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ORIGINAL PAPER

Managing cost implications for highway infrastructure sustainability

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Abstract Highway construction works have significant bearings on all aspects of sustainability. With the increasing level of public awareness and government regulatory measures, the construction industry is experiencing a cultural shift to recognise, embrace and pursue sustainability. Stakeholders are now keen to identify sustainable alternatives and the financial implications of including them on a life cycle basis. They need tools that can aid the evaluation of investment options. To date, however, there have not been many financial assessments on the sustainability aspects of highway projects. This is because the existing life cycle costing analysis models tend to focus on economic issues alone and are not able to deal with sustainability factors. This paper provides insights into the current practice of life cycle cost analysis, and the identification and quantification of sustainability-related cost components in highway projects through literature review, questionnaire surveys and semi-structured interviews. The results can serve as a platform for highway project stakeholders to develop practical tools to evaluate highway investment decisions and reach an optimum balance between financial viability and sustainability deliverables.

Keywords Highway infrastructure · Cost analysis · Life cycle · Sustainability

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Introduction

Sustainability adds a new dimension to the evaluation of highway investments. In the infrastructure context, sustainability means analysing the entire life of a facility, from social, economical as well as environmental perspectives (List 2007). Traditional priorities on financial justifications will need to be jointly considered with sustainability endeavours that will impact upon a project for the long term (Keoleian et al. 2005). Realising the impetus and advantages of pursuing sustainability, some researchers start to explore the links between sustainability and highway infrastructure. For example, Huang and Yeh (2008) implemented an assessment rating framework for green highway projects. Ugwu et al. (2006a, b) outline the demand for methods and techniques that can facilitate sustainability assessment and decision-making at the various project levels of highway construction.

Although sustainability is essential for Australian highway development, stakeholders are still very concerned with the long-term financial obligations and viability for their investments (Koppenjan and Enserink 2009; Engel et al. 2013). People believe that sustainability endeavours will have an impact on the developmental costs, and decisions based solely on acquisition cost may not be the best selection in the long run. The potential and cost implications of environmental and social dimensions must be investigated (Surahyo and El-Diraby 2009; Navabakhsh and Tamiz 2013).

With the influence of global financial crisis, decision-making on highway investment becomes crucial. Funding at all levels of government seems inadequate. Private investments are increasing. In this context, life cycle costing analysis (LCCA) can help explore alternatives. The concept of LCCA was firstly applied in highway development by AASHTO "Red Book" in the 1960s (Wilde et al. 1999). But no significant applications were reported for a few decades until the early 1990s when the federal highway administration started promoting the use of life cycle costs in highway design. Later, the US government imposed a requirement making LCCA compulsory in the National Highway System projects that costed over $25 million (Chan et al. 2008). Research interests on LCCA applications have been growing ever since (Zhang et al. 2008; List 2007; Chan et al. 2008).

Despite the recent studies, (Heijungs et al. 2013) believe there is still a gap between theory and practice and the main cause is the "imperfect understanding" of the merits of life cycle costs among practitioners. Concerning sustainability considerations, people cannot seem to justify sufficient reasons and benefits to include social and environmental costs into the equation. Study of literature reveals the following possible reasons:

- Most existing studies on life cycle costs of highway projects emphasise cost allocation and investment evaluation. These studies are primarily concerned with direct market costs, such as agency costs including road construction and maintenance costs, crash damages and how these costs vary depending on certain conditions. The existing studies assumed that the roadway conditions and requirements would not change over the lifetime of a highway project. They were not concerned with the upgrading and end of life costs, which is obviously not reflecting real-world situations (Goh and Yang 2013; Ozcan-Deniz et al. 2011; Santos and Ferreira 2013; Zhang et al. 2010).
- When faced with costs incurred from environmental impacts, primarily noise, air and water pollutions and various categories of land use impacts, many studies treat them as the external costs. As highlighted by Kumar et al. (2013), noise pollution is one of the major concern of communities living near to highways, road corridors and intersections. Most of the studies related to noise pollution and road barrier design were focus on a variety of differing scopes, methodologies, and approaches to deal with these costs therefore causing significant differences in results (Quinet 2004; Lee et al. 2010; Sölveling et al. 2011; Melemez 2013).
- There are unclear boundaries concerning costs incurred for pursuing sustainability matters in highway construction projects. Some researchers tend to focus on the global impacts of sustainability while others prefer to deal with microlevel issues (List 2007; Li and Chen 2013; Zhang et al. 2008).
- The estimation methods for sustainability-related costs for highway projects are often inconsistent (Li and Chen 2013): some use socioeconomic approaches, while others use technical/engineering approaches. Because of the professional orientation, these methods have in-built subjectivity and cannot cope with overall sustainability measures and expectations from the stakeholders.
- Highway infrastructure projects are often developed in different physical, legal, cultural and political settings. Because of this variability, studies assessing the risks and mitigating sustainability-related financial implications are still evolving (Surahyo and El-Diraby 2009).

