INCORPORATING SUSTAINABILITY MEASURES IN LIFE-CYCLE FINANCIAL DECISION MAKING FOR HIGHWAY CONSTRUCTION

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ABSTRACT

Public awareness and the nature of highway construction works demand that sustainability measures are first on the development agenda. However, in the current economic climate, individual volition and enthusiasm for such high capital investments do not present as strong cases for decision making as the financial pictures of pursuing sustainability. Some stakeholders consider sustainability to be extra work that costs additional money. Though, stakeholders realised its importance in infrastructure development. They are keen to identify the available alternatives and financial implications on a life-cycle basis. Highway infrastructure development is a complex process which requires expertise and tools to evaluate investment options, such as environmentally sustainable features for road and highway development.

Life-cycle cost analysis (LCCA) is a valuable approach for investment decision making for construction works. However, LCCA applications in highway development are still limited. Current models, for example focus on economic issues alone and do not deal with sustainability factors, which are more difficult to quantify and encapsulate in estimation modules.

This paper reports the research which identifies sustainability related factors in highway construction projects, in quantitative and qualitative forms of a multi-criteria analysis. These factors are then incorporated into past and proven LCCA models to produce a new long term decision support model. The research via questionnaire, model building, analytical hierarchy processes (AHP) and case studies have identified, evaluated and then processed highway sustainability related cost elements. These cost elements need to be verified by industry before being integrated for further development of the model. Then the Australian construction industry will have a practical tool to evaluate investment decisions which provide an optimum balance between financial viability and sustainability deliverables.

KEYWORDS:

Highway infrastructure; cost analysis; life-cycle; sustainability.

INTRODUCTION

Highways are an integral part of a modern society. However, developing highway infrastructure often impacts directly on the environment and local communities. The construction industry is challenged by sustainability concepts, because sustainability involves extra upfront capital investment. Costing of highway infrastructure is difficult to determine because of the highways long lifespan and sometimes these costs may even be more than the acquisition cost. As a result, stakeholders may not foresee all the hidden costs of responding to sustainability issues while they contemplate the significant investments and the significant investment risks. Therefore, there is a need for life cycle financial analysis and forecasting to present a more accurate decision for the client.

Life cycle cost analysis (LCCA) is a tool to identify and quantify all significant costs involved in acquiring, owing and operating physical assets over their useful lives (Woodward, 1997). Royal Institution of Chartered Surveyors (RICS) defines life cycle cost of an asset as the present value of the total cost of the asset over its operating life (including initial capital cost, occupation costs, operating costs and the cost or benefits of the eventual disposal of the asset at the end of its life).

Recent research addresses the related topics of life cycle cost analysis (LCCA) on highway project (Persad and Bansal, 2004, Walls Iii and Smith, 1998, Hawk, 2003, Hegazy et al., 2004). Research exists also making comparison between benefit-costs analysis and lifecycle cost analysis (Lee, 2002), assessment of state-of-the-practice in the use of LCCA tools (Ozbay et al., 2004), and ideas about how uncertainty should be introduced in LCCA, as in Tighe,(2001). However, these studies focus on the application of LCCA concept which is the economics of highway projects. The application of LCCA methods to the economic view of sustainability for highway projects is still lacking.

This paper examined a research project which indentified sustainability related cost elements and issues within highway projects. These factors are explored on an integral basis through quantitative and qualitative approaches. Industry experts ranked, evaluated and then integrated the sustainability related cost elements into the existing LCCA model to produce a long term decision support model. The resulting model provides valuable references and decision support tools to stakeholders involved in investments decisions for highway projects.

LIMITATION OF EXISTING LCCA STUDIES IN ADOPTING SUSTAINABLE MEASURES

The concept of sustainability has added a new dimension to the evaluation of highway investments. Sustainability means analysing the entire life of a facility, from an environmental as well as economic perspective (List, 2007). Keoleian et al. (2005) developed an integrated life cycle assessment and cost model to evaluate infrastructure sustainability, and compared alternative materials and designs using environmental, economic and social indicators. Despite an increasing enthusiasm to propose the LCC approach as useful in the sustainability context, the adoption and application of LCC in the highway infrastructure sector still remains limited (Zhang et al., 2008, Wilde et al., 2001, List, 2007, Chan et al., 2008). Cole and Sterner (2000) indicate that 'imperfect understanding' of LCC's merits among practitioners is the main cause for its limited adoption. However, there is still a gap between theory and practice as neither of them sufficiently explains the underlying reasons for indicating social and environmental costs into LCCA. Moreover, the actual incorporation of costs incurred for pursuing social and environmental matters in the LCC approach is not sufficiently clarified:

