with two objectives: to assess the global sustainability level of the transportation system throughout the urban area; and to see which subzones had the most shortcomings, in order to take action and improve their urban mobility at a local and eventually at a global level. With this objective in mind, an urban area was divided into subzones. Then the aforementioned model was applied at both a global and a local scale

According to the methodology proposed in the preceding section, the vi function values were calculated. The only data that the model requires are the values of the different Xalt corresponding to the 44 indicators, which are obtained from the information given by periodical statistics published by local, regional, and national government. The remainder of the calculations, until the sustainability index for urban transportation is produced, are the result of repeating the calculations in the inverse order to that of the formation of the tree, with the successive hierarchical weighting processes progressing from the level of the indicator to the criteria level, then to the requirement level, and finally to the level of the Index.

A better understanding of the methodology may be given by a practical example. The selected urban area is Donostia-San Sebastian (Fig. 3), a city and a metropolitan area located in northern Spain, on the coast of the Bay of Biscay and 20 kilometers from the border with France. The city is the capital of the province of Guipúzcoa, in the Basque Country. The population of the municipality is 186,500 (2013) and its metropolitan area extends over 60.73 km2, for a population density of 3,061.41 inhabitants=km2. Its main economic activities are commerce and tourism. Its landscape, dominated by the Bay of La Concha, and its modern architectural development, which commenced in the second half of the nineteenth century, contributed to its development as a European tourist destination (Donostia-San Sebastian City Council 2015b). The city of Donostia-San Sebastian is considered a reference in terms of sustainable mobility, largely because of policies developed

