

Article

Minimizing the Social Impact of Construction Work on Mobility: A Decision-Making Method

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Abstract: Minimising the impacts of construction work on mobility, especially in urban areas, is a major issue for local authorities and construction planners that has not been sufficiently studied. This paper proposes a deterministic decision-making method for quantifying the impacts of construction work on mobility, including emergency vehicles, mass transit, individual transport, bicycles, and pedestrians. The method is based on multi-attribute utility theory, interviews with experts representing various stakeholders in construction, and a review of the literature and legislation. The practical use is illustrated with a real case study in which two shaft-construction processes (diaphragm wall excavated using a hydromill and vertical shaft sinking machine) are compared and ranked. The sensitivity analysis shows the robustness of the results. The resulting Mobility Impact Index can easily be integrated with other social, economic, and environmental criteria, thereby enabling the evaluation of alternatives from a multi-criteria perspective, e.g., in tender processes. The method could be useful to public authorities and design and construction companies and is being piloted in construction projects of the city of Barcelona. It has implications for corporate social responsibility, social/sustainable procurement, and social/sustainable impact assessment in construction.

Keywords: mobility; construction work; multi-criteria decision-making; multi-attribute utility theory; social impact assessment; emergency vehicles; mass transit; individual transport; bicycles; pedestrians

1. Introduction

Construction provides society with infrastructure, buildings, and services, but it also has negative environmental and social impacts [1]. Contractors have increased their awareness of sustainability [2], and several studies have examined the environmental and economic impacts of construction work [3–5]. However, few studies have investigated and quantified the social impacts, which have been relegated to third priority, behind the economic and environmental impacts [6]. Matthews et al. [7] state that social costs are often ignored by engineers and project managers during project planning, design, and bid evaluation because “they cannot be calculated using standard estimating methods”. Kirchherr and Charles [8] stress the complexity of conceptualising the social impacts of infrastructure development, as they occur “over various time, space and value dimensions”. Obviating the social dimension in the development of an infrastructure can have short- and long-term detrimental effects [9].

One of the potentially significant social impacts of construction work is its effects on various types of mobility, especially in urban areas. Mitigating these impacts “is a major issue for construction managers, city officials and other regulatory bodies” [10]. Many studies have recognised the impacts of construction work on mobility [3,7,11–16]. They have studied the negative effects of construction projects on a general category of (road) traffic, among other impacts that are not related to mobility.

These studies either are, mainly, qualitative, or consider the impact on traffic as a social cost due to traffic delays or loss of parking revenues, that is to say, they quantify the impact in monetary terms. This lack of research on the traffic impacts of building construction has resulted in a lack of awareness amongst construction planners [10].

In fact, different construction processes can have different impacts on mobility. For example, trenchless technology for pipelines causes minimal surface disruption compared to open-cut methods [7]. Being able to quantify these impacts would help decision makers better plan construction work, especially in highly populated areas. The most promising opportunities for future research include the development of metrics for social sustainability [17].

Therefore, the present study aims to: (1) identify related work; (2) identify the various types of impacts on the different types of mobility due to construction work; (3) develop a method to quantify those impacts and enable the ranking and selection of the best construction process and plan; and (4) illustrate the method with a case study. To the best of the authors' knowledge, this is the first quantitative study, in non-monetary terms, that focuses specifically on the impacts of construction work on mobility and includes its different types such as mass transport, emergency vehicles, bicycles, etc. and their different importance. The research seeks to enable realism and impartiality in order to improve sustainable decision-making [18].

2. Related Work

The assessment of the social impact of construction work can be understood within the framework of the corporate social responsibility (CSR) of construction companies [17], sustainable public procurement (SPP), and environmental and social impact assessment (ESIA). In this regard, some authors have argued that CSR is increasingly valued in the construction industry but that understanding of what it means and how to apply it is limited [19–21]. As Zhao et al. [19] have observed, “A CSR indicator system for construction companies has not been established” and should be given more consideration.

In recent years, green public procurement, “a process whereby contracting authorities aim to procure services and products that meet environmental requirements”, has been evolving towards SPP, which includes both environmental and social considerations [22]. According to the European Public Procurement Directive [23], contracting authorities shall base the award of public contracts on the most economically advantageous tender. This should be done using a cost-effectiveness approach that may include qualitative, environmental, and/or social aspects. A number of organisations, such as the World Bank, the Asian Development Bank, and the United Nations Development Programme, have called for an obligatory social impact assessment (SIA) in the tender process [24]. Nevertheless, there is a lack of inclusion of social criteria in SPP [22] and no current understanding of what social procurement means for the construction industry; hence, further research is needed [6].

Since the environmental impact assessment (EIA) was first introduced, there have been debates over how to improve the issues involved in its implementation [25]. One important debate has concerned the weight assigned to social impacts, which is usually considered too low. Consequently, the SIA was introduced. However, for a long time it was regarded as secondary to the EIA [25,26]. As the importance of the social dimension of projects has become increasingly recognised, an integrated approach has emerged, namely, the ESIA, which places similar emphasis on both environmental and social dimensions [25].

Most of the authors cited in this section have researched the CSR, SPP, and ESIA in the construction industry. However, it can be concluded that there is still a gap in the knowledge regarding the social impacts of construction work and its implications on CSR, SPP, and ESIA. The research presented in this paper contributes to this social framework by providing a new method to assess the impacts of construction work on mobility.

3. Multi-Criteria Decision Analysis and Multi-Attribute Utility Theory

Multi-criteria decision analysis is a valuable tool for assisting with decision-making processes [27]. Amongst other things, it can be used to assess the impact of construction work [28,29]. For the present research, the five main multi-criteria decision theories were analysed. These are ordinal multi-criteria methods, multi-objective mathematical programming, multi-attribute utility theory (MAUT), outranking relation theory, and preference disaggregation analysis. Although ordinal multi-criteria methods were historically relevant, as they were the first, they have some drawbacks such as that the introduction or removal of alternatives may modify the ranking of the rest of the alternatives [30]. Multi-objective mathematical programming mainly aims at solving continuous problems [31], while the problem presented in this paper aims at choosing between discrete alternatives. Outranking relation theory methods can produce incomparabilities and violate transitivity. Ultimately, the well-known MAUT [32] was selected as the most suitable choice for decision-making in construction processes as it is helpful for solving discrete problems, is intuitive, and is based on a solid foundation [33]. It has also been successfully used in construction-related decision-making processes [34–36] as well as to assess various sustainability-related aspects of construction, such as the environmental impact [33,37].

4. Proposed Method

To develop the method presented in the current paper, new criteria, weights, and indicators were defined based on MAUT and following the steps shown in Figure 1.

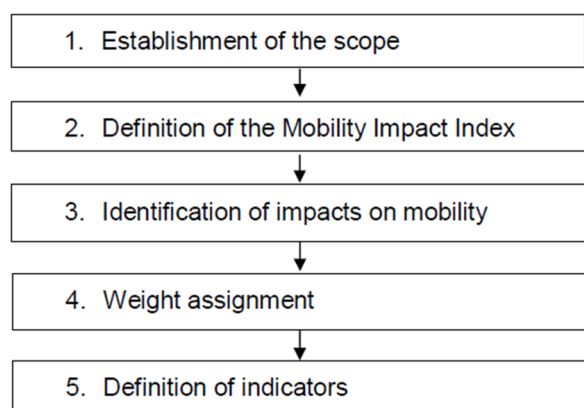


Figure 1. Main steps in the development of the method to quantify the impact of construction work on mobility.

