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Assessing the social sustainability contribution of an infrastructure project under conditions of uncertainty

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ABSTRACT

Assessing the viability of a public infrastructure includes economic, technical and environmental aspects; however, on many occasions, the social aspects are not always adequately considered. This article proposes a procedure to estimate the social sustainability of infrastructure projects under conditions of uncertainty, based on a multicriteria deterministic method. The variability of the method inputs is contributed by the decision-makers. Uncertain inputs are treated through uniform and beta PERT distributions. The Monte Carlo method is used to propagate uncertainty in the method. A case study of a road infrastructure improvement in El Salvador is used to illustrate this treatment. The main results determine the variability of the short and long-term social improvement indices by infrastructure and the probability of the position in the prioritization of the alternatives. The proposed mechanism improves the reliability of the decision making early in infrastructure projects, taking their social contribution into account. The results can complement environmental and economic sustainability assessments.

1. Introduction

The social dimension is a pillar of sustainable development together with the economic and environmental aspects. Yet the treatment of the social dimension is less evolved (Valdés-Vásquez and Klotz, 2013, Dominguez-Gómez, 2016). Several methods have focused on identifying the environmental and economic impacts of infrastructure projects, without explicitly considering their social approach (Ahmadvand and Karami, 2009, Penadés-Pla et al., 2016, Karami et al., 2017). Social assessment is an overarching framework that embodies the evaluation of all impacts on humans and on the ways in which people interact with their socio-cultural, economic and biophysical surroundings (Vanclay, 2002, 2003). Specifically, Vanclay (2002) identifies seven categories of social impacts that could be considered in an assessment: health and social well-being; liveability; economic and material well-being; cultural; family and community; institutional, political and equity; and gender relations.

In the last decade some initiatives have been proposed that take into account the assessment of the social contribution. In the MIVES ("Integrated Value Method for Sustainability Assessments"), a function proportional to the satisfaction of the beneficiaries deals with the social aspects (Gómez-López et al., 2013). In the SUSAIP ("Sustainability Appraisal in Infrastructure Projects"), the social aspects are treated homogenously in different regional contexts and the stakeholders are considered less in the decision-making (Ugwu et al., 2006). In the TSI ("Technical Sustainability Index"), the immediate impacts are not considered and aspects like health, wealth and politics are treated within a set of environmental indicators (Dasgupta and Tam, 2005). In addition, some sustainability rating systems such as ENVISION, CEEQUAL or IS have included social aspects in their evaluations. However, these are more appropriate for developed countries, and they give less importance to the social aspects (Diaz-Sarachaga et al., 2016).

In most of these proposals, the social aspects have been interwoven with environmental assessment methods to measure sustainability. Moreover, the little familiarity and the difficulty in dealing with the social aspects mean they are taken less into consideration (Pope et al., 2004; Pellicer et al., 2016). The heterogeneity of regional development or the impossibility of standardizing an impact in different contexts are relativized aspects in the usual methods (Esteves and Vanclay, 2009). Indeed, the interaction between infrastructure type and location context affects its social contribution. Normally, the contribution to social improvement in the short and long term justifies the decision-making of a public project. Yet the two approaches are not necessarily given simultaneously (Gannon and Liu, 1997). In a short-term approach the

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early return of the social benefits of an infrastructure is only possible in a consolidated context. By contrast, a long-term approach concentrates on the contexts with the greatest social weaknesses and greater potential contribution to improvement (van de Walle, 2009).

A multicriteria deterministic method was recently proposed to assess social sustainability in infrastructure projects (Sierra et al., 2017). This method is structured in three processes that determine (a) a short-term social improvement index; (b) a long-term social improvement index; and (c) a multi-objective prioritization of the public infrastructure investment alternatives. Short-term social improvement identifies an infrastructure's contribution in interaction with the present context. In this study, the short term considers the social effects of infrastructure planning, design and construction up to approximately three years from the start of the operation. On the other hand, in the long term, the distribution impact of the benefit considers the zones with social need. The long term considers the social effects on the type of tenure and preservation of the infrastructure. Once the social improvement for the different alternatives has been identified, these can then be prioritized according to their contribution to social sustainability.

However, the social contribution requires an assessment of qualitative and quantitative aspects, the impact of which on well-being and social development is not predetermined (Valdés-Vásquez and Klotz, 2013; Sierra et al., 2016, 2017). In this sense, the specific characteristics of a project have a high degree of uncertainty in the viability phase (Pan, 2009, Cárdenas and Halman, 2016). In the design and construction phases of an infrastructure, contingencies arise, the determinist assessment of which is not reliable in the early stages (Gervasio and Simoes da Silva, 2012). Specifically, the local or regional sources of information make it possible to establish the variability of certain social aspects. The social databases related to infrastructures and particularly qualitative aspects, however, are still nascent (Labuschagne and Brent, 2006; Sahely et al., 2005). Therefore, the experience of local experts can be a source of information that can be modeled to deal with the uncertainty (De la Cruz et al., 2015).

