Responding to Sustainability Challenge and Cost Implications in Highway Construction Projects

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Abstract

Highway construction often requires a significant capital input; therefore it often causes serious financial implications for developers, owners and operators. The recent industry-wide focus on sustainability has added a new dimension to the evaluation of highway projects, particularly on the economical scale of 'going green'. Comprehensive analysis of the whole-of-life highway development that responds to sustainability challenges is one of the primary concerns for stakeholders. Principles of engineering economics and life cycle costing have been used to determine the incremental capacity investments for highway projects. However, the consideration of costs and issues associated with sustainability is still very limited in current studies on highway projects. Previous studies have identified that highway project investments are primarily concerned with direct market costs that can be quantified through life cycle costing analysis (LCCA). But they tend to ignore costs that are difficult to calculate, as those related to environmental and social elements. On a more positive note, these studies proved that the inclusion of such costs is an essential part of the overall development investment and a primary concern for decision making by the stakeholders. This paper discusses a research attempt to identify and categorise sustainability cost elements for highway projects. Through questionnaire survey, a set of sustainability cost elements on highway projects has been proposed. These cost elements are incorporated into the extension of some of the existing Life Cycle Costing Analysis (LCCA) models in order to produce a holistic financial picture of the highway project. It is expected that a new LCCA model will be established to serve as a suitable tool for decision making for highway project stakeholders.

Keywords: sustainability, life-cycle costing, highway, cost elements, decision making

1. Introduction

Sustainability has become one of the prime issues that the current construction industry needs to respond to. Though the application of sustainability in built assets is beneficial, it often involves major capital investment. Costs always become the impeding factor for stakeholders when they contemplate sustainability initiatives in highway projects. While profit is still the main concern in highway investment, there is increasing social awareness of concerns relating to global warming and climate change. Thus, it is important to balance the financial benefits with sustainability deliverable in highway infrastructure development.

To achieve such a balance, the construction industry needs to predict financial, social and environmental benefits in the long term. Life cycle cost analysis (LCCA) is an economic assessment approach that is able to predict the costs of a facility from its operation, maintenance, and replacement until the end of its life-time. It takes into account time, value of money and reduces a flow of running costs over a period of time to a single current value or present worth (PW). Life cycle costing can be used as a management tool and can be used intermittently throughout the economic life of the asset. The selection is based on the different options available to determine the alternative with the lowest LCC. As a result, LCCA is proved as a useful approach in managing the financial/ monetary aspects of the asset while emphasing sustainability in its service life.

Although in an ideal sense, the principles of sustainability should integrate into the LCCA concept, the processes of measuring costs related to sustainability and inconsistency in measurement approaches seem to complicate the matter. Previous literature studies have shown unclear boundaries and ambiguities in identifying sustainability costs and impacts of highway development (Wilde et al., 2001, List, 2007, Kendall et al., 2008, Zhang et al., 2008). Understandably, existing LCCA studies tend to omit social and environmental costs given such costs are usually difficult to measure and the values are often disputed. Worse still, these studies also create a large degree of variance in the estimation methods, resulting the lack of sustainable measures in current LCCA. (Figure 1)