4.1. Establishment of the Scope

The method was designed to compare the impacts on mobility of different construction processes and plans. The proposed method is deterministic, that is to say, although some variables of the method are exposed to uncertainty, such as the duration of the effects on accessibility, it has not been included in the study.

4.2. Definition of the Mobility Impact Index

For the present research, the Mobility Impact Index (MII) was defined similarly to the Environmental Impact Index (EII) defined in Casanovas-Rubio and Ramos [33], as both are based on an adaptation of MAUT and measure impacts of construction work. The MII_i of construction process i (the alternative being assessed) is a measure of the social impact of construction work on mobility. It is the weighted sum of all the impacts on mobility (Equation (1)). The best alternative in terms of impact on mobility is the one with the lowest MII.

$$MII_i = \sum_j w_j \cdot \text{Impact on mobility}_{ij} \quad (1)$$

where w_j is the weight or importance assigned to the impact j on the mobility criterion. The impacts on mobility criteria are identified in Section 4.3, and reference weights are provided in Section 4.4. $\text{Impact on mobility}_{ij}$ is the relative impact produced by construction process i for criterion j . It can be defined using an alternative as a reference, as shown in Equation (2).

$$\text{Impact on mobility}_{ij} = \frac{I_{ij}}{I_{refj}} \quad (2)$$

where I_{ij} is the measurement of the indicator of criterion j of alternative i , and I_{refj} is the measurement of the indicator of criterion j for the alternative used as a reference. The reference alternative has a relative impact equal to 1, whilst the remaining alternatives have a proportionate impact. Equation (2) can be applied when the reference alternative produces all the impact types generated by the other alternatives. Otherwise, if a measurement of the reference alternative were 0, according to Equation (2), the relative impact of the remaining alternatives would be infinite. Alternatively, the $\text{Impact on mobility}_{ij}$ can be defined as shown in Equation (3), taking the highest-impact alternative for each criterion as a reference.

$$\text{Impact on mobility}_{ij} = \frac{I_{ij}}{\max \{I_{ij}\}_{j=\text{constant}}} \quad (3)$$

where $\max \{I_{ij}\}_{j=\text{constant}}$ is the maximum measurement of the indicator of criterion j of all the considered alternatives. The relative impact can thus have values between 0 and 1. For the alternatives to be comparable, the same equation (i.e., either (2) or (3)) must be used to calculate the relative impact of each alternative. Both equations can be understood as adaptations of a linear value function (MAUT). Linear functions were considered to be adequate to assess the social impact of construction work on mobility in this novel first approach.

Some criteria have two indicators. In those cases, the $\text{Impact on mobility}_{ij}$ can similarly be defined as presented in Equation (4) or (5).

$$\text{Impact on mobility}_{ij} = w_{j1} \frac{I_{ij1}}{I_{refj1}} + w_{j2} \frac{I_{ij2}}{I_{refj2}} \quad (4)$$

$$\text{Impact on mobility}_{ij} = w_{j1} \frac{I_{ij1}}{\max \{I_{ij1}\}_{j=\text{constant}}} + w_{j2} \frac{I_{ij2}}{\max \{I_{ij2}\}_{j=\text{constant}}} \quad (5)$$

where w_{j1} and w_{j2} are the weights or importance assigned to indicators 1 and 2, respectively, of criterion j . Reference weights for the indicators are provided in Section 4.4. I_{ij1} and I_{ij2} are the measurements of indicators 1 and 2, respectively, of criterion j of alternative i . I_{refj1} and I_{refj2} are the measurements of indicators 1 and 2, respectively, of criterion j for the alternative taken as a reference. $\max \{I_{ij1}\}_{j=\text{constant}}$ and $\max \{I_{ij2}\}_{j=\text{constant}}$ are the maximum measurements of indicators 1 and 2, respectively, of criterion j amongst all the alternatives considered. If $I_{ij1} = 0$ or $I_{ij2} = 0$ for all the compared alternatives, the impact on mobility should be calculated as a criterion with a single indicator without weighting because the null indicator does not help to discriminate between alternatives.

4.3. Identification of Impacts on Mobility

The identification of the impacts on mobility caused by construction work was based on an initial round of interviews with experts on decision-making in construction and a review of the literature and European and Spanish legislation. This first round of interviews was conducted with a

panel of 11 members representing the various stakeholders in construction: Local, regional, and state government; construction companies; environmental and engineering consulting firms; concessionaires; academia; and civil engineer associations. Their educational background was in civil engineering or architecture, and some of them have a PhD. Their minimum and maximum professional experience was 11 and 41 years, with an average experience of 26 years. Most of them were directors of civil engineering, infrastructures, construction, public space, and managing departments, although there also were some technical advisors and a full professor.

The means of transport that construction work can impact were identified in this step as: (1) emergency vehicles, (2) mass transit, (3) individual transport, (4) bicycles and other cycles, and (5) pedestrians. In the construction of mobility projects, an additional impact of the construction work on mobility was identified, namely, (6) the duration of the work or time until the mobility project is finished and can start to be used. This criterion refers to the necessity or urgency of beginning to use the mobility service being constructed once it has been finished. The different impacts of construction work on the different means of transport and other elements were also analysed in this step. They are presented in Table 1.

Table 1. Classification of the impacts on mobility according to the affected element and type of effect.

Affected Element	Effect
Lane or track	Diversion Closure
Stop, station, or parking space	Relocation Total or partial closure

4.4. Weight Assignment

Based on an analysis of 20 weight assignment methods (direct assignment, ordinal methods, comparison on the basis of a single reference, alternative comparison methods, pairwise comparison matrix, etc.) and a practical exercise in the first round of interviews, the ratio assignment method [38] was chosen. It was selected because it considers both ordinal and cardinal information from the decision maker and does not involve an excessive cognitive workload or time commitment. As explained in Casanovas-Rubio and Ramos [33], it “consists in assessing the relative importance of each criterion with respect to the least important criterion, taken as a reference”. Thus, for example, a criterion might be said to be twice as important as the least important criterion.

This method was used to assign the final weights of the MII in a second round of interviews with six expert panellists representing construction stakeholders. Table 2 shows the weights obtained as the arithmetic mean of the weights assigned by the experts for different environments: Urban, suburban, and rural. The weights in the “OM” columns were assigned considering that the analysed construction work was intended to solve an imminent problem of obligatory mobility (OM) (for reasons of work or study), especially mass transit projects. In this case, the duration of the work becomes more important because there is an urgent social need to start using the mobility service to be provided through the project. The weights in the “M” columns were assigned considering that the analysed construction work was intended to solve a mobility problem (M) that is not an imminent problem of obligatory mobility. If the project being constructed is not related to mobility (NM) (e.g., a wastewater treatment plant or school), the criterion duration of the work (time until the mobility project is finished and can start to be used) does not apply. The weights in the “NM” columns were calculated by distributing a total weight of 100% between all the criteria except for the duration of the work (time until the mobility project is finished and can start to be used), proportionally to the weights in “M” columns. In other words, the weights in “NM” columns are a normalisation of the weights in column “M” to sum 100% when the criterion duration of the work is not used (in NM projects).

Table 2. Reference weights assigned by the experts to the impacts of construction work on mobility for urban (U), suburban (S), and rural (R) environments.