- Most existing LCCA studies emphasis on the cost allocation and investment evaluation of highway projects. These studies are primarily concerned with direct market costs, such as road construction and maintenance costs and crash damages and how these vary depending on roadway conditions. They assumed that the roadway conditions and requirements do not change in a highway lifetime and so were unconcerned with the upgrading and end of life costs (Quinet, 2004).
- Existing studies incorporate costs incurred from environmental impacts, primarily air pollution, noise and water pollution and various categories of land use impacts. Some studies have only

considered them as the external costs. Their results often differ significantly, but can usually be explained by differences in their methodology and scope (Quinet, 2004).

- Existing studies also show unclear boundaries in identifying costs incurred for pursuing sustainability matters in highway infrastructure. Some researchers have considered the global impacts of sustainability while others only considered micro impacts (List, 2007, Wilde et al., 2001, Zhang et al., 2008).
- Surahyo and El-Diraby (2009) highlighted that the inconsistent estimation methods in current studies in estimating sustainability related costs for highways. Some use socioeconomic approaches, while others use technical/ engineering approaches. Due to the subjectivity of sustainability and the soft factors of the related cost elements, it is become difficult for current research to create consistent estimation methods.
- Highway infrastructure projects also take place in different physical, legal, and political environments, and studies assessing and mitigating costs incurred for pursuing sustainability matters are still evolving. Therefore, it is difficult to develop a universal standard to address this forecast sustainability related cost element estimation methods (Surahyo and El-Diraby, 2009).

These limitations show the significance and necessity of incorporating costs incurred for including pursuing sustainability measures into LCC practice. Consequently, this research attempts to propose a long term decision support model that deal with sustainability indicators as well as the life cycle cost analysis and estimate and correlate the various costs elements concerned by the construction stakeholders in highway projects.

INTEGRATION OF QUANTITATIVE AND QUALITATIVE APPROACH

To respond to the challenge of incorporating sustainability measures in LCCA model, this research employed an integrated approach involved questionnaire. The questionnaire is to identify the sustainability related cost elements in life-cycle costing analysis that influence construction stakeholders in selecting highway projects. A qualitative approach will also be used to develop and evaluate the long term decision support model from the adaption of available LCCA techniques. This includes comparison of alternative choices based on the sustainability indicators in the highway projects using Analytical Hierarchy Process (AHP) approach, and testing and evaluation of the new long term decision support model through case studies method.

Preliminary model development

The research started with a literature exploration of the scope and issues in sustainability related cost issues in highway construction. The preliminary model development follows these through understanding of the extent of the cost elements in some of the existing life-cycle costing analyses. A preliminary model development was or will be based on the sustainability indicators and cost elements identified through previous research and Australian project reports. Imperative aspect of cost elements and sustainability issues in highway project were identified and tabulated according to their significance before incorporate into questionnaire for further verification by industry stakeholders.

The Questionnaire Survey

Questionnaire method is selected in this research because they are effective in gathering information about the characteristics, actions, or opinions of a large group of people (Tanur, 1983). If questionnaires include demographic questions on the participants, they can be used to correlate performance and satisfaction with the test system among different groups of users.

The questionnaire used in this research was based on the combination of the literature review on contemporary LCCA models, preliminary model development, and also the sustainability related cost elements and issues in highway infrastructure. Unless a study is quite narrowly construed, researchers cannot study all relevant circumstances, events or people intensively and in-depth; they select samples

(Marshall and Rossman, 1999). For this research, three main construction industry players that involved in highway projects namely, consulting companies, contractors and government agencies from Australia were included. They are the decision makers in highway investments and are more concerned on the economic dimension of highway construction projects.