Donostia/San Sebastian

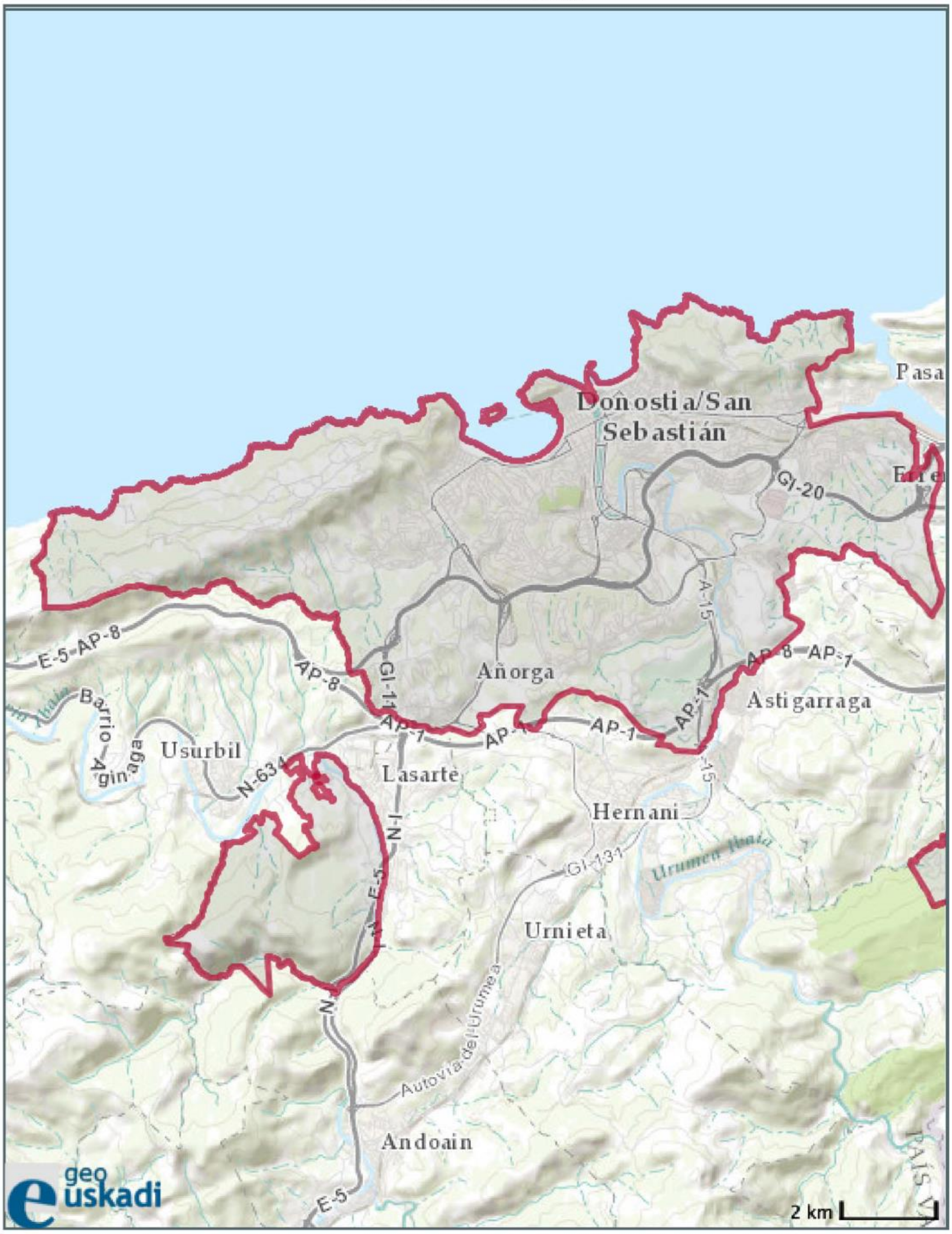


Fig. 3. Aerial view of San Sebastian (map data from GeoEuskadi, Basque Government, Bizkaia and Gipuzkoa Provincial Councils, Esri, HERE, DeLorme, Intermap, Increment P. Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China, Swisstopo, MapmyIndia, © Openstreetmap contributors, and the GIS user community)

since the turn of the last century which have been continually applied until the present (Donostia-San Sebastian City Council 2008). These policies have targeted the following objectives:

- A profound change in the conception of urban traffic and the functionality of the road network, leading to major changes in the management of traffic, eliminating transit traffic and limitedaccess;
- A coordinated policy on pedestrian networks, mainly in the expansion of the city;
- A parking policy with controlled surface parking and newparking for residents and visitors;
- A firm commitment to cyclist mobility;
- Improvements to and optimization of the urban bus network; and
- The installation of footpaths between districts, which has progressed by removing barriers and

implementing modes of vertical transportation (elevators).

Today, the city's hilly terrain and steep slopes is divided into 18districts. Five of the 18 districts are located on hills or hillsides that complicate pedestrian mobility. Mobility in the area follows two distinct patterns: internal mobility to and from the center of Donostia-San Sebastian, with a significant component of nonmotorized mobility and public transportation trips; and external mobility to the municipality, grouped into three corridors (to the west, the south, and the east). If one-way trips are followed, without considering the return journeys, the total number of trips in the metropolitan area of Donostia-San Sebastian was 101,500, of which 72,000 corresponded to trips into the city from the outlying areas. Donostia-San Sebastian has a typically urban behavior, with numerous movements to access the city and local public transportation. In the urban area, 242,000 one-way trips took place. Most travel originated in the eastern corridor, where the major nucleus of the population is located. The largest volume was in the easterncorridor (75,000 trips), followed closely by the center (60,000 trips). These areas respectively attracted 31 and 25% of trips in theDonostia-San Sebastian area. The southern and western corridors had similar volumes, with approximately 40,000 displacements, each representing 17% of the total for Donostia-San Sebastian. Motorized mobility represents approximately 50% of the urban trips, and mobility in public transportation is mainly by urban bus,whereas the use of trains is marginal. All mobility information anddata were obtained from recent statistics (2012) available in different yearbooks published by the city council and the government ofthe Basque Country.

With the urban area in which the model will be implemented described, the procedure to obtain the value of one of the indicatorsis then briefly outlined. The environmental requirement was evaluated by four criteria: air quality, *greenhouse gas* (GHG) emissions, modal split, and more-sustainable and nonmotorized modes(Table 2).