Literature findings suggest the need to probe into the financial concerns and obligations of implementing sustainability in highway projects. Lee et al. (2013) reported that costs of social impacts of road construction, for example, impacts to public health from pollution, emission, and noise, are independent to other costs. But none of the current LCCA models can deal with them. Therefore, poor understandings and lack of ways to deal with sustainability-related costs through LCCA is an important gap this research aims to fill.

In this research, literature study and semi-structured interview of senior practitioners in highway projects help to develop in-depth understandings of current industry practice in applying life cycle costs, ways to quantify sustainability-related cost, and the challenges to integrate these cost components into a LCCA practice. On such a basis, a platform for managing financial implications of sustainability measures in highway development over the long-term is brought forward. The research efforts bridge some of the knowledge gaps between sustainability endeavours and assessment of financial viability. They are also the starting point towards developing practical tools for making long-term decisions on financial investment in the Australian highway sector.

Materials and methods

This research uses a triangulation of literature reviews, questionnaire surveys and semi-structured interviews to gather relevant data from the Australian highway construction sector. The literature study has shown the need to quantify sustainability-related cost components and the limitation of current LCCA model in handling them. To identify which are the most important in real-life projects therefore must be dealt with, surveys of the local industry practitioners are necessary.

Questionnaire survey of industry practitioners

This study used questionnaire-based surveys to identify the sustainability-related cost components in highway infrastructure. 40 sustainability-related cost components were identified through literature as the potentially important cost components and to provide a basis to formulate the questionnaire survey. A pilot study was carried out among three academic experts and six industry experts. This process resulted in several improvements to the questionnaire and changes to some of the cost components in order to improve participants' understanding of the questions. Following this pilot study, a list of 42 potentially important sustainability-related cost components was included in the questionnaire survey.

The questionnaire survey was administered over a 3-month period in 2011. A total of 150 questionnaires were delivered to survey participants with a covering letter explaining the purpose of the study, ethical considerations and the assurance of anonymity. Typical participants include local authorities and government officers, project managers, engineers, quantity surveyors, planners, contractors and subcontractors. The questionnaire respondents were selected at random from industry databases such as (a) the National Innovative Contractors Database; (b) Directories of the Australian Institute of Quantity Surveyors; and (c) Directories of the Association of Consulting Engineers Australia. These databases are commonly considered as the most authoritative and complete for the infrastructure sector. Therefore, the sample is a fair representation of the views from the Australian infrastructure stakeholders. 75 organisations throughout Australia are selected based on their recent involvement in highway projects. Through random sampling among contacts listed in these organisations, a total of 150 potential respondents were selected and approached, 71 questionnaires were collected and nine were not completed in full. This yields 62 usable responses and a response rate of 42 %. Participants were asked to rate the importance level of each proposed cost component for LCCA consideration in highway project. Most participants have more than 20 years of experience in highway construction and are now in project management roles. They are categorised into three groups of consultants, contractors and government agency. The distribution is 53 % for government agencies and local authorities, 24 % contractors and 23 % for consultants.

