

Methodology for evaluating infrastructure projects in the context of sustainable development

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ABSTRACT: The construction sector is involved in creating the physical infrastructure assets which are the basis of virtually every aspect of development. The challenge for the sector is to become an increasingly significant contributor to sustainable development for the society. Both environmental and social sustainability form part of a necessary holistic system that complements economic performance measures of viability from a long-term perspective. Infrastructure projects, therefore, will need to be objectively selected and procured based on a combination of social, economic and environmental costs and benefits. This paper presents a methodology that has the potential to aid both planners and developers in selecting the best alternative (design or project) in order to achieve desirable sustainable project outcomes. The methodology utilises a combination of the analytic network process and fuzzy mathematics in order to capture and model the objective as well as subjective parameters across three dimensions (i.e. social, economic and environmental).

1 INTRODUCTION

More than 70 definitions of sustainable development (SD) have been made and used or interpreted by different groups to suit their own goals (Langston, 1997). However, the most popular and cited definition is the one given by the World Commission on Environment and Development (WCED 1987): 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. The idea of meeting our needs without detracting from the ability of future generations to meet their needs is an intuitive and compelling idea. In spite of differing perceptions about the precise meaning of the term SD, most of the definitions incorporate the social, environmental and economic dimensions.

The term 'development' includes activities across different industry sectors including construction. The construction sector is involved in creating the physical infrastructure assets which are the basis of virtually every aspect of development, and thus in the creation of much of the world's man-made capital. Throughout the world, the contribution of the construction sector to national economies is significant, however, negative community perceptions continue to emerge. Being one of the largest exploiters of natural resources and having the worst work-related accidents record, this sector is often perceived as 'dumb, dirty and dangerous' regardless of its application of high technology. As such, the chal-

lenge for this sector is to become, and be seen to become, an increasingly significant contributor to SD for society and the environment. With this in mind, economically, socially and environmentally SD of the construction sector has to be assessed in terms of its performance. It is, therefore, important – during the feasibility study of a major infrastructure project – to know what and how to measure such performance in areas that are important for SD. Langston & Ding (1997) consider SD, in the construction context, as the interaction of the three pillars of sustainability (i.e. economics, environmental responsibility as well as social responsibility).

The well-known concept of triple bottom line (TBL) holds that performance should not be judged on short-term financial bottom line measures only. Both environmental and social sustainability form part of a necessary holistic system that compliments economic performance measures of viability from a long-term perspective (Graham & Walker 2000). To demonstrate a positive contribution to SD, companies are expected not only to deliver sound financial success but also to contribute beneficial social as well as environmental outcomes. This TBL concept presents acute challenges to business enterprises in general and to construction companies in particular. To this end, many research studies have addressed the application of the TBL concept by business enterprises, but little attention has so far been given to its application at a construction project level (Uher 2000).

The implementation of SD in construction presents substantial challenges to the existing practice of construction project management, especially to the area of project selection criteria. Literally, the traditional functions of project management – usually characterised in terms of cost, time and quality – will no longer be considered the only indicators for a successful project management process. Furthermore, infrastructure projects will need to be objectively selected and procured based on a combination of social, economic and environmental costs and benefits (Langston 1997). Against this backdrop, it is clear that a much broader perspective of project feasibility assessment is required, one which allows decision-makers to swerve away from only considering the traditional monetary benefit/cost analysis, to a more rigorous procedural framework incorporating social and environmental costs to reflect the growth of social and environmental consciousness.

2 INFRASTRUCTURE PROJECTS

Compared to other project types, large infrastructure projects involve multi-disciplinary stakeholders, longer durations and substantial development costs. These projects also affect the environment in various ways across their life cycle from inception to design, construction, operation and demolition. Previous studies suggest that many environmental problems are construction-related. For example, building works within the European Union consume approximately 40% of the total energy, and is responsible for some 30% of CO₂ emissions (Sjostrom & Bakens 1999). Another example is from Australia where 14 million tonnages of waste have been put into landfill each year, 44% of this waste is attributed to the construction industry (McDonald 1996). The concept of sustainable infrastructure construction is still in its infancy and therefore needs to be properly researched to allow for effective integration of sustainable objectives into the process of project design, planning, delivery, maintenance and demolition (Shen et al. 2000).