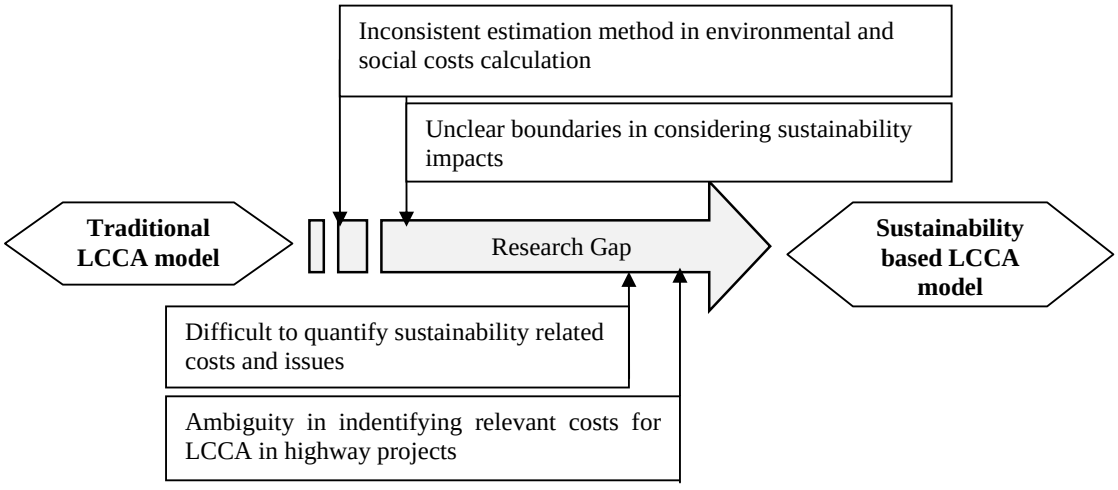

Figure 1: Relative variances to sustainability based LCCA model)

This phenomenon calls for new LCCA models that are able to integrate sustainability related cost elements and issues for investment decision support among various stakeholders, with understanding of the importance of relevant cost elements and issues in highway infrastructure development.

2. Existing life cycle cost studies in highway

Over the past few decades, many studies dealt with LCC evaluation in the road infrastructure area. The US Federal Highway Administration (FHWA) plays a major role in the research on life-cycle cost analysis (LCCA). FHWA has issued guidelines about how life-cycle cost analyses should be conducted, especially with regard to feasibility studies on pavements. Besides, the FHWA requires the application of the LCCA concept in its major highway projects. FWHA believes that life-cycle cost analysis (LCCA) can help the transportation agency officials to answer and exhibit their administration of taxpayer investments in highway infrastructure. This shows that the LCCA concept is increasingly significant in highway infrastructure management.

A few research had been carried out in the last decade, addressing the related topics of life-cycle cost analysis on highway projects (Walls Iii and Smith, 1998, Hawk, 2003, Hegazy et al., 2004, Persad and Bansal, 2004). There are also papers that focus on comparisons between benefit-cost analysis and life-cycle cost analysis, as in Lee (2002b); assessments of the state-of-the-practice in the use of these tools, as in Ozbay et al.(2004); and ideas about how uncertainty should be introduced, as in Tighe et al. (2001). However, these previous efforts did not focus on sustainability in considering the economic benefits for the stakeholders in highway development.

As many of these existing LCCA models cannot measures environmental and socially related cost elements in highway infrastructure development, Federal Highway Administration of United states (FHWA) has called for their replacement by more reliable models, especially ones that can calibrate with specific local conditions and improve the prediction quality and consistency.

The authors have conducted literature reviews to have a broader understanding of several prominent life cycle cost models in road infrastructure. Based on the findings, new model is proposed to focus on costs incurred for pursuing sustainability matters in highway projects. This review analyses the elemental features of the existing models and the cost elements concerned with current LCCA practice. This review is important because although existing studies follow the life cycle costing concept, they differ in their approaches and application to different types of projects.

Based on the literature review, it can be concluded that current studies of LCCA are focusing on different elements in highway infrastructure. These studies are divided into three main categories:

- Starting from 2001-2002, the study of LCCA is mainly focused on pavement (Wilde et al., 2001, Lee, 2002a);

- From 2003-2006, the studies focused mainly on highway bridges (Hawk, 2003, Hegazy et al., 2004, Singh and Tiong, 2005, Ugwu et al., 2005, Lee et al., 2006);

- From 2007 onwards, the studies shifted to the area of highway management (List, 2007, Lagaros, 2007, Hong and Hastak, 2007, Gerbrandt and Berthelot, 2007, Tysseland, 2008, Garcia Marquez et al., 2008, Chan et al., 2008).

Although existing studies promote the LCCA concept in highway infrastructure and establish several features in the models developed, there are still limitations in existing LCCA models.

Existing LCC methodologies tend to omit costs incurred for pursuing sustainability matters in the life cycle cost analysis calculation in highway infrastructure projects. Sustainability related costs involve agency, social and environmental costs caused by the activities in highway construction and maintenance. As mentioned by Singh and Tiong (2005), user costs are social costs incurred by the highway user, and include accident costs, delay costs and vehicle operating costs (such as fuel, tires, engine oil, and vehicle maintenance). Thus, these costs are increasingly important given that they will indirectly influence the financial budget for a long term investment.