This study uses the mean indexing and the *t*-test as the statistical measures and analysis. These analysis are widely used in exploratory and descriptive data analysis (Yang and Peng 2008; Ahuja et al. 2009; Shehu and Akintoye 2010). In the questionnaire survey, the level of importance was based on the respondents' professional judgment on a five-point Likert scale from 1 to 5 (where 1 was "not important at all" and 5 was "most important"). Respondents were asked to consider the importance of the sustainability-related cost components based on project level considerations from their past and current work experiences. Specific terminology and industry practitioners are being used to define the questions. This ensured that interviewees understood and responded accordingly. The critical rating was set at 3.75 representing "important" to "most important". Likert scales facilitate the quantification of responses so that statistical analysis can be undertaken. Perceptions of differences between participants can also be observed. This study also employed descriptive statistics to analyse the survey results on the critical cost components. Prior to proceeding with the analysis, a Cronbach α reliability analysis was conducted. Data reliability was set for $\alpha \geq 0.7$ as recommended (Chan et al. 2011; Yip Robin and Poon 2009). Yang and Peng (2008) suggest that in the early stages of research on predictor tests or hypothesised measures of a construct, reliability of $\alpha \geq 0.7$ or higher will be adequate. In this research, $\alpha = 0.948$.

Exisitng studies used *t*-test analysis to identify the relative importance between variables (Ekanayake and Ofori 2004; Wong and Li 2006; Shehu and Akintoye 2010). The rule used in this survey analysis was that cost components with a rank value larger than 3.75 were considered critical. The null hypothesis (H0: $\mu 1 < \mu 0$) against the alternative hypothesis (H1: $\mu 1 > \mu 0$) was tested, where $\mu 1$ represented the critical rating above which the indicators were considered as "important", and $\mu 0$ represented the mean score of the survey that shows the rating below which the indicators were considered as "less important". The value of $\mu 0$ was fixed at 3.75. The decision rule was to reject H0 when the result of the observed *t* values (t0) (Eq. 1) was larger than the critical *t* value (tC) (Eq. 2) as shown in Eq. (3).

$$t_0 = \frac{\bar{x} - \mu_0}{SD/\sqrt{n}} \quad (1)$$

$$t_c = t_{(n-1,\alpha)} \quad (2)$$

$$t_0 > t_c \quad (3)$$

where $\bar{x}$ is the sample mean, $SD/\sqrt{n}$ is the estimated standard error different mean score, SD is the sampled standard deviation of difference score in the population, n is the sample size (62 in this study), $n - 1$ represents the degree of freedom, and α represents the significant level which is set at 5 % (0.05).

This study examined the criticality of cost components by using Eqs. 2 and 3. If the observed *t* value was larger than the critical *t* value $t_0 > t_C$, $t_{(61,0.05)} = 1.671$ at 95 % confidence interval, then H_0 for which the indicator was "moderately important", "less important" and "not important" was rejected, and only the H_1 was accepted. If the observed *t* value of the mean ratings weighted by the respondents was less than the critical *t* values ($t_O < t_C$), the H_O that was "less important" and "not suitable" only was accepted.

Semi-structured interviews

Semi-structured interviews were carried out following the data analysis of the questionnaire survey. The main objectives are to explore the perceptions, expectations and requirements of various stakeholders on long-term financial management practices in highway projects across Australia. Thirteen professionals involved with highway development were interviewed, with most (76 %) being senior to top managers involved in decision-making roles. The interviewees include government officers (46 %), consultants (15 %), contractors (15 %) and researchers (23 %). In particular, the government officers include managers in most relevant disciplines such as asset strategies, asset and network performance, and road transport policy and investment. The researchers include two full professors and one senior research fellow involved in highway investment research. Consultants and contractors include senior civil engineer and general manager in highway design and construction and transportation management. The interviews were held in capital cities in Australia including Sydney, Melbourne, Perth and Brisbane, through face-to-face or telephone discussions. Prior to the interviews, questions were sent to the interviewees by email for their early perusal and preparation.

Opinions of the interviewees were recorded then transcribed into text documents using a software tool—Macspeech Scribe version 1.1. The authors then listened to the transcriptions and filled gaps (where the software cannot handle) as well as check on consistency and correct mistakes. Interviewee opinions were categorised to reflect each stakeholder's perspective on integrating sustainability-related cost components in LCCA.

Industry feedback during the semi-structured interviews presented a broad picture on the current practices of long-term financial management in Australian highway projects. The findings also reveal important clues on how sustainability-related cost components are considered and calculated. Unquantified variables are also suggested for further investigation.