Criterion	Weight (%)								
	U			S			R		
	NM	M	OM	NM	M	OM	NM	M	OM
Emergency vehicles	33.4	29.3	30.9	33.9	29.2	30.9	36.0	29.9	31.3
Mass transit	23.9	20.9	18.5	24.6	21.2	18.5	23.2	19.3	18.8
Individual transport	14.7	12.9	8.6	15.6	13.4	8.6	18.6	15.5	11.2
Bicycles	12.1	10.6	6.2	11.7	10.1	6.2	10.9	9.1	6.2
Pedestrians	15.9	13.9	11.1	14.2	12.2	11.1	11.3	9.4	7.5
Duration of the work	-	12.4	24.7	-	13.9	24.7	-	16.8	25.0

Note: NM = non-mobility project, M = mobility project, and OM = obligatory mobility project.

The highest priority was assigned to minimising the disruption for emergency vehicles, followed by mass transit for all three of the environments considered. In a rural environment, more importance was given to minimising the impacts on individual transport than in the other environments, as rural populations might be more dependent on individual transport than their urban or suburban counterparts. In contrast, minimising the impact on pedestrians was considered more important in urban and suburban areas than in rural ones, as the number of pedestrians is higher.

When none of the compared alternatives has an impact from Table 2, that impact should be excluded from the decision-making, as it does not help to discriminate between alternatives [33]. For example, if none of the alternatives affect mass transit, this impact should not be included in the decision. When a criterion is eliminated, the weights of the rest of the criteria should be standardised to total 100, as that way the impact of the alternative taken as a reference will equal 1 when using Equation (2), and the impact of a hypothetical alternative with the maximum impact amongst all the alternatives will equal 1 when using Equation (3) [33].

In the second round of interviews, the experts also assigned weights to the indicators belonging to a criterion with more than one indicator, i.e., as explained in Section 4.5, individual transport and bicycles. Table 3 presents the weights obtained as the arithmetic mean of the weights assigned by the experts for the three different environments. The weights in Tables 2 and 3 can be used as a reference and adjusted to the specific construction environment.

Table 3. Reference weights assigned by the experts to the indicators belonging to a single criterion for urban, suburban, and rural environments.

Criterion.	Indicator for Impacts on	Weight (%)		
		U	S	R
Individual transport	Lanes	51.4	62.8	72.7
	Parking spaces	48.6	37.2	27.3
Bicycles	Cycle lanes	72.9	64.4	64.1
	Bicycle parking spaces	27.1	35.6	35.9

4.5. Definition of Indicators

The general scheme presented in Equation (6) was taken as a starting point based on the interviews and the authors' analysis. The literature review provided scarce information on the quantification of the social effects of construction work on mobility.

$$I = \text{Duration} \cdot \text{No. of people affected} \cdot \text{Intensity} \quad (6)$$

The indicators are defined in the next subsections. The following should be noted:

- (1) "Intensity" was defined specifically for each impact based on the increase in distance and price, the closure or relocation of the service, and other factors.

- (2) The data in parentheses for some indicators mean that they may be difficult to obtain or unavailable. If a datum is unavailable, the indicator can alternatively be defined without it, provided that the impacts of all the construction alternatives are calculated equally. The units in parentheses refer to the data in parentheses.
- (3) Some coefficients were defined to better differentiate between the impacts of the construction alternatives in a standardised manner (C_{int} , C_{type} , C_{dan} , and C_{dens} in Table 4 and Table 7, Table 8, Table 9 and Table 10). They do not have an absolute value but reflect a ranking. These coefficients were determined by the experts interviewed according to the intensity/severity of the social impact caused by the construction work.
- (4) The distance of the itinerary during construction is measured from the starting point of the diversion to its end point.

4.5.1. Emergency Vehicles

All types of emergency vehicles are considered (ambulances, firefighters, security forces, civil defence, etc.) and all are assumed to have the same importance. The indicator of effects on emergency vehicles I_1 is defined in Equation (7).

$$I_1 = \sum_i \sum_j t_{ij} \cdot (n_i) \cdot C_{int_{ij}} \quad (7)$$

In $\left[days \cdot \left(\frac{\text{no. of trips}}{365 \text{ days}} \right) \right]$, where:

i = Entry and exit point of emergency vehicles at their premises (hospital, fire station, police station, etc.) or area where an emergency could occur that is inaccessible or offers only limited accessibility for a period of time due to the construction work.

j = Construction stage with a markedly different effect on the accessibility to the entry and exit points for emergency vehicles or to the area.

t_{ij} = Duration of the effects on the accessibility to i during j (days).

n_i = Number of people affected per unit of time. Average number of trips by the emergency vehicles per unit of time at entry and exit point i or average number of people that need an emergency vehicle in the affected area i . The latter can be calculated as the surface area of the affected area multiplied by the population density and the average number of annual trips by the emergency vehicles per 100,000 inhabitants. In the region of Catalonia, 12,649 trips per 100,000 inhabitants can be used as a reference [39–41] (calculations by the authors; number of trips/365 days).

$C_{int_{ij}}$ = Coefficient reflecting the intensity of the effects on i during j depending on whether the construction work hinders or prevents the emergency vehicles from passing (Table 4) (adimensional).

Table 4. Intensity coefficient according to the construction work's effect on emergency vehicles.

Effect	Clear Width ^a (m)	C _{int} for Emergency Vehicles
Null	>3.5	0
Narrowing that hinders, but does not prevent, emergency vehicles from passing	>3.1 and ≤3.5	1
Emergency vehicles cannot pass	≤3.10	5

^a Calculated based on the maximum authorised vehicle width in Spain: 2.55 m [42].

4.5.2. Mass Transit

The following collective means of transport are considered: Bus, coach, underground, tram, and train. The indicator of the effects on mass transit I_2 is defined in Equation (8) using Table 1.

$$I_2 = \sum_i \sum_j \frac{t_{ij} \cdot (n_i) \cdot rd_{ij} \cdot dcons_{ij} \cdot rp_{ij}}{rc_{ij}} \quad (8)$$

In $\left[days \cdot \left(\frac{no.of\ people}{day} \right) \cdot km \right]$, where:

i = Stop, station, lane, or track affected by the construction work.

j = Construction stage with a markedly different effect on the stop, station, lane, or track.

t_{ij} = Duration of the effects on i during j (days).

n_i = In case of diversion or relocation of i , the number of people who use i per day. In case of closure of lanes or tracks, the number of people who use the closed lanes or tracks plus the number of people who use the lanes or tracks that receive the diverted traffic during the closure. In case of closure of stops or stations, the number of people who use the closed stops or stations plus the number of people who use the previous and following stops or stations (no. of people/day).

rd_{ij} = Relative increase in the distance of itinerary i during j expressed as the ratio of the distance of the itinerary during construction to the distance of the itinerary without construction (adimensional). In case of closure of a lane or track in a stretch with more lanes or tracks, $rd_{ij} = 1$.

$$rd_{ij} = \begin{cases} \left(\frac{d_{with\ construction}}{d_{without\ construction}} \right)_{ij} \quad \forall i = \text{lane or track} \\ \left(\frac{maxd_{between\ stops\ or\ stations\ with\ construction}}{maxd_{between\ stops\ or\ stations\ without\ construction}} \right)_{ij} \quad \forall i = \text{stop or station} \end{cases}$$

where $d_{cons_{ij}}$ = Distance of the itinerary in case of effects on the lane or track or maximum distance between stops or stations during j in case of effects on stops or stations (km). Note: Both the relative increase in the distance (rd_{ij}) and the distance during construction in absolute value ($d_{cons_{ij}}$) have been considered. The first is useful to compare alternatives with similar distance in absolute value, the second to compare alternatives with similar relative increase in the distance.

rp_{ij} = Relative increase in the price of the itinerary with i during j expressed as the ratio of the price of the itinerary during construction to the price without construction (adimensional).

rc_{ij} = Relative increase in the capacity of i and the adjacent stops, stations, lanes, or tracks, as applicable, during j (adimensional). In case of diversion of the lane or track or relocation of the stop or station, $rc_{ij} = 1$. In case of closure:

$$rc_{ij} = \begin{cases} \left(\frac{no.\ of\ lanes_{with\ construction}}{no.\ of\ lanes_{without\ construction}} \right)_{ij} \quad \forall i = \text{lane or track} \\ \left(\frac{no.\ of\ stops_{with\ construction}}{no.\ of\ stops_{without\ construction}} \right)_{ij} \quad \forall i = \text{stop or station} \end{cases}$$

where $no.\ of\ lanes_{with\ construction}$ = Number of lanes or tracks on which the mass transit from the closed lanes or tracks i travels during j .