3. Significance of incorporating costs and elements related to sustainable measures in LCCA

The sustainable concept has added a new dimension to the evaluation of highway investments. It places an emphasis on analysing the entire life of a facility, from an environmental as well as social and economic perspectives (List, 2007). Keoleian et al. (2005) developed an integrated life cycle assessment and cost model to evaluate infrastructure sustainability, and compare alternative materials and designs using environmental, economic and social indicators. Despite increasing enthusiasm to propose the LCC approach as useful in the sustainable context, the adoption and application of LCC in the highway infrastructure sector remains limited (Zhang et al., 2008, Wilde et al., 2001, List, 2007, Chan et al., 2008). Cole and Sterner (2000) suggest that practitioners' "imperfect understanding" of LCC's merits is the main cause of the limited adoption of LCC; however, there is still a gap between theory and practice. Neither of the current studies sufficiently explained underlying reasons for this gap. Moreover, the actual incorporation of social and environmental consequences in the LCC approach is not sufficiently clarified.

As mentioned by Quinet (2004), most existing LCCA cost allocation and investment evaluation for highways 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. Some existing studies tend to incorporate environmental impacts, primarily air pollution, noise and water pollution and various categories of land use impacts, however, these studies have only considered them as the external costs. Their results often differ significantly, but these can usually be explained by differences in their methodology and scope (Quinet, 2004).

Existing studies also show blurred boundaries in identifying social and environmental costs in highway infrastructure (Surahyo and El-Diraby, 2009). Some researchers considered the global impacts of sustainability while others took into account the issues of sustainability at micro levels (List, 2007, Wilde et al., 2001, Zhang et al., 2008). Surahyo and El-Diraby (2009) highlighted the

inconsistency in current estimation methods for highway construction. Some use socioeconomic approaches, while others use purely technical or engineering approaches. Due to the complexity of sustainability issues and various factors involved in financial perspective, cost elements related to sustainable measures become the difficulties of current research to create consistent estimation methods.

Meanwhile, the studies in assessing and mitigating cost risk and issues related to sustainable measures are still evolving. Highway infrastructure projects are also taking place in different physical, legal, and political environments. Therefore, it is difficult to develop a universal standard of estimation method to address social and environmental costs (Surahyo and El-Diraby, 2009). Due to these limitations, it is therefore believed more significant to incorporate sustainability related cost elements into the LCCA practice. Consequently, this study attempts to propose a life cycle cost model that is able to estimate as well as correlating social and environmental costs elements in highway project investment throughout its life cycle.

4. Research methodology

The authors used quantitative approaches to identify the level of importance of sustainability related cost elements in highway infrastructure. Questionnaires were distributed among the professional stakeholders involved in highway infrastructure projects to seek their expert comments.

To develop a conceptual primary model for sustainability assessment of LCCA in highway projects, sustainability indicators and cost elements were identified through previous research. A comprehensive literature review has revealed 40 sustainability related cost elements in highway development. This provides a platform for formulating the questionnaire survey. To improve these cost elements and questions in the questionnaire survey, a pilot study was accomplished with 3 academic experts and 6 industry experts. This resulted in several improvements and changes to the questionnaire, and also improves participants understanding of the questions. Based on this pilot study, a list of 42 sustainability related cost elements in highway projects has been selected in the final line up for inclusion in the questionnaire survey.

A total of 150 questionnaires were delivered to the participants in three main categories of consultants, contractors, and local authorities and government agencies, together with a covering letter explaining the purpose of the study and assuring them of anonymity. Typically, participants in this questionnaire are local authorities and government officers, project managers, engineers, quantity surveyors, planners, contractors and subcontractors involved in highway projects. These respondents were selected based on their expertise in highway infrastructure development to ensure the validity of the data. They are professionals at middle or higher management level thus ensuring credibility in the data collected.

To help the data collection, 70 organisations involved in highway development in Australia were chosen. Invitations of participation were distributed through supporting e-mail to all respondents, encouraging them to participate in the questionnaire survey. Because of the strong industry support

from the highway construction sector, this study managed to obtain a good response rate. Out of a total of 150 questionnaires, 71 questionnaires had been returned with nine not completed in full. As a result, the useable response rate was 42% or 62 questionnaires. Participants were asked to rate the importance of each cost element related to life-cycle cost analysis in highway project. The level of importance was based on their professional judgment, given on a five-point Likert-scale from 1 to 5 (where 1 is not important at all and 5 is very important).