To illustrate, great design challenges typically require large number of design decisions which are often inter-dependent, with options influencing the values of multiple indicators relevant for SD (De Groot van Dam 2002). Due to the complexity of infrastructure projects, there is a need for a more holistic assessment methodology based on a systems approach that is capable of incorporating social, economic and environmental issues. This paper present an assessment methodology for infrastructure projects that is based on a combination of the analytic network process and fuzzy mathematics in order to capture and model the objective as well as subjective parameters across the three pillars of sustainability.

3 PREVIOUS WORK

Over the past few years, a variety of conceptual models were developed in an attempt to present and to capture the interactions between the three pillars of sustainability. Some models stressed that sustainability can only be achieved when the economic, social and environmental dimensions are balanced, whereas other models suggested adding a fourth dimension (e.g. well-being, bio-physical, institutional or corporate governance). Interested readers are referred to Harding (1998), Chambers et al. (2000), and (Atkisson & Hatcher 2001) for a good description of some of these models.

Construction projects are expected to have various impacts on SD, at different stages, in various formats, throughout the project lifecycle. Unfortunately, the different conceptual models of sustainability could be criticized for failing to incorporate the time factor which is a vital element of sustainability. This fact, coupled with the lack of having a coherent and generic set of substantiality indicators (measures) developed specifically for the construction sector, has contributed to the difficulty in properly incorporating the pillars of sustainability in the feasibility study of infrastructure projects. This difficulty is further complicated when some of these indicators are qualitative in nature.

An earlier attempt by Fleming (1999) succeeded in including the time factor as well as concept of continuous improvement, thus improving sustainability conceptualization. However, it were Shen et al. (2002) who have successfully introduced the time factor in assessing construction projects' contribution to the attainment of SD. They developed a SD value function (SDV) whereby a project with a total positive SDV value can be considered adequate in line with the SD principle.

More recently, Seo et al. (2004) have developed a methodology using a fuzzy-set approach for evaluating sustainability of residential buildings under uncertainty. They examined the problem of choosing the best alternative to support decision-makers when faced with uncertainty. Fuzzy-set theory and hierarchical structure analysis were used to formulate a methodology for evaluating alternatives, resulting in a final overall impact for residential buildings. In their research, a decision is being made among the different alternatives based on select criteria that influence residential buildings. Seo et al. (2004) have argued that their approach could allow for other civil infrastructure projects taking into account a large criterion set and extensive number of alternatives, especially where conflicting objectives exist. The author, however, challenges this argument on the basis of the inability of their approach to appreciate the interactions and inter-dependencies among the various criteria, which can significantly affect the validity of analysis results.

A basic assumption in the works by Shen et al. (2003) and Seo et al. (2004) is to structure sustainability criteria, and hence associated indicators, using a hierarchical structure. Although techniques employing such structures allow the decision-maker to examine criteria clearly and assess their impact in a systematic manner, they are based on the assumption that upper level criteria are wholly dependent on lower level ones, and individual criteria cannot interact either within or between the hierarchy levels. In other words, criteria are dealt with in a disaggregated form that prevents considering the three pillars of sustainability simultaneously.

4 SUSTAINABILITY INDICATORS

Sustainability indicators' studies got their impetus from the 1992 Rio Earth summit and the publication of the Local Agenda 21 (UNSD 1992). Since then, interest in monitoring and communicating progress towards sustainability has led to the development and adoption of numerous economic, environmental and social indicators which are increasingly seen as important tools in the implementation of SD. The role played by these indicators is briefly discussed below.

Economic indicators are appealing as a means to convert hosts of qualitative values into a single dollar metric so that economic policies could be devised rationally and perhaps ranked quantitatively (Anderson 1991). The development of environmental indicators is increasing with the growth of interest in ecological problems and environmental management (Panzieri et al. 2002). International guidance (e.g. ISO 14000 series), for example, envisages evaluation of environmental performance as proof of good environmental management for every type of activity. Finally, social indicators represent measures of general welfare that give social problems more visibility, change policy priorities, and offer policy makers the means to measure social progress 'over and above' economic statistics (MacRae 1985).

From the above, it is clear that the key function of SD indicators is to translate sustainability issues into (usually) quantifiable measures of economic, environmental and social performance with the ultimate aim of helping address the key concerns (Azapagic 2004). Identification of relevant issues that capture the specific characteristics of each type of industry is, therefore, crucial in the development of indicators. Addressing sustainable development requires a holistic approach based on lifecycle thinking and the construction industry is no exception to this. Thus, identification of sustainability issues must be done by considering all activities in the supply chain from 'cradle-to-grave' (Wyatt 1994). Without adopting such approach, the industry will not be able to respond appropriately to the challenge of SD.