$no.\ of\ lanes_{without\ construction}$ = $no.\ of\ lanes_{with\ construction}$ plus the number of closed lanes or tracks.

$no.\ of\ stops_{with\ construction}$ = Number of stops or stations used by the people who use the closed stops or stations i during j .

$no.\ of\ stops_{without\ construction}$ = $no.\ of\ stops_{with\ construction}$ plus the number of stops or stations closed.

Table 5 shows the most common relative increases in capacity in case of closure of one or two stops or stations assuming that the users of the closed stops or stations will use the next closest ones on the same line.

Table 5. Relative increase in capacity in case of closure of one or two stops or stations according to their location.

Number of Stops or Stations Closed	Location of the Closed Stop(s) or Station(s)	
	Intermediate	Terminus
1	2/3	1/2
2	2/4	1/3

4.5.3. Individual Transport

Motorcycles, cars, high-occupancy vehicles (HOVs), taxis, vans, and other individual means of transport are considered here. Two indicators were defined to quantify the effects of construction work on individual transport: $I_{3,1}$ for the effect on lanes (Equation (9)) and $I_{3,2}$ for the effect on parking spaces (Equation (10)).

$$I_{3,1} = \sum_i \sum_j \frac{t_{ij} \cdot (ADT_i) \cdot (n_i) \cdot rd_{ij} \cdot dcons_{ij} \cdot rp_{ij}}{rc_{ij}} \quad (9)$$

In $\left[days \cdot \left(\frac{\text{no. of vehicles}}{\text{day}} \right) \cdot \left(\frac{\text{no. of people}}{\text{vehicle}} \right) \cdot km \right]$ or, in some cases, $\left[days \cdot \left(\frac{\text{no. of vehicles}}{\text{day}} \right) \cdot \left(\frac{\text{no. of people}}{\text{vehicle}} \right) \cdot \$ \cdot km \right]$, where:

i = Lane or lanes affected by the construction work.

j = Construction stage with a markedly different effect on the lane.

t_{ij} = Duration of the effects on i during j (days).

ADT_i = Average daily traffic of i (no. of vehicles/day).

n_i = Average vehicle occupancy in i (no. of people/vehicle). In the absence of more precise information, and where deemed applicable, data from Table 6 can be used.

rd_{ij} = Relative increase in the distance due to the effects on i during j expressed as the ratio of the distance of the itinerary with construction to the distance of the itinerary without construction (adimensional). In case of closure of a lane on a carriageway that has one or more other lanes for traffic heading in the same direction, $rd_{ij} = 1$.

$dcons_{ij}$ = Distance of itinerary i during j (km). Note: Both the relative increase in the distance (rd_{ij}) and the distance during construction in absolute value ($dcons_{ij}$) have been considered for the reasons explained in Section 4.5.2.

Table 6. Average vehicle occupancy according to the type of lane.

Type of Lane	Average Vehicle Occupancy (No. of People/Vehicle)
Conventional lane in the city of Barcelona or similar	1.17 ^a
HOV lane	Minimum number of people required to drive in the HOV lane

^a Includes cars and motorcycles [43].

rp_{ij} = Relative increase in the price of the itinerary equivalent to i during j expressed, in general, as defined in Section 4.5.2 (adimensional). If there is an alternative with $Price_{without\ construction\ ij} = 0$ and $Price_{with\ construction\ ij} \neq 0$, rp_{ij} is defined as follows (currency units):

$$rp_{ij} = \begin{cases} \frac{Price_{with\ construction\ ij} - Price_{without\ construction\ ij}}{Price_{without\ construction\ ij}} & \forall ij \text{ with } Price_{with\ construction\ ij} - Price_{without\ construction\ ij} \geq 1 \\ 1 & \forall ij \text{ with } Price_{with\ construction\ ij} - Price_{without\ construction\ ij} < 1 \end{cases}$$

A threshold was set at 1 in the alternative definition of rp_{ij} . Without the threshold, when $Price_{with\ construction\ ij} - Price_{without\ construction\ ij} < 1$, rp_{ij} would be < 1 and would produce a reduction in the indicator of impacts on individual transport ($I_{3,1}$, Equation (9)), whereas there would actually be an increase in the impact due to the increase in the price of the itinerary.

rc_{ij} = Relative increase in the capacity of i and the adjacent lanes during j expressed as the ratio of the capacity with construction to the capacity without construction, defined similarly to Section 4.5.2 for lanes (adimensional). In case of lane diversion, $rc_{ij} = 1$.

$$I_{3,2} = \sum_i \sum_j \sum_k t_{ijk} \cdot n_{ijk} \cdot rp_{ijk} \cdot Ctype_k \cdot Cint_{ijk} \quad (10)$$

In $[days \cdot \text{no. of parking spaces}]$ or, in some cases, $[days \cdot \text{no. of parking spaces} \cdot \frac{\$}{\text{day}}]$, where:
 i = Parking area affected by the construction work.

j = Construction stage with a markedly different effect on the parking area.
 k = Type of parking space.
 t_{ijk} = Duration of the effects on type k parking spaces in i during j (days).
 n_{ijk} = Number of type k parking spaces in i affected during j (no. of spaces).
 rp_{ijk} = Relative increase in the price of a parking space equivalent to a type k parking space in i during j in the closest alternative parking area, expressed, in general, as the ratio of the price of the parking space with construction to the price of the parking space without construction (adimensional).
 If $\exists ijk$ of any alternative with $Price_{without\ construction\ ijk} = 0$ and $Price_{with\ construction\ ijk} \neq 0$, rp_{ijk} is defined as follows (currency units/day):

$$rp_{ijk} = \begin{cases} Price_{with\ construction\ ijk} - Price_{without\ construction\ ijk} \\ \forall i \text{ with } Price_{with\ construction\ ijk} - Price_{without\ construction\ ijk} \geq 1 \\ 1, \quad \forall i \text{ with } Price_{with\ construction\ ijk} - Price_{without\ construction\ ijk} < 1 \end{cases}$$

$Ctype_k$ = Coefficient according to the type of parking space affected (Table 7) (adimensional).
 $Cint_{ijk}$ = Coefficient of the intensity of the effects of the construction work on type k parking spaces in i during j depending on whether the parking spaces are relocated or simply closed (Table 8) (adimensional).

Table 7. Coefficient according to the type of parking space affected by the construction work.

Type of Parking Space	Ctype
Conventional	1
Taxis	1
Taxis connected with another service (hospital, hotel, train station, bus station, airport, etc.)	5
Bus close to cultural heritage and tourist attractions	5
Loading and unloading	5
Reserved for people with reduced mobility	10

Table 8. Intensity coefficient according to the effects of the construction work on parking.