Based on the data collected, almost half of the participants are working or have worked in government agencies; and most have more than 20 years of experience in highway projects. Participants were then divided into the following four groups: client representatives, project management consultants, design consultants, and construction contractors according to the nature of their organisation. The majority of participants are involved in highway design and construction activities. A small number of participants are also involved in the maintenance and extension work. Many participants have project management responsibilities and had emphasized on sustainability issues in LCCA practice.

5. Survey analysis for cost elements and issues related to sustainable measures

Table 1-3 shows the overall rating for the most significant cost elements and issues related to sustainable measures in highway projects. Results in each table show the mean scores and respective ranks of the level of importance for overall cost elements based on agency, social and environmental aspects. In the agency cost category, participants ranked the most significant costs elements in highway investments as material costs, plant and equipment costs, and rehabilitation costs. According to them, accident costs consist of internal costs, economic value of damage and external costs are the most significant costs in social aspects. And finally, environmental costs elements and issues that rated the most important include hydrological impacts, loss of wetland and cost of barriers.

Table 1: Survey analysis for sustainability related cost and issues in agency aspects

Agency Cost Rank level (All)	*Mean*	*Std. Deviation*	*Rank*
Material costs	*4.4*	*0.74*	*1*
Plant and equipment costs	*4.16*	*0.77*	*2*
Major maintenance costs	*4.06*	*0.89*	*3*
Rehabilitation costs	*4.06*	*0.87*	*3*
Labour costs	*3.87*	*0.91*	*5*
Routine maintenance costs	*3.84*	*1.06*	*6*
Recycle costs	*3.44*	*1.15*	*7*
Dispose asphalt materials costs	*3.29*	*1.07*	*8*
Demolition costs	*3.13*	*1.18*	*9*
Pavement extension costs	*3.02*	*1.02*	*10*

Table 2: Survey analysis for sustainability related cost and issues in environmental aspects

Environmental Cost Rank level (All)	*Mean*	*Std. Deviation*	*Rank*
Hydrological impacts	*4.08*	*0.88*	*1*
Loss of wetland	*4.05*	*0.88*	*2*
Cost of barriers	*4.00*	*1.05*	*3*
Disposal of material costs	*3.98*	*0.97*	*4*
Dust emission	*3.94*	*1.05*	*5*
Ground extraction costs	*3.92*	*0.92*	*6*
Waste management costs	*3.84*	*1.09*	*7*
Land use	*3.84*	*0.98*	*7*
Habitat disruption	*3.84*	*0.88*	*7*
Soil disturbance	*3.79*	*0.87*	*10*
CO2 emission	*3.79*	*1.14*	*10*
Extent of tree felling	*3.77*	*0.93*	*12*
Rough surface produce more tyre noise	*3.73*	*1.07*	*13*
Ecological damage	*3.69*	*0.99*	*14*
Environmental degradation	*3.63*	*1.02*	*15*
Air pollution effects on human health	*3.63*	*1.17*	*15*
Fuel consumption	*3.40*	*1.11*	*17*
Vehicles engine acceleration noise	*3.37*	*1.19*	*18*
Energy consumption	*3.32*	*1.01*	*19*
Driver attitudes	*3.05*	*1.3*	*20*

Table 3: Survey analysis for sustainability related cost and issues in social aspects

Social Cost Rank level (All)	*Mean*	*Std. Deviation*	*Rank*
Road accident- internal costs	*4.21*	*0.99*	*1*
Road accident- economic value of damage	*4.13*	*0.92*	*2*
Road accident- external costs	*3.85*	*1.14*	*3*
Vehicle operation costs	*3.70*	*1.07*	*4*
Traffic congestion	*3.70*	*1.26*	*5*
Resettling cost	*3.54*	*1.16*	*6*
Reduction of culture heritage	*3.52*	*1.10*	*7*
Reduce speed through work zone	*3.41*	*1.30*	*8*
Community cohesion	*3.39*	*1.21*	*9*
Negative visual impact	*3.38*	*0.95*	*10*
Property devaluation	*3.03*	*0.98*	*11*
Road Tax and Insurance	*2.85*	*1.15*	*12*

The results show that the ranking for these cost elements can be very specific in the context of highway infrastructure projects. Only those that ranked significant for highway investment, ie, scoring 3.75 or 75% or above have then been incorporated into the preliminary LCCA model for further development. Low ranking of such cost elements is rather relative to other cost elements, which have been perceived as more important in this context.