Taking the air quality criterion as an example, a daily air quality index (AQI) was proposed for consideration when assessing this criterion. Air quality index is a useful tool to inform the population about the quality of the air in a clear and simple way. This index value was divided into five categories that classify the quality of the air as very good, good, improvable, bad, and very bad. To establish ranges of concentrations, the values set out in the Directive 2008/ 50/EC were taken into account (European Parliament and Council of the European Union 2008). To calculate the AQI, an AQI value is given to each contaminant and weather station (defined by the worst value of all pollutants), and this AQI value is calculated hourly and daily by contaminant and station.

The daily AQI ranges (Table 13) were used to assess the percentage of days with different air quality index values over a period of time (1 year). A coherent punctuation system (Table 14) was proposed to evaluate the indicator. Having obtained the result rates for the city of Donostia-San Sebastian using data obtained by measurement stations located near traffic corridors, the resulting scores were calculated. The AQI mean punctuation value in 2014 was 4.76, and its normalized value was 0.958. The shape of the value function, which defines the selected indicator, had an ascendant linear behavior in this case.

Table 13. Air Quality Index Ranges

Air quality	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	CO (mg/m^3)	O_3 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	PM2.5 ($\mu g/m^3$)
Very good	0–50	0–50	0–5	0–60	0–25	0–16
Good	50–100	50–85	5–7	60–100	25–50	16–33
Improvable	100–200	85–125	7–10	100–140	50–65	33–39
Bad	200–400	125–200	10–15	140–160	65–85	39–50
Very bad	>400	>200	>15	>160	>85	>50

Table 14. Air Quality Index Points System

AQI	Points
Very good	4
Good	3
Improvable	2
Bad	1
Very bad	0

The same procedure must be followed to quantify each criterion used to define each requirement. Tables 3–8 present a brief description of the measurement of each criterion. In this way, a set of results for each requirement were deduced, and then a global value was found for the sustainability of the urban transportation system in Donostia-San Sebastian. It seems logical to assume that these global values are mean values and that there are zones in the studied urban area with their parameter values near the mean values, but there could be other zones with weaknesses in comparison with others or vice versa. The model can be applied to a subzone to evaluate its situation in order to detect these weaknesses.

With the aforementioned objective, it seems useful to divide the urban area into different subzones and use this tool to assess each indicator, criteria, and requirement in each subzone belonging to the initial zone, in this case Donostia-San Sebastian. The city is divided into 18 districts, and these districts were the selected subzones for the study. Two of these 18 districts with contrasting characteristics were selected to apply the methodology and to study the coherence of the results and the possible solutions.

The first district, Alza, has 21,500 inhabitants and a populationdensity of 4,175 inhabitants=km^2. Among the most populous districts of San Sebastian, it is located in the periphery and on a hillside, but is nevertheless well connected to the city center.

The second district, Zubieta, is located 9.5 km from the center of Donostia-San Sebastian. Its municipality covers approximately 4.5 km^2 and it is home to a population of 294 inhabitants. Its connection with the city center is poor and it has few or no services.

The global data for Donostia-San Sebastian and the selected districts are presented for comparative purposes in the tables. Table 15presents the results of the environmental requirement; the first twocriteria of this requirement show the same value for the entire urban area and for the two selected districts. The PM_{10}, SO_2, NO_2, CO, and O_3 pollutant emissions and the patterns of CO_2 emissions from transportation, motorization rate, and percentage of car use had similar values because traffic is the largest contributor to air pollution in a fairly uniform way across the city, and none of the areas are badly affected by air pollution or GHG emissions (Cristina Enea Foundation and Donostia-San Sebastian City Council 2014; Environment Department of Basque Government 2014, 2015).

	Value				Result		
Criterion of environmental requirement	SS	Alza	Zubieta	Weight (%)	SS	Alza	Zubieta
Air quality	0.94	0.94	0.94	16	0.15	0.15	0.15
GHG emissions	0.60	0.60	0.60	16	0.09	0.09	0.09
Modal splits	0.76	0.76	0.44	61	0.47	0.47	0.27
More sustainable and nonmotorized modes	0.40	0.43	0.09	7	0.03	0.03	0.01
Environmental requirement					0.74	0.74	0.52

Regarding the modal split, the district of Alza, located on east side of the city and on a hillside, is well connected and has a rathersimilar modal split to the global results. In the district of Zubieta, private vehicle use increases and PT use decreases because of poor frequencies and connections with the rest of the urban area (Donostia-San Sebastian City Council 2008). The overall value of the modal split criteria for Donostia-San Sebastian and forAlza district was almost 0.8, which is very reasonable in terms of sustainability, and the value for Zubieta district fell to 0.5 because of the aforementioned factors.