Effect	Cint for Parking Spaces
Relocation	1
Closure	2

4.5.4. Bicycles

The effects on transport by bicycle and other cycles are considered here. Two indicators were defined to quantify the effects of construction work on bicycle transport: $I_{4.1}$ for the effect on the cycle lanes (Equation (11)) and $I_{4.2}$ for the bicycle parking spaces (Equation (12)). Effects on public bicycle parking spaces are considered as important as effects on those of rental services.

$$I_{4.1} = \sum_i \sum_j t_{ij} \cdot (ADT_i) \cdot rd_{ij} \cdot dcons_{ij} \cdot Cdan_{ij} \tag{11}$$

In $\left[days \cdot \left(\frac{no.of\ cycles}{day} \right) \cdot km \right]$, where:

i = Cycle lane affected by construction work.
 j = Construction stage with a markedly different effect on the cycle lane.
 t_{ij} = Duration of the effects on i during j (days).
 ADT_i = Average daily traffic of cycles in i (no. of cycles/day).
 rd_{ij} = Relative increase in distance due to the effects on i during j as defined in Section 4.5.3.
 In case of closure of a cycle lane in a street with conventional lanes that have not been closed and without an equivalent alternative itinerary by a cycle lane, $rd_{ij} = 1$.
 $dcons_{ij}$ = Distance of the itinerary by i during j (km).

$Cdan_{ij}$ = Coefficient for the increase in danger of the alternative itinerary equivalent to i during j (Table 9) (adimensional).

$$I_{4.2} = \sum_i \sum_j t_{ij} \cdot n_{ij} \cdot C_{int_{ij}} \quad (12)$$

In [days·no. of bicycle parking spaces], where:

i = Bicycle parking area affected by the construction work.

j = Construction stage with a markedly different effect on the bicycle parking area.

t_{ij} = Duration of the effects on i during j (days).

n_{ij} = Number of bicycle parking spaces in i affected during j (no. of bicycle parking spaces).

$C_{int_{ijk}}$ = Coefficient of the intensity of the effects of the construction work on i during j (Table 8) (adimensional).

Table 9. Coefficients for the increase in danger according to the alternative equivalent itinerary during construction.

Alternative Equivalent Itinerary	Traffic Density	Cdan
Cycle lane (for cyclists only)	-	1
Conventional lane (no alternative equivalent cycle-lane itinerary)	Low	2
	Medium	3
	High	5

4.5.5. Pedestrians

The indicator of effects on pedestrians I_5 is defined in Equation (13). A simplified indicator I_{5s} is defined in Equation (14).

$$I_5 = \sum_i \sum_j \frac{t_{ij} \cdot C_{dens_i} \cdot a_i \cdot rd_{ij} \cdot d_{cons_{ij}}}{ra_{ij}} \quad (13)$$

In [days·m²], where:

i = Pedestrian area (area in which pedestrians have priority; pavements, pedestrian crossings, and precincts, etc.) that has become inaccessible to pedestrians due to the construction work.

j = Construction stage with a markedly different effect on the pedestrian area.

t_{ij} = Duration of the effects on i during j (days).

C_{dens_i} = Coefficient representing the usual pedestrian density of i (Table 10) (adimensional).

a_i = Width of i without construction work (m).

rd_{ij} = Relative increase in the distance due to the effects in i during j as defined in Section 4.5.3.

$d_{cons_{ij}}$ = Distance of the itinerary through i during j (km).

ra_{ij} = Relative increase in the width of i due to the effects of j expressed as the ratio of the width of i with construction to the width of i without construction (adimensional).

$$I_{5s} = \sum_i \sum_j t_{ij} \cdot C_{dens_i} \cdot S_{ij} \quad (14)$$

In [days·m²], where:

i, j, t_{ij} and C_{dens_i} are defined in indicator I_5 .

S_{ij} = Area of i inaccessible to pedestrians during j (m²).

Table 10. Density coefficient according to the usual pedestrian density.

Pedestrian Density	Cdens
Low ^a	0.5
Medium ^b	1
High ^c	5

^a Few houses, services or business; pedestrians every now and then. ^b Mainly residential area with some businesses; the flow of people is quite constant but not very dense. ^c Continuous flow and high number of people.

4.5.6. Duration of the Work (Time Until the Mobility Project Is Finished and Can Start to Be Used)

In the case of mobility-related construction projects, the indicator I_6 defined in Equation (15) should also be used.

$$I_6 = t \quad (15)$$

where t is the time in days from the start of the construction work until its completion.

The duration of the construction work has already been considered in the rest of the indicators (a longer duration leads to a higher impact on mobility). However, one aspect of the duration has not been included in the rest of the indicators and is considered here: The urgency and need to start using the mobility service to be provided once the construction is finished. As the method presented in this paper evaluates the impacts of construction work on mobility, I_6 only considers work that, once finished, will enable the supply of services related to the mobility of people or freight transport. In the case of the construction of projects unrelated to mobility, the indicator I_6 should not be applied, and its weight should be proportionally distributed between the rest of the criteria (as presented in Table 2).

5. Case Study

5.1. Description and Input Data

The proposed method was applied to the construction of two real ventilation and emergency exit shafts on the Madrid–Barcelona–French border high-speed rail line. The two shafts are located in the Eixample district of Barcelona and have very similar mobility conditions.

The first shaft is located at the crossing of Bruc Street with Provença Street (see Figure 2). It was built according to the conventional process of a diaphragm wall excavated using a hydromill and has an inside diameter of 20 m. The reinforced walls, which are 1.20 m thick, extend 43 m below ground level. The construction work consisted of three phases involving different land occupation. The second shaft is located at the crossing of Enric Granados Street with Provença Street (see Figure 3). At the request of the Barcelona City Council, in order to reduce the social impact of the construction, the design of this shaft was different. It was built with a vertical shaft sinking machine (VSM) and has an inside diameter of 9 m and a depth of 47 m. The shaft casing consists of concrete rings with four arches with a thickness of 0.40 m. The construction work was also performed in three phases. For a more detailed description of the case study, input data, and performed calculations, refer to Casanovas-Rubio [44], (pp. 133–139).



Figure 2. Conventional construction of ventilation and emergency exit shaft in Bruc street in Barcelona. Reproduced with permission from Sacyr Construcción, Línea de alta velocidad Madrid-Zaragoza-Barcelona-Frontera francesa. Túnel de conexión de Sants-La Sagrera (Barcelona); published by Sacyr Construcción, 2013.