The purpose of sustainability indicators for industry is to help measure a company or project's economic, environmental and social performance and to provide information on how it contributes to SD (Azapagic 2004). In addition to taking a life cycle approach, indicators should be designed to reflect both the micro and macro levels of sustainability analysis. Also, it is imperative to adopt a combination of quantitative and qualitative indicators to present a complete and balanced picture of sustainability performance.

Good sustainability indicators, according to a survey of the literature conducted by Maclaren (1996), are: "scientifically valid, representative of a broad range of conditions, responsive to change, relevant to the needs of potential users, based on accurate and accessible data, based on data that are available over time, understandable by potential users, comparable with indicators developed in other jurisdictions, cost-effective to collect and use, attractive to the media, and unambiguous." The challenge in selecting indicators lies not in the lack of data, but rather in selecting the data sets that best capture the desired function of the system in question. To aid this decision, it is common in sustainability indicators to employ a number of selection criteria (Global Reporting Initiative 2004).

Dividing the holistic concept of sustainability into three pillars as a starting point invariably runs the risk of the sum of the parts being less than the whole. This is particularly true, if the inter-relations between the three pillars are not adequately understood and described. Also, the separation of the criteria into three pillars tends to emphasize potentially competing interest rather than the linkages and interdependencies between them, and therefore sustainability is reduced to a consideration of separate economic, environmental and social criteria, the sum of which is less than the whole, i.e. SD. Gibson (2001) expresses this concern by pointing out that there are sustainability discourses that are: "not always incorporated in pillar-based sustainability literature and practice".

To be truly integrated, the inter-relations between the three pillars of impacts must be considered (George, 2001), since it has been recognised that "the combined impacts, positive and negative, of the sets of measures as a whole, are likely to be more than the simple sum of the impacts of their constituent measures because of synergistic effects" (Lee & Kirkpatrick 2001). Many examples demonstrate not only how indicators could relate to more than one pillar, but also how a single indicator can affect other indicators belonging to other pillars. At the macro-level, for example, anecdotal evidence suggests increasing wealth (economic indicator) would enhance the individual's ability to consume more resources (environmental indicator) to a certain level. The complex relationship between a decrease in en-

vironmental stress and high-income levels is well documented (Arrow 1995). Another example is community volunteerism which could be a sign of social vitality and personal fulfillment, but may also be inflated during times of economic stress. Similarly, at the micro- or project-level, creating affordable housing may be good, but when the new housing is built in areas far from workplaces, the result is increased traffic and pollution.

5 PROPOSED METHODOLOGY

As previously noted, a basic assumption in reported works to-date is to structure sustainability criteria, and hence associated indicators, using a structure based on the analytical hierarchy process (AHP) which was developed in the early 1970s as a general theory of measurement that derives ratio scales from paired comparisons in multilevel hierarchic structures. A fundamental assumption of the AHP is that all indicators and criteria within the structure are independent of each other. The AHP does cater for the identification of individual criteria, but it does not allow for inter-dependencies between these criteria to be modelled (McCowan & Mohamed 2004).

The Analytical Network Process (ANP) was developed in order to cater for the dependence of individual elements, both within and in-between criteria (Saaty, 2001). The ANP is a variation of the AHP that looks more like a network than a hierarchy, thus making it an ideal technique for modelling interaction and inter-dependency among indicators. The ANP employs the same fundamental scale of comparison as the AHP in order to generate relative priorities of criteria with respect to the goal (i.e. selecting the project or design that contributes most to the attainment of SD over its life-cycle), and the preference of different alternatives, with respect to criteria. However, it adds a third dimension to the decision problem by allowing for any element (e.g. goal, criteria, alternative) to influence any other element within the network (Saaty, 2001).

The proposed methodology applies fuzzy numbers in the context of additive weighting which, in its various forms, is perhaps the most commonly used method of evaluating alternatives characterised in terms of multiple criteria (Smith 1995). Fuzzy additive weighting has been successfully used in the evaluation of projects in terms of multiple criteria in which the fuzzy outcomes of each project with respect to each criterion are multiplied by respective fuzzy importance weights and summed to yield an aggregate score (Goodwin & Wright 1991). Also it is a useful method for combining linguistic expressions of performance (e.g. 'moderate' wildlife impact) or in many situations, linguistic expressions of performance and quantitative data (e.g. total volume of water discharged into waterways).