Therefore, in line with the previous points, the social aspects require adequate treatment in the evaluation of sustainability. In this vein, Sierra et al. (2017) proposed a deterministic evaluation method of the social sustainability of infrastructures in the short and long term. However, assessing the social aspects requires a procedure to deal with their uncertainty (Gervasio and Simoes da Silva, 2012; Cárdenas and Halman, 2016). This is the starting point of the present study. Given the above, this paper proposes an additional treatment to estimate the contribution to the social sustainability of infrastructure projects under conditions of uncertainty.

The article debates, first of all, the techniques to treat uncertainty addressed in this work. Next, the method for assessing the social sustainability of infrastructures as proposed by Sierra et al. (2017) is presented. Then, the proposal to deal with the uncertain variables within the evaluation method is described step-by-step. The proposed treatment is illustrated through a case study. Finally, the contributions, limitations and future lines of research are presented in the conclusions.

2. Dealing with uncertainty

In the phase of the service life of a public project, different infrastructure alternatives are assessed. In this phase the social aspects are important due to their vagueness and uncertainty of their effects on society (Gervasio and Simoes da Silva, 2012). The uncertainty can be internal or external. The first takes into account the variability of the method to be used and the input data. External uncertainty refers to the lack of knowledge about a choice (Gervasio and Simoes da Silva, 2012).

Multicriteria decision-making requires consideration of the weights of each criterion and the assessment of these criteria for each alternative (Zamarron-Mieza et al., 2017). In each of these processes there are uncertain variables that can be defined by ranges of behavior expected according to a probability (Jato-Espino et al., 2014). When the amount of data available is not sufficient for a classic probabilistic adjustment, a discrete uniform distribution can be used (Gervasio and Simoes da Silva, 2012). In other cases, knowledge and experience can permit the maximum and minimum parameters and the mode that describes a triangular distribution to be known (De la Cruz et al., 2015). Alternatively, the parameters of a triangular distribution can be assimilated to a beta PERT distribution. This function allows a greater ease of use and a more real continuity in the adjustment of the turning points (Jato-Espino et al., 2014).

In addition, a method widely used to give functionality to the simultaneous propagation of uncertainty through decision-making processes is the Monte Carlo method (Gervasio and Simoes da Silva, 2012, De la Cruz et al., 2015). The Monte Carlo method can be used as a risk management tool that aims to elicit the probability of contributing a series of achievements for a certain alternative (Jato-Espino et al., 2014). Thus, from a set of random variables, with specific and iterative distributions, it is possible to control the uncertainty of the set of decision-making alternatives.

3. Estimation method of the social sustainability of infrastructures

This method for estimating sustainability includes an approach for short and long-term social improvement and prioritization. The second and third column of Fig. 1 illustrate the processes that intervene in the evaluation method. The processes called "A" and "B" intervene in short and long-term social improvement, respectively. The process "C" weighs the results of "A" and "B", and determines the prioritized solution of socially sustainable alternatives. In line with Sierra et al. (2017), the stages that determine the method are presented as follows.

Stages A.0 and B.0: A group of multidisciplinary decision-makers selects the criteria and social goals according to the set of infrastructures and the context. To approximate a consensus the Delphi method is applied. The profile of the decision-makers is adjusted to the suggestions by Hallowell and Gambatese (2010) to guarantee the rigor of the method.

Stages A.1 and B.2: The set of decision-makers determines the weights of the criteria and social improvement objectives. The decision-makers compare the importance between pairs of criteria and among social goals through an Analytic Hierarchy Process (AHP) (Saaty, 1987).

Stages A.2.1 and B.2.1: For each criterion i and objective k the project variables r_i and indicators of the zone v_k are identified, respectively. Both the variables and the indicators must potentially be influenced in the lifecycle of the infrastructure. In addition, the effect of each variable r_i is determined by conditioning factors of the zone c_{ir} that are identified. The selection of the variables r_i, the conditioning factors c_{ir} and the indicators v_k are the result of a field study and the consensus of the decision-makers.

Stages A.2.2 and B.2.2: The group of decision-makers determines the weights of the variables of the project w_{ri} and social indicators w_{kv}. The decision-makers compare dually the importance between criteria and indicators by applying the AHP method.

Stages A.2.3 and B.2.3: The project variable r_i and social indicator v_k determine the social contribution $Y_{ir}{}^{st}$ and $Y_{kv}{}^{lt}$, respectively. For each project variable r_i and its conditioning factors from the zone c_{ir}, a transference function is formulated. The transference functions are interpolation functions. The functions transform the qualitative and quantitative inputs to a value $Y_{ir}{}^{st}$ of 0 (no contribution) to 100 (maximum contribution). In turn, for each indicator v_k the degree of future benefit of the project Z_{kv} is determined, as well as the degree of current weakness of the zone C_{kv}. The values of Z_{kv} and C_{kv} are agreed upon by the decision-makers on a scale from 1 (minimum benefit/weakness) to 5 (maximum benefit/weakness). Thus, the value of $Y_{kv}{}^{lt}$ is the product between Z_{kv} and C_{kv} for each indicator v_k.

Stages A.2.4 and B.2.4: The social contributions $Y_{ir}{}^{st}$ and $Y_{kv}{}^{lt}$ of a