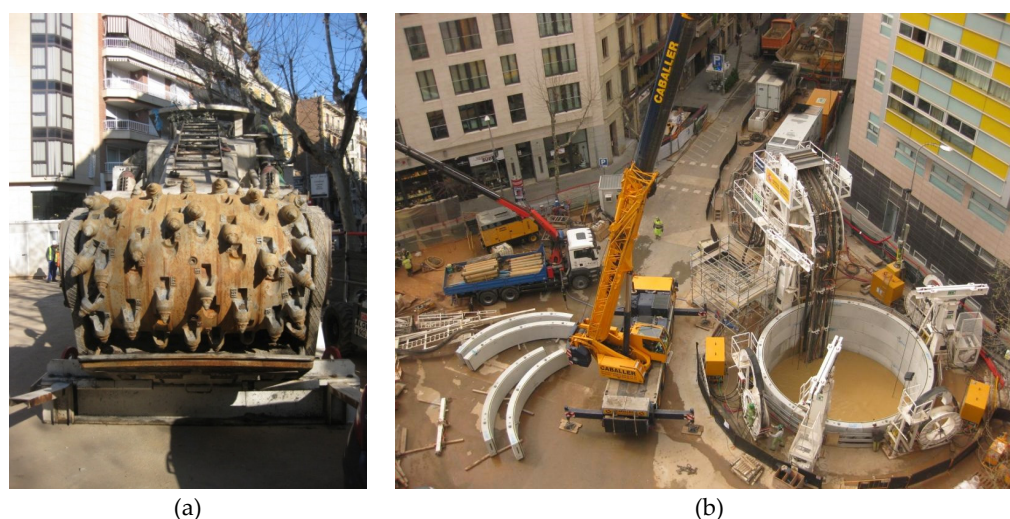


Figure 3. Ventilation and emergency shaft built with a vertical shaft sinking machine (VSM) in Enric Granados street in Barcelona (a) VSM; (b) aerial view of the construction. Reproduced with permission from Sacyr Construcción, Línea de alta velocidad Madrid-Zaragoza-Barcelona-Frontera francesa. Túnel de conexión de Sants-La Sagrera (Barcelona); published by Sacyr Construcción, 2013.

5.2. Results and Discussion

The results of the indicators of the two shafts are presented in Table 11. Table 12 shows the relative impacts and the MII using Equations (2) and (3). The weights in Tables 2 and 3 for an urban area were used. As the high-speed rail line is not considered to solve an urgent problem of obligatory mobility, the weights in the M column were used.

According to Tables 11 and 12, the alternative built with the VSM had the lowest impact on the mobility of emergency vehicles, mass transit, individual transport lanes, bicycle parking spaces, pedestrians, and the duration of the work. Together, these criteria account for 86% of the total weight. The alternative built with the conventional process was the best in terms of the impact on individual transport and bicycle mobility, considering both lanes and parking spaces. It was also the best with regard to the impact on parking spaces for individual transport and cycle lanes.

The results in Table 12 show that the VSM alternative had the lowest MII for all three references and according to the weights assigned by the experts. Hence, the VSM alternative was the best in terms of its impact on mobility. The differences between the MII of the conventional and VSM alternatives were 22.5%, 70.2%, and 36.9%, respectively, for each of the three ways of calculating it.

Table 11. Indicators of the impact on mobility calculated for the conventional and VSM construction processes.

Criterion	Results of the Indicators		
	Conventional (Bruc)	VSM (Enric Granados)	Unit
Emergency vehicles	219.7	154.5	no. of trips
Mass transit	5528	554	km·days
Individual transport Lanes	2910	1938	km·days
Individual transport Parking spaces	56595	107326	days·parking spaces
Bicycles Lanes	994	2772	km·days
Bicycles Parking spaces	32340	8336	days·parking spaces
Pedestrians	1407×10^3	428×10^3	days·m ²
Duration of the work	539	521	days

Table 12. Impacts on mobility and Mobility Impact Index (MII for conventional and VSM construction processes calculated with Equations (2) and (3).

Criterion	Indicator	Criterion Weight (%)	Indicator Weight (%)	Equation (2): Conventional as Reference		Equation (2): VSM as Reference		Equation (3)	
				Conventional	VSM	Conventional	VSM	Conventional	VSM
Emergency vehicles		29.3	-	1.000	0.703	1.422	1.000	1.000	0.703
Mass transit		20.9	-	1.000	0.100	9.978	1.000	1.000	0.100
Individual transport	Lanes	12.9	51.4	$51.4\% \cdot 1.000 +$	$51.4\% \cdot 0.666 +$	$51.4\% \cdot 1.502 +$	$51.4\% \cdot 1.000 +$	$51.4\% \cdot 1.000 +$	$51.4\% \cdot 0.666 +$
			48.6	$48.6\% \cdot 1.000 = 1.000^a$	$48.6\% \cdot 1.896 = 1.264^a$	$48.6\% \cdot 0.527 = 1.028^a$	$48.6\% \cdot 1.000 = 1.000^a$	$48.6\% \cdot 0.527 = 0.770^b$	$48.6\% \cdot 1.000 = 0.828^b$
Bicycles	Parking spaces	10.6	72.9	$72.9\% \cdot 1.000 +$	$72.9\% \cdot 2.789 +$	$72.9\% \cdot 0.359 +$	$72.9\% \cdot 1.000 +$	$72.9\% \cdot 0.359 +$	$72.9\% \cdot 1.000 +$
			27.1	$27.1\% \cdot 1.000 = 1.000^a$	$27.1\% \cdot 0.258 = 2.103^a$	$27.1\% \cdot 3.880 = 1.313^a$	$27.1\% \cdot 1.000 = 1.000^a$	$27.1\% \cdot 1.000 = 0.532^b$	$27.1\% \cdot 0.258 = 0.799^b$
Pedestrians		13.9	-	1.000	0.304	3.287	1.000	1.000	0.304
Duration of the work		12.4	-	1.000	0.967	1.035	1.000	1.000	0.967
	MII			1.000	0.775	3.359	1.000	0.921	0.581

Calculated using: ^a Equation (4), ^b Equation (5).

5.3. Sensitivity Analysis

A sensitivity analysis was performed to determine the stability of the results when the weights are changed. It was performed using weight sets (1) to (6), assigned by the six experts interviewed (Table 13). This made it possible to consider the variability in the experts' preferences. Notice that if the arithmetic mean of the six weights of each criteria and indicator in Table 13 are calculated, the weights in Table 2 (column U, M) and Table 3 (column U) are obtained. The resulting MIIs are presented in Table 14.

Table 13. Sets of weights assigned by the experts used in the sensitivity analysis.

Criterion	Indicator	Weights					
		(1)	(2)	(3)	(4)	(5)	(6)
Emergency vehicles		34.0	34.5	26.7	22.2	30.7	27.8
Mass transit		20.4	20.7	20.0	18.9	23.1	22.2
Individual transport		9.5	10.3	13.3	12.2	15.4	16.7
Individual transport	Lanes	66.7	33.3	75.0	33.3	66.7	33.3
	Parking spaces	33.3	66.7	25.0	66.7	33.3	66.7
Bicycles		6.8	6.9	13.3	17.8	7.7	11.1
Bicycles	Lanes	80.0	75.0	75.0	57.1	75.0	75.0
	Parking spaces	20.0	25.0	25.0	42.9	25.0	25.0
Pedestrians		12.3	6.9	20.0	17.8	15.4	11.1
Duration of the work		17.0	20.7	6.7	11.1	7.7	11.1

As shown in Table 14, the VSM construction alternative had the lowest MII for all the sets of weights assigned by the experts and for all three ways of calculating it. The variability in the weightings assigned by the experts did not affect the identification of the alternative with the lowest impact on mobility through the use of the proposed method.

Table 14. MIIs for the conventional and VSM construction alternatives resulting from the sensitivity analysis.