The total value for nonmotorized and the more sustainable modes of travel remained below 0.5, because although there are many facilities for the use of bicycle and pedestrian traffic onthe interconnections between different districts, distances and slopes make that option impractical [Donostia-San Sebastian City Council (Fomento San Sebastián) 2016; Economy and Public Finance Department of Basque Government 2016; Eustat 2016].

Table 16 presents global and local results for the economic requirement. The data needed to assess the criteria for growthof transportation and energy consumption are global, assuming that there are no large differences between different areas of Donostia-San Sebastian in this field (Basque Government andEVE 2015; Environment Department of Basque Government 2014). Regarding the third criterion, in order to reduce the useof private vehicles, some successful actions such as surchargeson national payments, parking fees, and urban road and congestionpricing should be implemented in more areas.

	Value				Result		
Criterion of economic requirement	SS	Alza	Zubieta	Weight (%)	SS	Alza	Zubieta
Growth of transportation	0.17	0.17	0.17	16	0.03	0.03	0.03
Energy consumption	0.67	0.67	0.67	25	0.17	0.17	0.17
Costs of urban transportation	0.39	0	0	59	0.23	0	0
Economic requirement					0.43	0.2	0.2

Table 17 shows global and local results for the social requirement. There were no differences between the safety and the accessibility criteria in the values obtained for the city and for the selected districts. A degree of randomness is assumed in relation tosafety. Accidents, both with and without victims, generally decreased, but there was an increase in vehicle accidents involvingpedestrians, slightly reducing the value of this criterion. Public transportation accessibility in the area is good (Dbus 2016; Donostia-San Sebastian City Council 2016).

Criterion of social requirement	Value			Weight (%)	Result		
	SS	Alza	Zubieta		SS	Alza	Zubieta
Safety	0.58	0.58	0.58	35	0.20	0.20	0.20
Noise	0.553	0.589	0.709	11	0.06	0.06	0.08
Comfort of public transportation	0.507	0.472	0.2235	35	0.18	0.17	0.078
Accessibility	0.9	0.9	0.9	19	0.17	0.17	0.17
Social requirement					0.61	0.6	0.53

Noise emissions are perfectly detailed in noise maps of the city,and this second criterion was accurately quantified for each zone (Donostia-San Sebastian City Council 2015a). The mean value was above 0.5 and it was enhanced in both districts due to their peripheral positions. As expected, Zubieta is noticeably better because of its low density of roads with heavy traffic, low population, and geographic location.

The third criterion of this requirement, comfort of public transportation, was obtained by taking into account the most significantvariables to the user when choosing a mode of transportation for aparticular trip and penalizing differences in PT and private car travel time, low PT frequency, and number of PT transfers. The result forthe global area was 0.507, which could be improved by optimizingthe PT of certain outlying areas—for example, Zubieta, because it has very bad PT connections with almost all subzones. Alza has better PT services, so the value of this criterion was close to the mean value.

The assessment of the two criteria for the urban form requirement (Table 18) yielded global values for the urban area that weremaintained in the districts. The global and local values of urban compactness and residential land use intensity were very poor asa result of an unsustainable urban model. Efforts have been made to improve the sustainability of the transportation network, especially by expanding the bicycle network, but with poor results in the criterion assessment because a structural change is needed to enhance this requirement (Cristina Enea Foundation and Donostia-San Sebastian City Council 2014).

Criterion of urban model requirement	Value			Weight (%)	Result		
	SS	Alza	Zubieta		SS	Alza	Zubieta
Urban model	0.15	0.15	0.15	25	0.04	0.04	0.04
Characteristics of the transportation network	0.25	0.25	0.25	75	0.19	0.19	0.19
Urban model requirement					0.23	0.23	0.23

The model assumes homogeneity in the urban area and the global value is maintained for the selected districts. The city hasa high motorization rate, but it has remained constant over the lastfew years, and a rise in environmental vehicles was observed in the acquisition of new vehicles (Table 19) (Economy and Public Finance Department of Basque Government 2016).