Through the questionnaire survey, stakeholders namely local and state government officers, project managers, engineers, quantity surveyors, planners, civil contractors and subcontractors involved in highway projects were ranked the cost elements and issues based on their experience in highway projects. These cost elements are incorporated into proposed long term decision support model for further development as shown in Figure 2. Analytical hierarchy approach (AHP) will then be employed to analyse un-quantified and inconsistent estimation methods for social and environmental related cost elements and issues.

The Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a method of multi-criteria decision making (MCDM) and is considered as a descriptive approach to decision-making (Saaty, 1980, Lee and Chan, 2008, Nobrega et al., 2009). According to Cho (2003), the MCDM method involves decisions on the choice of a best or appropriate alternative from several potential 'candidates', subject to several criteria or attributes. To deal with a MCDM problem, an AHP model is proposed. The proposed AHP model does not merely constitute a technical solution for an isolated problem, but rather represents a comprehensive concept of the entire selection process.

As outlined in Figure 1, the model comprises benefit evaluation of alternatives. It will pass through the stages in AHP principles. It involves a multi-criteria decision making problem, where there are a number of significant criteria that need to be consider in the selection process. The related important factors and criteria require the prioritisation or weighting of some factors will be identified. Those factors or criteria with high ranking are said to be critical. To perform the operation successfully, the decision maker must first organize and prioritize the problem. Then it requires an effective decision making technique to systematically evaluate the selection process, which will help the individual to select the most appropriate choice for highway projects based on sustainability indicators and long term financial aspects. The Analytical Hierarchy Process (AHP) was chosen for this research to provide the decision maker a logical framework to model a complex decision scenario which can integrate perceptions, judgments and experiences into hierarchy. It therefore allows a better understanding of the problem, its criteria and possible choices.

The Case studies

To test and validate the long term decision support model, the case studies approach will be used. As highlighted by Stake (2005), the research derived from qualitative case studies which are more concrete, contextual and further developed through the case studies researcher's own experiential understanding, combined with the findings. Previously unknown relationships and variables could be expected to emerge from case studies, leading to rethinking of the phenomenon being studied (Stake, 2005). This is expected to occur in this research to improve the understanding of the long term decision support model and the application in highway projects. The stakeholders' requirements and comments to the model can also be determined by case studies. Their comments are used for further improvement to the model and prove this model is able to improve the decision making process in selecting highway projects with the consideration of sustainability factors.

