Sustainability Performance Assessment: Hybrid Fuzzy Approach

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ABSTRACT

This paper provides a novel model that has the capability to consider the interaction among the various sustainability indicators (SIs), and integrating uncertainty analysis into the overall sustainability assessment process for infrastructure projects. The results of model application, using a real-life case study, demonstrate that considering the interrelationship among SIs has an effect on the outcome of the sustainability assessment process.

KEYWORDS: Infrastructure and Sustainability Assessment

1. INTRODUCTION

A study on sustainability requires an inter-disciplinary approach covering environmental, social, economic, and engineering sciences (Sahely et al., 2005). Thus, conducting a sustainability assessment for civil infrastructure systems (e.g. roads, pipes, etc.) is a difficult and complex process that involves consulting experts across many fields. Owing to the multi-faceted nature of sustainability, the assessment process has become more complex, and utilising sound scientific decision-making models has become increasingly important. In many cases, sustainability assessment decisions are based on multiple and conflicting criteria that are subject to different levels and types of uncertainty (Alsulami, 2012). Further, these decisions incorporate subjective judgement and expert opinions. Among sustainability assessment methods, the indicator approach is the most promising in terms of transparency and usefulness to the decision-making process. In the infrastructure context, many studies have utilised sustainability indicators (SIs) to produce sustainability assessment models aiming to quantify sustainability performance (López and Monzón, 2010). However, a major limitation is the failure to take into account the interaction among SIs. This would give an unclear picture about the sustainability of the infrastructure system under investigation. This paper presents an overview of a hybrid fuzzy model developed with the aim of overcoming the shortcomings of existing models in mind. Then, the proposed assessment model steps are presented via its application to a real-life case study.

2. MODEL DEVELOPMENT

The sustainability assessment process is complex and difficult to specify precisely having its various aspects (and associated indicators) interacting with each other. The economic, environmental, social, and technical aspects for each CIS are different in terms of how stakeholders perceive them. As stakeholders perceive sustainability aspects differently, it is necessary, therefore, to determine the importance of the individual aspects, their interrelationships with one another and their effect on the overall sustainability score. In an attempt to achieve these objectives, first, a fuzzy cognitive map (FCM) is used to identify the interactions among sustainability indicators, second the fuzzy analytic network process (FANP) is used to calculate the aspects and indicators weighting, third, fuzzy set theory (FST) is used to deal with uncertainty of decision makers' judgments, and finally in order to allow for the integration of the qualitative and quantitative SIs, normalisation was undertaken in order to calculate an overall sustainability index. The proposed assessment model, as shown in Figure 1, involves the calculation of the sustainability performance index according to the 14-steps of the assessment model. The model steps are discussed in the following subsection in the context of applying the model to a real-life case study.

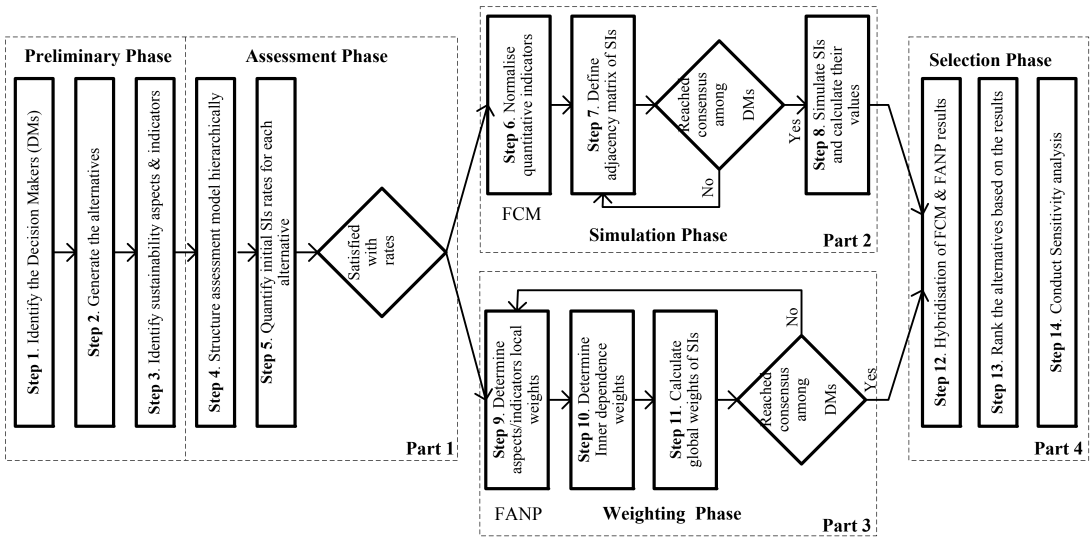

Figure 1. Proposed Assessment Model

3. MODEL APPLICATION

A new rail infrastructure project located in the state of Victoria, Australia was used to evaluate the applicability of the proposed sustainability assessment model. The project is a social transit based initiative; its objective is to provide public transport services to major towns that are located along the Mildura to Melbourne corridor (541 km) in the State of Victoria, Australia. The case study information and judgements input from decision makers have been used to test validity of the proposed assessment model. The data utilized in this case study were extracted from two independent sources. Two representatives from the project stakeholders, who were directly involved in the sustainability assessment process, have been interviewed to collect the required data. Eight proposed project alternatives (A1 through to A8) were reported by the decision makers for the case study project. Nine sustainability indicators identified in the case study were classified into four aspects: economic, technical, environmental and social. The assessment model is composed of three levels (as shown in Figure 2). The goal of the first level was to determine the overall sustainability index for the project alternatives. Their aspects and indicators are included in the second and third levels, respectively. Also, the interaction among the different aspects is presented in this step. Both the qualitative and quantitative indicators types needed to be calculated differently.