6. Discussion of results

Table 1-3 reveals the top three highest-scoring cost elements and issues relating sustainability. The findings also answer the question of why cost elements and issues related to sustainable measures are important in highway projects and how these costs may influence the financial decisions for highway investments.

6.1 Agency cost and issues

Agency costs comprise of all costs generated by the highway agencies' activities during the lifetime of overlay systems. These typically include construction and preservation spending such as material costs, plant and equipment costs and labour costs. As ranked by the participants, material, and plant and equipment costs are the top main costs in this category. This finding was also consistent with the viewpoint of previous literature (Ugwu et al., 2005, Singh and Tiong, 2005, Tighe, 2001). Material costs, and plant and equipments costs are selected because of the huge amount of capital needed for these elements during the highway constructions stage. Meanwhile, participants also ranked that rehabilitation costs as the third most important costs in highway investment. They stated that rehabilitation usually involves a huge percentage of the total cost of operation over a highway's life-time. Gerbrandt and Berthelot (2007) indicated that the discount rates used by rehabilitation activities in highways, generally ranging from 4% to 8% in the range of 30 years or more for highways. The highway rehabilitation activities involved a massive cost for the future value, which indirectly increase the overall cost of the highway projects. This shows that in an LCC analysis relating to highway project, stakeholders will allocate financial budget to manage the main element of the highway infrastructure.

6.2 Social cost and issues

Road accident costs and issues have emerged as the most important theme in social aspects. These costs refer to the economic value of damages caused by vehicle crashes that include: Internal costs, which are damages and risks to the individual travelling by a particular vehicle or mode; and external costs, which are uncompensated damages and risks imposed by an individual on other people (Partheeban et al., 2008). Based on the comments of participants, road accident costs were ranked as the most important criteria because highway safety is becoming the main agenda in modern highway development. They mentioned that highway construction needs to improve general access for the community while highway upgrade, maintenance and rehabilitation also help in improving road safety

for users. Often decisions regarding highway design selection are made not only focusing on the financial budget of the development, but also on the design safety for road users. Thus, road accident costs become a primary concern in the social aspects of LCC analysis for highway projects.

6.3 Environmental cost and issues

Highway systems produce a mixture of impacts on the environment, and costs involved in environmental issues also vary depending on the situation and the natural of the projects (Surahyo and El-Diraby, 2009). Water pollution, such as loss of wetland, and hydrological impacts, are ranked as the most important by the participants. They highlighted that water pollution impacts impose various costs including those related to polluted surfaces and ground water, contaminated drinking water, increased flooding and flood control costs, loss of unique natural features, and aesthetic losses. Quantifying these costs is challenging. It is difficult to determine how many motor vehicles contribute to water pollution problems since impacts are diffused and cumulative.

Cost of barriers is also ranked as the third highest in the environmental category. Participants mentioned that the construction of barriers is important to reduce noise and dust emission impacts on real estate near to the highway. Kenneth Dodd el al., (2004) also found that barriers are effective in reducing wildlife mortality on a heavily traveled highway. However, barriers such as walls and other structures, trees, and hills can contribute to a significant proportion of the cost during the construction stage. These barriers would also require maintenance during the highway operation stage. Therefore, stakeholders ranked cost of barriers as one of the crucial aspects in highway investment.

7. Conclusion

To stimulate economic recovery from the global financial crisis (GFC) and to support sustained growth, many levels of the Australian government have focused on transport sector and in particular highway infrastructure development and the upgrade. However, stakeholders are facing significant challenges in response to the sustainability agenda, which will indeed require expensive capital investments. Currently, there are no reliable estimates of the sustainability related cost implications or policy instruments to reduce and mitigate the financial risks that stakeholders will have to face.

This paper reports the highway stakeholders' view on the importance and priority of the substantial cost elements and issues related to sustainable measures. It also explored potential ways of incorporating these factors into the LCCA practice for a more holistic consideration of developing highway projects. The survey shows that stakeholders are starting to realize the benefits of sustainable measures in highway projects for long-term investment and prosperity. Further research is necessary to develop practical tools on LCCA analysis to aid stakeholders' in making decisions and evaluating investment risks and returns, while ensuring sustainability outcomes in highway project development.

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