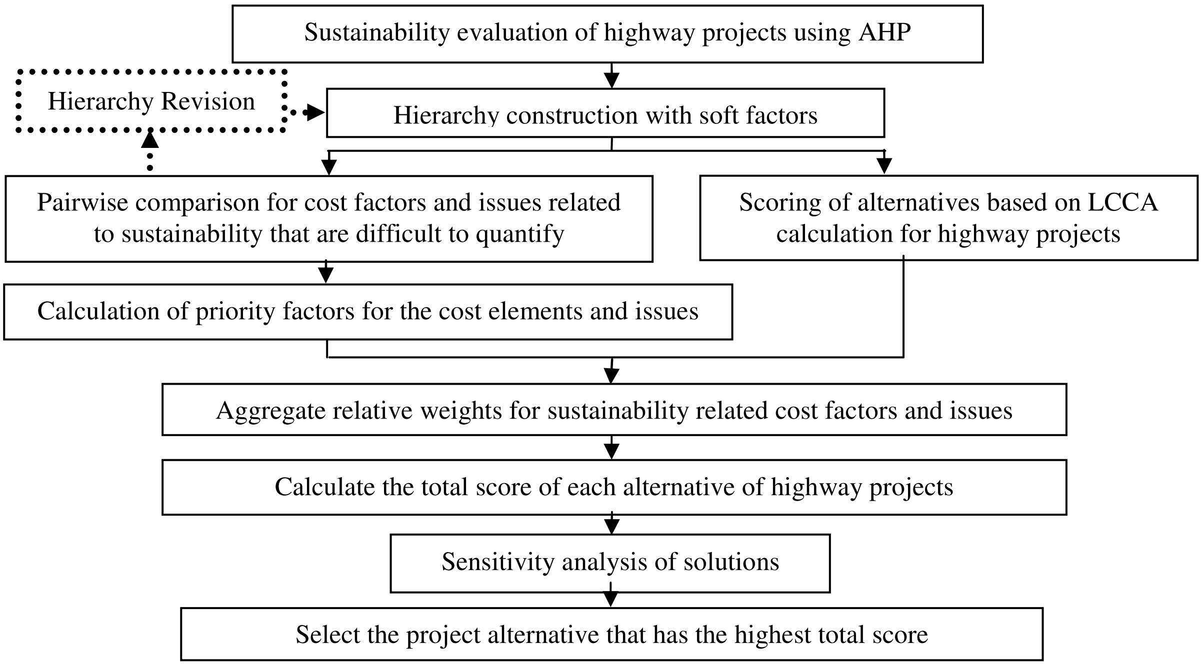

Figure 1- Proposed Analytic Hierarchy Process (AHP) model for highway projects

RESEARCH PROGRESS TO DATE

Research work to date has identified an initial set of cost elements for highway projects most likely suited for Australian conditions, pending final industry verification. A preliminary model was developed from adaptations of several existing and traditional LCCA models. Devising the new preliminary model fills a knowledge gap because while existing models provide economic evaluation on prospective highway infrastructure, they cannot process sustainability related cost data. The new model will also include features to compare alternative choice of highway construction materials and designs using environmental, economic and social indicators.

The three main cost categories namely agency, user and environmental costs were identified from literature studies and industry reports. As shown in Table 1, these cost categories can be expanded into 14 main factors with 42 sub factors for the in-depth research investigation and was used to guide the questionnaire development. A total of 150 questionnaires were delivered to the sample population, or survey participants, in three main categories of consults, contractors, and local authority and government agencies. Typical participants in this questionnaire are local and state government officers, project managers, engineers, quantity surveyors, planners, civil contractors and subcontractors involved in highway projects. Together they represent around 70 organizations throughout Australia. They were selected because of their relevant expertise in highway development. Invitations of participation were sent out through supporting e-mail request to all associated respondents and encouraged them to participate in the questionnaire surveys. With strong support from the stakeholders in highway industry, this study managed to achieve around 47 % of response rate. Out of a total of 150 questionnaires sent out, 71 questionnaires have been collected with 9 of them not complete. Therefore, the useable response rate is 42%, or 62 valid returns. Participants were asked to rank the importance of each cost element that related to life-cycle cost analysis and at the same time complement to sustainability in highway project. The level of importance will rank based on their professional judgment on a given five-point likert-scale from 1 to 5 (where 1 – not important at all and 5 – very important). Each category of data was analysed and ranked ordered on their importance. Only those cost elements and issues ranked significant for highway investment, ie, scoring 3.75 or 75% or above, will then incorporated into the preliminary long term decision support model (Figure 2) for further development. The model will also have features to compare alternative choice of highway projects using agency, environmental, and social indicators.

Table 1 - Sustainability related cost elements and issues for highway infrastructure

Sustainability Criteria	Sustainable Cost Components and Issues (Main Factors)	Sustainable Cost Components and Issues (Sub Factors)
Agency Cost	Initial Construction Costs	Labours Cost Materials Cost Plants and Equipments Cost
	Maintenance Costs	Major Maintenance Cost Routine Maintenance Cost
	Pavement Upgrading Costs	Rehabilitation Cost Pavement Extension Cost
	Pavement End of Life Costs	Demolition Cost Disposal Cost Recycle and Reuse Cost
Social Cost	Vehicle Operating Costs	Vehicle Elements Cost Road Tax and Insurance Cost
	Travel Delay Costs	Speed Changing Cost Traffic Congestion Cost
	Social Impact Influence	Cost of Resettling People Property Devaluation Reduction of Culture Heritages and Healthy Landscapes Community Cohesion Negative Visual Impact
	Accident Cost	Economy Value of Damages Internal Cost External Cost
Environmental Cost	Solid Waste Generation Cost	Cost of Dredge/Excavate Material Waste Management Cost Materials Disposal Cost
	Pollution Damage by Agency Activities	Land Use Cost Distraction to Soil Extent of Tree Felling Habitat Disruption and Loss Ecology Damage Environmental Degradation
	Resource Consumption	Fuel Consumption Cost Energy Consumption Cost
	Noise Pollution	Cost of Barriers Tire Noise Engine Noise Drivers' Attitude
	Air Pollution	Effects to Human Health Dust Emission CO2 Emission
	Water Pollution	Loss of Wetland Hydrological Impacts