The first step in the proposed methodology is to select the basic sustainability criteria that are applicable to the infrastructure project under investigation. It is assumed that each criterion has a combination of qualitative and quantitative of sustainability indicators.

Quantitative data may be defined precisely in terms of a single value or imprecisely as a range of values, perhaps with a modal or most likely value. Given the uncertainty associated with indicators, values need to be expressed for each design, construction or location alternative. Fuzzy numbers should represent linguistic expressions and imprecise quantitative data whilst conventional crisp numbers should represent precise quantitative data.

The second step involves normalizing the basic criteria to one common unit. Thus, avoiding any mathematical complications that would arise from using different units.

The inter-dependency between indicators is expressed by the use of the ANP. This step aims to perform pair-wise comparisons on the indicators as they influence each other (within and beyond their own criteria). Community consultation and/or consultation with a local multi-disciplinary panel of experts (based on the indicators being considered) is needed to properly assign the linkages (and the strength) between indicators.

Allocating the relative importance weights for each inter-dependency paired comparison matrix follows this step. The primary stage in determining weightings is to determine which group of project stakeholders will be affected by the project and whose values must be represented in this exercise.

Given that an index being an amalgam of more than one indicator, the computation results of the ANP network, for each set of interdependent indicators, would give rise to a sustainability development Index (SDI). In this context, each SDI can generally be understood as a quantitative tool that reflect how a set of economic, social and environmental affect each other with respect to a sustainability criterion, see Figure 1.

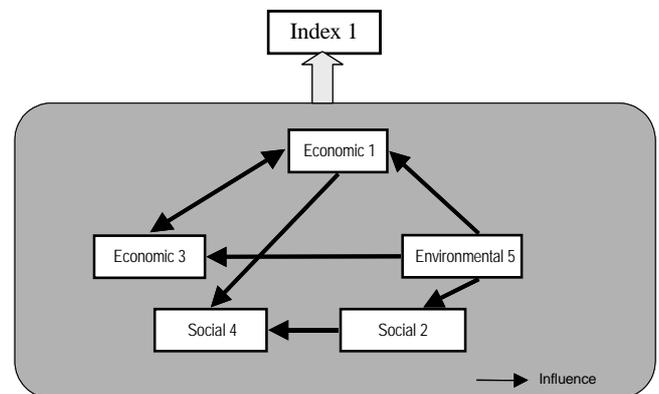


Figure 1. Set of inter-dependent indicators leading to an index

Having now reduced the number of indicators to a lesser, and more manageable, number of SDIs, one can proceed with aggregating these SDIs toward obtaining a decision index.

Since decisions are based on the testing of all the weighted indices for each project or design alternative, the indices must be integrated in some manner in order to make a decision (Seo et al. 2004). Depending on their relative importance, differential or equal weightings could be applied to the SDIs. It is worth noting that the process of weighting is a necessarily subjective process, so utmost care needs to be taken in allocating the weighting to avoid distorting the outcomes.

Finally, the decision index for each alternative is of little use unless the results of aggregation are compared to some benchmark or target. Therefore, decision indices will need to be used for ranking the alternatives. The alternative that has the highest ordering value with respect to its contribution to the attainment of SD is then selected as the best alternative. Depending on the nature of the infrastructure projects under investigation, the above exercise could be repeated more than once, to reflect, for example, short- vs. long-term, or micro- vs. macro-level contribution to SD.

6 CONCLUDING REMARKS

The term sustainability is a multi-faceted concept which is used frequently and in many ways. The three pillars of sustainability inevitably overlap and should not be treated as mutually exclusive.

Previous attempts to evaluate the contribution of infrastructure construction projects to sustainable development have ignored the incorporation of the linkages between these three pillars. They dealt with this issue in a piecemeal fashion.

This paper attempted to rectify this situation by proposing a methodology that employs the analytic network process to capture and model the overall impact generated by the existing linkages (i.e. dynamic interactions) between sustainability indicators.

An evaluation methodology has been presented which facilitates the aggregation of quantitative and qualitative sustainability indicators. The primary focus of the paper is on the inter-dependency of these indicators. Utilising a combination of the analytic network process and fuzzy additive weightings, the paper proposes incorporating the indicators inter-dependence and reducing the number of sustainability indicators to a manageable number of quantitative indices which in turn could be aggregated to form a decision index similar to that recently proposed by Seo et al. (2004) to help selecting the best project or design alternative in the context of environmental sustainable buildings.

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