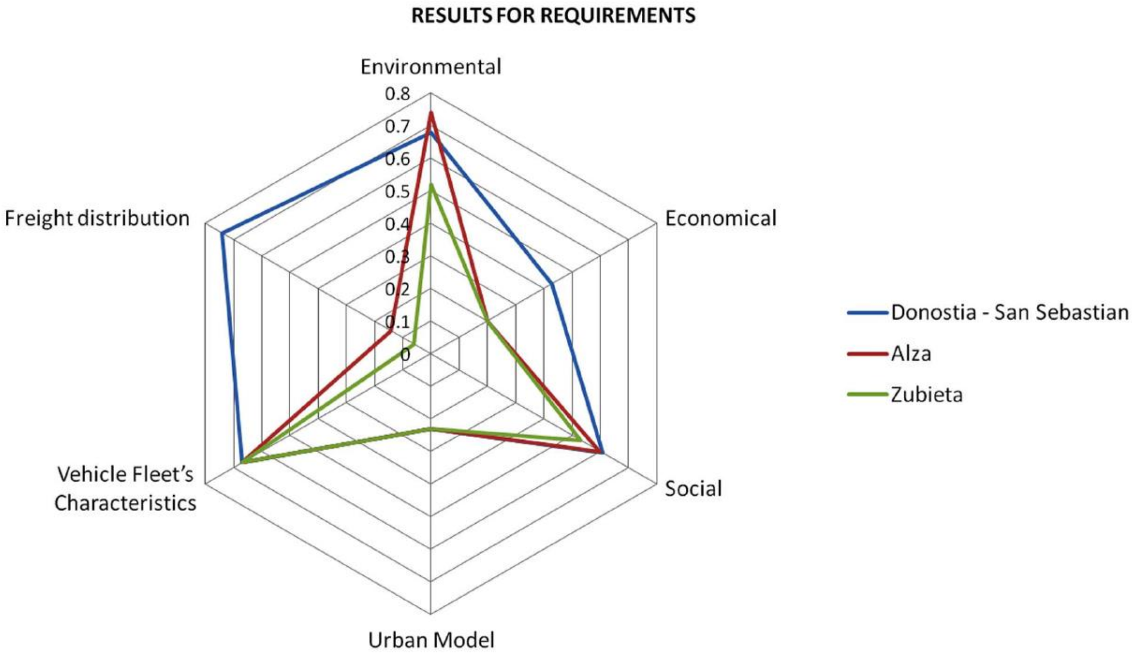
Criterion of vehicle fleet characteristics requirement	Value			Weight (%)	Result		
	SS	Alza	Zubieta		SS	Alza	Zubieta
Motorization rate	0.63	0.63	0.63	50	0.32	0.32	0.32
Vehicle type	0.71	0.71	0.71	50	0.36	0.36	0.36
Vehicle fleet characteristics requirement					0.67	0.67	0.67

Donostia-San Sebastian has implemented different policies to improve sustainability in freight distribution, but they are nearly alllocated in the central and the oldest neighborhoods, which are mainly commercial areas of the city. Almost all other districts work independently; they are self-sufficient using traditional methods that take no account of sustainability (Donostia-San SebastianCity Council 2016). Therefore very poor values were obtained from the point of view of sustainability (Table 20). Table 21 summarizesthe results of the requirements for Donostia-San Sebastian and thetwo selected districts.

Criterion of freight distribution requirement	Value			Weight (%)	Result		
	SS	Alza	Zubieta		SS	Alza	Zubieta
Supply	1	0.33	0.0	43	0.43	0.15	0.0
Demand	0.17	0.0	0.4286	14	0.02	0.00	0.06
Efficiency	0.67	0.0	0.0	43	0.29	0.00	0.00
Freight distribution requirement					0.74	0.15	0.06

Requirement	Donostia	Alza	Zubieta
Environmental	0.74	0.74	0.52
Economical	0.43	0.2	0.2
Social	0.61	0.6	0.53
Urban model	0.23	0.23	0.23
Vehicle fleet characteristics	0.67	0.67	0.67
Freight distribution	0.74	0.15	0.06
Index	0.57	0.43	0.37