The fuzzy set is used to convert the linguistic variables that were assigned to the six qualitative indicators, to numerical measures. Thus, the classic fuzzy linguistic variables were used to convert linguistic variables into triangular fuzzy numbers (TFN). Then, TFN were aggregated and defuzzified. Three quantitative indicators, belonging to the economic and environmental group of indicators, are quantified. In the economic indicators, the cost and benefits indicators have been quantitatively measured. The third is the Green House Gas emissions (GHG) indicator. In order to employ the sustainability indicator values, the sustainability indicator numerical rates were normalised.

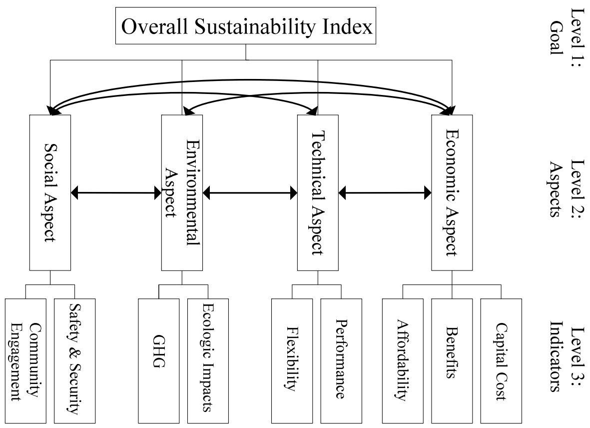

Figure 2. Hierarchy Structure Model

The decision makers (DMs) were consulted to develop the adjacency matrix (Fuzzy Cognitive Mapping matrix). Each DM used linguistic variables to assess the fuzzy causal relationships among the sustainability indicators. Local weights of the sustainability aspects and the indicators were calculated. Fuzzy Pair-wise comparison matrices were formed by the two DMs. For example, both the economic aspect (EA) and technical aspect (TA) were compared using the question, "How important is (EA) when it is compared with (TA) for this project"? The interdependent weights of the sustainability aspects were calculated, and the dependencies among the aspects were considered. Dependence among the aspects was determined by analysing the impact of each aspect on every other aspect using pairwise comparisons. The pairwise comparison matrices were formed for the four aspects.

According to the indicators' global weights, the four most important indicators, contributing toward sustainability performance in our case study project, are: *Safety and Security (C8), Performance (C4), Ecological Impacts (C7)*, and *Capital Cost (C1)*. The overall sustainability index (OSI) for each and every project alternative is calculated. Table 1 shows OSI for the project's alternatives with and without considering interaction among the SIs. Since the aim of proposed assessment model, is supporting DMs to identify the most sustainable project alternative, the DMs, based on the OSI results of the alternatives, were able to rank the project's alternatives, and select the most sustainable alternative. On the basis of the results, the interaction has a notable effect on the ranking results. For example, A8, which ranks first in the assessment results, calculated without considering the interaction, goes down to the third rank when considering the interaction among the indicators. Furthermore, a similar result occurs for alternatives A1 and A5; they are both ranked sixth when the interaction is ignored, and slide to fourth rank when the interaction is considered.

Table 1. Summary of Calculated Sustainable Indices for Each Project Alternative

Alternative	OSI without interaction	OSI with Interaction
A1	0.62	0.57
A2	0.67	0.57
A3	0.56	0.19
A4	0.78	0.68
A5	0.62	0.57
A6	0.65	0.57
A7	0.77	0.68
A8	0.91	0.64

4. CONCLUDING REMARKS

This paper has briefly described and demonstrated the implementation of a a hybrid fuzzy sustainability assessment model using a real-life infrastructure project. The improvement degree achieved using the proposed model, to overcome the other models' limitations, is discussed in the light of the obtained case study results. Therefore, to identify the extent to which the proposed model can effectively overcome other models limitations, the discussion focuses on those limitations. There are three expectations from the proposed model: 1) it will consider the interaction among the SIs; 2) it will manage the uncertainty that is inherent in the assessment process; and 3) it will effectively manage the qualitative and quantitative information.

The proposed model enhances the capability of the decision makers, so that they are better able to manage the complexity of the sustainability assessment through a consideration of the interactions among the SIs. This process was achieved through the use of the Fuzzy Cognitive Mapping method, which led to the discovery of the hidden sustainability performance that would not have been realised if the interaction is ignored. This outcome answers the criticism that most sustainability assessment models are static in nature and, especially, neglect the interaction among the sustainability components.

The case study results prove that a consideration of the interaction among the different sustainability indicators have a significant impact on the sustainability performance values which were later reflected on the projects' alternatives ranking.

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