Equation	Construction Process	Weights						
		Original	(1)	(2)	(3)	(4)	(5)	(6)
Equation (2): Conventional as reference	Conventional	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	VSM	0.775	0.719	0.786	0.750	0.821	0.692	0.846
Equation (2): VSM as reference	Conventional	3.359	3.283	3.170	3.434	3.338	3.604	3.370
	VSM	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Equation (3)	Conventional	0.921	0.950	0.934	0.920	0.896	0.939	0.894
	VSM	0.581	0.593	0.632	0.541	0.566	0.543	0.598

6. Conclusions

This paper presents the Mobility Impact Index (MII), a new method to assess the impact of construction work on mobility based on an adaptation of MAUT. A panel of experts contributed to identify the impacts and the definition of weights. The method has been successfully applied to the construction of two real ventilation and emergency exit shafts of the Madrid–Barcelona–French border high-speed rail line located in the Eixample district of Barcelona that were built with diaphragm wall excavated using hydromill (conventional) and vertical shaft-sinking machine (VSM). The conclusions drawn from the study are listed below:

- (1) Emergency vehicles, mass transit, individual transport, bicycles and other cycles, and pedestrians were found to be the appropriate classification of means of transport in order to quantify the impact on mobility;

- (2) The diversion and closure of lanes and tracks and the relocation and closure of stops, stations, and parking spaces were found to be the potential impacts on mobility and affected elements by the construction work;
- (3) Minimising the disruption for emergency vehicles was assigned the highest priority by the panel of experts followed by mass transit for urban, suburban, and rural environments;
- (4) Minimising the impact on pedestrians was considered more important in urban and suburban areas than in rural ones, as the number of pedestrians is higher;
- (5) Minimising the impact on individual transport in rural areas was given more importance than in the other environments, as rural populations might be more dependent on individual transport than their urban or suburban counterparts;
- (6) The duration of the work takes higher importance when the project is intended to solve mobility for reasons of work or study;
- (7) The case study showed that the construction with VSM has an impact on mobility 22.5%, 70.2%, and 36.9% lower than the conventional construction for each of the three ways of calculating it;
- (8) The sensitivity analysis showed the robustness of the method, as the results show small variations (ranging from 0.1% to 10.7%). In all cases, the MII classification does not change, VSM being the best for all the seven sets of weights.

A limitation of this study is that the proposed method is deterministic and, hence, does not include uncertainty in the variables. Monte Carlo method or fuzzy arithmetic could be added to the proposed method to deal with uncertainty. The uncertainty in the weights has already been partially considered in the performed sensitivity analysis. Linear functions (Equations (2) and (3)) were considered appropriate as a first approach to assess the social impact of construction work on mobility. Further research may explore non-linear functions and include them in the uncertainty analysis.

The Mobility Impact Index contributes to the sustainability assessment of construction processes by quantifying the impacts on mobility and, thus, increasing the awareness on social aspects. In fact, all the research presented in this paper can be framed within the CSR of design and construction companies. The findings make it possible to consider the impacts of construction work on mobility in decision-making in construction during the design and tender stages, as well as to monitor them during construction. They have several practical applications:

- (1) During the design stage, the MII enables optimisation of the construction process and planning of the stages to minimise the impact on mobility, thereby improving the ESIA;
- (2) In the tender stage, the method enables the ranking of the alternatives proposed by the construction companies in terms of their impact on mobility, as another aspect to consider in the tender. Therefore, it could be of interest to public authorities and other bodies aiming to achieve SPP;
- (3) The method could also afford construction companies an edge when tendering for building contracts. They could use it to justify that the construction process and plan they offer are the best of the various possibilities in terms of mobility because they would be able to use the MII to compare the processes objectively and quantitatively;
- (4) It could likewise be used to monitor projects during the construction process itself, in order to compare the actual impact on mobility with the impact predicted in the design stage, enabling corrective measures to be proposed in timely fashion in case of deviation.

A further study could assess, by means of MII, the impact on mobility of different construction processes, and the findings could serve as reference for public administration and design and construction companies. The proposed MII can easily be integrated with other economic, environmental [33], and social criteria, including occupational risks [45], to evaluate construction processes and plans and select the best alternative from a multi-criteria perspective. Other social impacts of construction such as impacts on utility services, shops and other businesses, or facilities have scarcely been studied. Further research is thus required to understand and quantify such impacts, especially

in urban environments, as well as to fully incorporate the social dimension into the decision-making process for construction work. Further research might also explore how to adapt this method in order that it can be useful in emergency situations caused by natural or anthropogenic disasters.

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References

1. Kylili, A.; Fokaides, P.A. Policy trends for the sustainability assessment of construction materials: A review. *Sustain. Cities Soc.* **2017**, *35*, 280–288. [[CrossRef](#)]
2. Yin, B.C.L.; Laing, R.; Leon, M.; Mabon, L. An evaluation of sustainable construction perceptions and practices in Singapore. *Sustain. Cities Soc.* **2018**, *39*, 613–620. [[CrossRef](#)]
3. Gangoellis, M.; Casals, M.; Gassó, S.; Forcada, N.; Roca, X.; Fuertes, A.; Gasso-Domingo, S.; Roca-Ramon, X. Assessing concerns of interested parties when predicting the significance of environmental impacts related to the construction process of residential buildings. *Build. Environ.* **2011**, *46*, 1023–1037. [[CrossRef](#)]
4. Ozcan-Deniz, G.; Zhu, Y. Multi-objective optimization of greenhouse gas emissions in highway construction projects. *Sustain. Cities Soc.* **2017**, *28*, 162–171. [[CrossRef](#)]
5. Sandanayake, M.; Zhang, G.; Setunge, S.; Luo, W.; Li, C.-Q. Estimation and comparison of environmental emissions and impacts at foundation and structure construction stages of a building—A case study. *J. Clean. Prod.* **2017**, *151*, 319–329. [[CrossRef](#)]
6. Loosemore, M. Social procurement in UK construction projects. *Int. J. Proj. Manag.* **2016**, *34*, 133–144. [[CrossRef](#)]
7. Matthews, J.C.; Allouche, E.N.; Sterling, R.L. Social cost impact assessment of pipeline infrastructure projects. *Environ. Impact Assess. Rev.* **2015**, *50*, 196–202. [[CrossRef](#)]
8. Kirchherr, J.; Charles, K.J. The social impacts of dams: A new framework for scholarly analysis. *Environ. Impact Assess. Rev.* **2016**, *60*, 99–114. [[CrossRef](#)]
9. Sierra, L.A.; Pellicer, E.; Yepes, V.; Sierra-Varela, L. Social Sustainability in the Lifecycle of Chilean Public Infrastructure. *J. Constr. Eng. Manag.* **2016**, *142*, 05015020. [[CrossRef](#)]
10. Hyari, K.H.; El-Mashaleh, M.S.; Rababeh, S.M. Framework for managing the traffic impacts of building construction projects. *J. Constr. Dev. Ctries.* **2015**, *20*, 97–113.
11. Arya, C.; Vassie, P.; Amiri, A. A new method for evaluating the sustainability of bridges. *Proc. Inst. Civ. Eng.—Struct. Build.* **2015**, *168*, 441–453. [[CrossRef](#)]
12. Çelik, T.; Kamali, S.; Arayici, Y. Social cost in construction projects. *Environ. Impact Assess. Rev.* **2017**, *64*, 77–86. [[CrossRef](#)]
13. Fuertes, A.; Casals, M.; Gangoellis, M.; Forcada, N.; Macarulla, M.; Roca, X.; Martí, M.M.; Roca-Ramon, X. An Environmental Impact Causal Model for improving the environmental performance of construction processes. *J. Clean. Prod.* **2013**, *52*, 425–437. [[CrossRef](#)]
14. Gilchrist, A.; Allouche, E.N. Quantification of social costs associated with construction projects: state-of-the-art review. *Tunn. Undergr. Space Technol.* **2005**, *20*, 89–104. [[CrossRef](#)]
15. Guerin, T. A case study identifying and mitigating the environmental and community impacts from construction of a utility-scale solar photovoltaic power plant in eastern Australia. *Sol. Energy* **2017**, *146*, 94–104. [[CrossRef](#)]
16. Xue, X.; Zhang, R.; Zhang, X.; Yang, R.J.; Li, H. Environmental and social challenges for urban subway construction: An empirical study in China. *Int. J. Proj. Manag.* **2015**, *33*, 576–588. [[CrossRef](#)]
17. Valdes-Vasquez, R.; Klotz, L.E. Social Sustainability Considerations during Planning and Design: Framework of Processes for Construction Projects. *J. Constr. Eng. Manag.* **2013**, *139*, 80–89. [[CrossRef](#)]