A graphic representation in the form of a spider diagram of theset of results for all requirements covering the global area shows that the mean value was exceeded in four requirements: environmental, social, freight distribution, and characteristics of the vehicle fleet (Fig. 5). The urban model requirement obtained the lowest score. The results were as expected in the selected districts. The mean value of three requirements was exceeded in the district of Alza: environmental, social, and characteristics of the vehicle fleet,whereas the freight distribution requirement obtained the lowest score. The selected districts are outside the core commercial zone in which specific regulations apply.



Conclusions and Suggestions for Further Research

Urban transportation projects are increasingly complex and are associated with situations that require robust decision making. Thesedecisions are made at different stages of civil engineering projects.

Decision making in this field can be facilitated by an application of formal methods, such as MCDM and discrete or continuous optimization methods.

The present methodology, based on MCDM methods and applicable to assessing the sustainability of urban transportation, is userfriendly, accessible, versatile, and intuitive. No specific studies arenecessary to obtain the input data, because they are publicly available in the statistical summaries provided by local government and each indicator has a brief description of the required data in order to avoid problems concerning data collection and its interpretation Furthermore, the proposed model is intended to be a global tool, adjustable to the reality of any urban environment with different characteristics, and it can be used in a whole area or in a partof it.

The results are easily understandable and give an idea of sustainability in the urban area in either a global or a specific way. Two challenges can be overcome by applying this methodology: a totalvalue for sustainable transportation can be calculated and the aspects that form those requirements can then be improved to obtain better global results; and within an urban area, subzones with shortcomings can be detected and evaluated in relation to different objectives. The first case could involve measuring the extent to whichthe mean global value is the local value for the sustainability of thetransportation system, and the second case involves determining how local actions affect the global value and vice versa.

The practical results obtained using the proposed methodologyfor the case of Donostia-San Sebastian and the two selected districts are consistent and logical, in view of the reality of the urbanenvironment. Commerce and tourism are the main activities of thecity, although its industrial activity is hardly significant. Regarding mobility, almost half of all journeys in the city are made by walking, and a network of bicycle lanes crisscrosses the city. The city has a rather complicated orography, but several methods of verticaltransportation have been installed to circumvent these steep rises (lifts, escalators, and so on) while maximizing pedestrian mobility. From the point of view of sustainability, the urban form of Donostia-San Sebastian is improvable. It has a low intensity of residential land use and urban compactness (few habitants and buildings per hectare); the efficiency of the public transportation systemof the city is therefore not as good as it would be with a more appropriate urban model. Some districts of the city with low population densities and those located at the periphery have no other choice than to use private vehicles as a mode of transportation, decreasing the sustainability of the system.

Policy makers may also use the tool described in this paper as an evaluation tool. When the numerical value of sustainability is obtained, any change in the urban transportation system will modify this initial value, so different changes in the transportation design or different transportation plans can be evaluated through numerical quantifications compared with the preceding values. Furthermore,the efficiency of different local policies can be measured and compared by applying the methodology to a part of the urban area in order to detect which policy would be more appropriate in a local and a global manner. The model can be used for planning and engineering decisions to increase sustainability based on the results, for example, regarding

- Different itineraries of a new PT line;
- Changes in the itineraries or frequencies of existing PT lines;
- Changes in freight distribution planning; or
- Changes in urban form for new districts.

In order to improve the assessment tool and to establish the limits of the approach, further research on the following issues could be addressed:

- The character of the indicators presented in this work is easily available in the statistical summaries provided by local government. Assuming that not all urban areas have the same information available, many of these indicators may be estimated in most medium and large European municipalities. Nevertheless,a study to create default values or similar indicator groups couldbe proposed in a future version of the index.
- The objective of the tool is to assess the sustainability of the urban transportation system in different urban areas and to estimate the influence of possible actions in this direction, rather than to compare different cities. Therefore the resulting ranking could be debatable, because city-specific characteristics may play a crucial role (size, location, activities of the zone, and so on). A discussion of the use of the index might help to define whether this index permits a comparison of different cities.

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