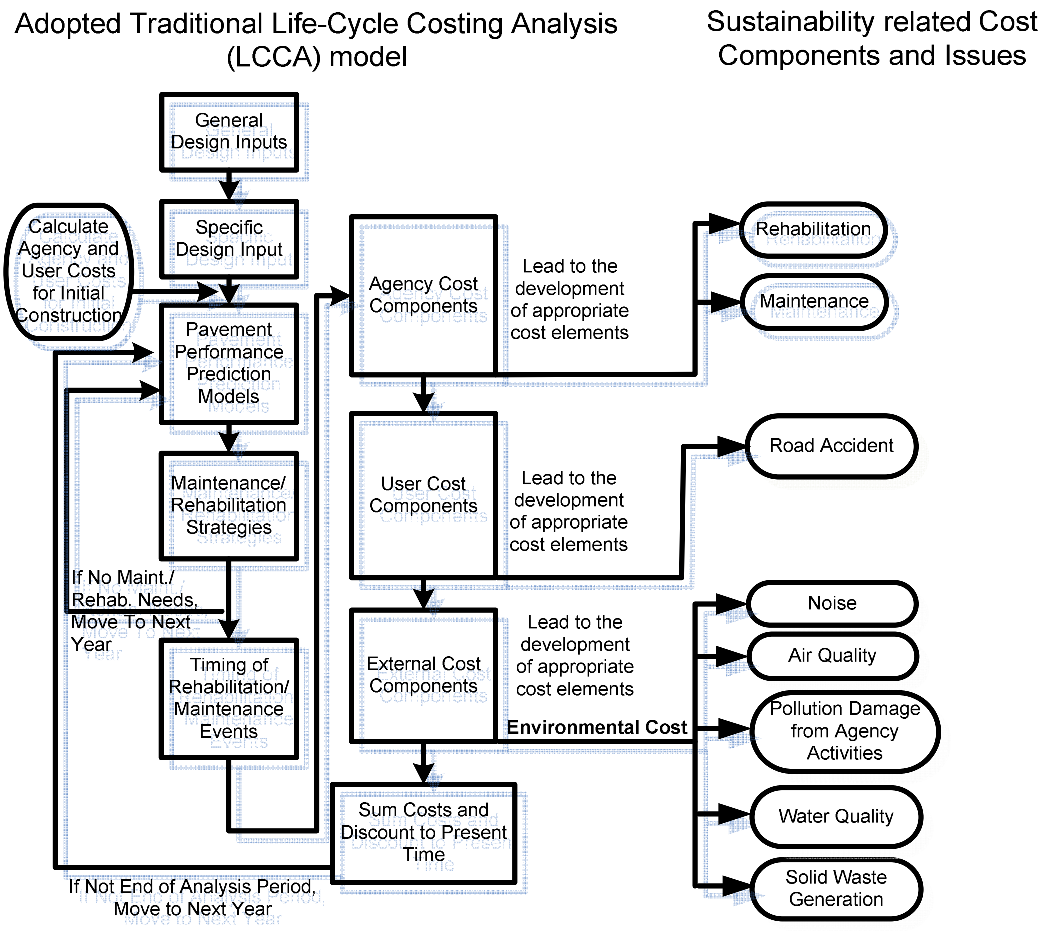

Figure 2- Proposed Long Term Decision Support Model for Highway Projects

CONCLUSION

Australia is emphasising on the development and rejuvenation of highway infrastructure because of the recent resource boom and regional economic growth. Stakeholders of highway projects must respond to the sustainability challenge while ensuring the associated financial implications and risks are managed and controlled. This calls for better decision support tools to make precise investment decisions among the complex sets of issues and agenda. This paper reports an integrated approach to developing a long term decision support model, to support construction stakeholders in making financial decisions on highway projects. Questionnaires, model development, analytical hierarchy processes (AHP) and case studies methods used in this research help in identifying, evaluating and developing a long term decision support model suited for local conditions.

Surveys to industry and literature reviews to date both confirmed the necessity of such decision support tools, which provide a platform to quantify costs of alternative investment options in regards to sustainability issues in highway projects. Through these tools, infrastructure stakeholders may identify win-win scenarios that improve market competitiveness while responding to sustainability challenges to benefit the society.

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