18. Bastons, M.; Armengou, J. Realism and Impartiality: Making Sustainability Effective in Decision-Making. *Sci. Eng. Ethics* **2017**, *23*, 969–987. [CrossRef]
19. Zhao, Z.-Y.; Zhao, X.-J.; Davidson, K.; Zuo, J. A corporate social responsibility indicator system for construction enterprises. *J. Clean. Prod.* **2012**, *29*, 277–289. [CrossRef]
20. Wang, H.; Lu, W.; Ye, M.; Chau, K.; Zhang, X. The curvilinear relationship between corporate social performance and corporate financial performance: Evidence from the international construction industry. *J. Clean. Prod.* **2016**, *137*, 1313–1322. [CrossRef]
21. Zahidy, A.A.; Sorooshian, S.; Hamid, A.; Hamid, Z.A. Critical Success Factors for Corporate Social Responsibility Adoption in the Construction Industry in Malaysia. *Sustainability* **2019**, *11*, 6411. [CrossRef]
22. Uttam, K.; Roos, C.L.L. Competitive dialogue procedure for sustainable public procurement. *J. Clean. Prod.* **2015**, *86*, 403–416. [CrossRef]
23. European Union. Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on Public Procurement and Repealing Directive 2004/18/EC. 2014. Available online: <https://eur-lex.europa.eu/eli/dir/2014/24/2016-01-01> (accessed on 5 February 2020).
24. Wang, Y.; Han, Q.; De Vries, B.; Zuo, J. How the public reacts to social impacts in construction projects? A structural equation modeling study. *Int. J. Proj. Manag.* **2016**, *34*, 1433–1448. [CrossRef]
25. Dendena, B.; Corsi, S. The Environmental and Social Impact Assessment: a further step towards an integrated assessment process. *J. Clean. Prod.* **2015**, *108*, 965–977. [CrossRef]
26. Hildebrandt, L.; Sandham, L. Social Impact Assessment: The lesser sibling in the South African EIA process? *Environ. Impact Assess. Rev.* **2014**, *48*, 20–26. [CrossRef]
27. Shahtaheri, Y.; Flint, M.M.; De La Garza, J.M. Sustainable Infrastructure Multi-Criteria Preference Assessment of Alternatives for Early Design. *Autom. Constr.* **2018**, *96*, 16–28. [CrossRef]
28. Casanovas-Rubio, M.D.M.; Pujadas, P.; Pardo-Bosch, F.; Blanco, A.; Aguado, A. Sustainability assessment of trenches including the new eco-trench: A multi-criteria decision-making tool. *J. Clean. Prod.* **2019**, *238*, 117957. [CrossRef]
29. Silgado, S.S.; Valdiviezo, L.C.; Domingo, S.G.; Roca, X. Multi-criteria decision analysis to assess the environmental and economic performance of using recycled gypsum cement and recycled aggregate to produce concrete: The case of Catalonia (Spain). *Resour. Conserv. Recycl.* **2018**, *133*, 120–131. [CrossRef]
30. Barba-Romero, S.; Pomerol, J. *Decisiones Multicriterio: Fundamentos Teóricos y Utilización Práctica*; Universidad de Alcalá: Alcalá de Henares, Spain, 1997.
31. Hwang, C.; Paidy, S.; Yoon, K.; Masud, A. Mathematical programming with multiple objectives: A tutorial. *Comput. Oper. Res.* **1980**, *7*, 5–31. [CrossRef]
32. Keeney, R.L.; Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*; Wiley: New York, NY, USA, 1976.
33. Casanovas-Rubio, M.D.M.; Ramos, G. Decision-making tool for the assessment and selection of construction processes based on environmental criteria: Application to precast and cast-in-situ alternatives. *Resour. Conserv. Recycl.* **2017**, *126*, 107–117. [CrossRef]
34. Arif, F.; Bayraktar, M.E.; Chowdhury, A.G. Decision Support Framework for Infrastructure Maintenance Investment Decision Making. *J. Manag. Eng.* **2016**, *32*, 04015030. [CrossRef]
35. Casanovas-Rubio, M.D.M.; Armengou, J. Decision-making tool for the optimal selection of a domestic water-heating system considering economic, environmental and social criteria: Application to Barcelona (Spain). *Renew. Sustain. Energy Rev.* **2018**, *91*, 741–753. [CrossRef]
36. Perera, N.A.; Sutrisna, M.; Yiu, T.W. Decision-Making Model for Selecting the Optimum Method of Delay Analysis in Construction Projects. *J. Manag. Eng.* **2016**, *32*, 04016009. [CrossRef]
37. De La Fuente, A.; Pons, O.; Josa, A.; Aguado, A.; Antequera, A.D.L.F. Multi-Criteria Decision Making in the sustainability assessment of sewerage pipe systems. *J. Clean. Prod.* **2016**, *112*, 4762–4770. [CrossRef]
38. Von Winterfeldt, D.; Edwards, W. *Decision Analysis and Behavioural Research*; Cambridge University Press: Cambridge, UK, 1986.
39. Generalitat de Catalunya. SEM 2013 Annual Report. Available online: <http://sem.gencat.cat/ca/coneixer-el-sem/el-sem-en-xifres/> (accessed on 17 January 2017).
40. Generalitat de Catalunya. (n.d.). Estadístiques anuals de bombers. Available online: http://interior.gencat.cat/ca/arees_dactuacio/bombers/coneix_els_bombers/estadistiques_anuals/ (accessed on 2 November 2017).

41. Statistical Institute of Catalonia. Population on 1 January: 1900–2017. Available online: <https://idescat.cat/pub/aec/245/en> (accessed on 30 August 2017).
42. Spain. Real Decreto 2822/1998, de 23 de diciembre, por el que se aprueba el Reglamento General de Vehículos. *Boletín Oficial del Estado* **1998**, *22*, 3440–3528.
43. Ajuntament de Barcelona. Pla de Mobilitat Urbana de Barcelona PMU 2013–2018. Available online: http://mobilitat.ajuntament.barcelona.cat/sites/default/files/docs/PMU%20BCN%202013-2018_Introducci%C3%B3%20i%20Diagnosi.pdf (accessed on 8 September 2017).
44. Casanovas-Rubio, M. Metodología Para la Evaluación y Seguimiento de Procedimientos Constructivos de Forma Sostenible e Integrada. Ph.D. Thesis, Supervised by Gonzalo Ramos. Universitat Politècnica de Catalunya, Barcelona, Spain, 2014. Available online: <http://hdl.handle.net/10803/285293> (accessed on 5 February 2020).
45. Casanovas, M.D.M.; Armengou, J.; Ramos, G.; Casanovas-Rubio, M.D.M. Occupational Risk Index for Assessment of Risk in Construction Work by Activity. *J. Constr. Eng. Manag.* **2014**, *140*, 04013035. [[CrossRef](#)]



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