Results and discussion

The questionnaire survey focused on the identification of critical cost components related to sustainable measures that industry stakeholders believed to be necessary to incorporate into highway investment decisions. The questions in the questionnaire focused on the level of importance of three groups of sustainability-related cost components: agency, social and environmental cost components.

Cost implications for highway sustainability

Table 1 reveals that the top scoring cost components centre on agency, social and environmental aspects. This is elaborated below.

Agency cost components

Agency costs comprise of all costs generated by the highway agencies' activities over the project lifetime. They typically include construction, maintenance and preservation costs such as material, plant and labour costs. Survey participants consider material costs (mean = 4.40) and plant and equipment costs (mean = 4.16) most important comparatively. This is consistent to previous research (Ugwu et al. 2005; Singh and Tiong 2005). They are important because of the significant amount of capital needed for these items during the constructions stage.

Meanwhile, participants ranked that maintenance and rehabilitation costs (Mean = 4.06) as the third most important. They believe rehabilitation activities are important to preserve the effectiveness of transportation, safety of road users and economic development, and the related costs should be considered from a life cycle perspective. An optimal balance between benefits and costs is crucial to achieving long-term financial viability while ensuring the best service to road users (Rouse and Chiu 2009).

Understandably, some factors are considered more important by different stakeholders. For example, pavement recycling costs rank as the third most critical by the contractors. Contractors found that the costs of applying a recycled mixture as a base or binder course were more efficient when compared with a new bituminous. This finding also supported by Widyatmoko (2008) believes that recycled materials are more cost-effective compared to conventional materials yet can maintain similar pavement performance. This instance shows contractors' increasing concern over material conservation and cost-effectiveness.

Social cost components

Road accident costs emerge as the most important in this category. These costs refer to the economic value of damages (Mean = 4.10) caused by vehicle crashes which includes internal costs—those incurred due to damages and risks to the individual travelling in a particular vehicle; and external costs—which are uncompensated damages and risks imposed by an individual on other people (Partheeban et al. 2008). Road accident-internal costs (Mean = 4.23) were ranked as the most important because safety is becoming a main agenda. Decisions are often made not only on the basis of financial concerns but also on road

Table 1 Perceptions of "Importance Level" costs components related to sustainable measure by industry stakeholders

Sustainability indicators	Subcost components	Mean (SD, ranking)	
		All ($N = 62$)	t value
Agency category	Material costs	4.40 (0.74, 1)	1.0383
	Plant and equipment costs	4.16 (0.77, 2)	6.9164*
	Rehabilitation costs	4.06 (0.87, 3)	4.1927*
	Major maintenance costs	4.06 (0.89, 3)	2.7426*
	Labour costs	3.87 (0.91,5)	0.6685
	Routine maintenance costs	3.84 (1.06, 6)	2.8057*
	Recycle costs	3.44 (1.15, 7)	−5.6353
	Dispose asphalt materials costs	3.29 (1.07, 8)	−4.1372
	Demolition costs	3.13 (1.18, 9)	−2.1226
	Pavement extension costs	3.02 (1.02, 10)	−3.3851
Social category	Road accident—internal costs	4.23 (0.99, 1)	−0.3318
	Road accident—economic value of damage	4.10 (0.92, 2)	−6.1330
	Road accident–external costs	3.84 (1.14, 3)	−2.0669
	Vehicle operation costs	3.71 (1.07, 4)	−0.2826
	Traffic congestion	3.71 (1.26, 4)	−1.4152
	Resettling cost	3.53 (1.16, 6)	−5.7471
	Reduction of culture heritage	3.50 (1.10, 7)	−1.6068
	Community cohesion	3.40 (1.21, 8)	−2.3109
	Reduce speed through work zone	3.37 (1.30, 9)	−3.0861
	Negative visual impact	3.35 (0.95, 10)	3.2568*
	Property devaluation	3.03 (0.98, 11)	3.7016*
	Road tax and insurance	2.84 (1.15, 12)	0.7091
Environmental category	Hydrological impacts	4.08 (0.88, 1)	1.4550
	Loss of wetland	4.05 (0.88, 2)	0.6501
	Disposal of material costs	4.00 (1.05, 3)	1.8670*
	Cost of barriers	3.98 (0.97, 4)	0.7231
	Dust emission	3.94 (1.05, 5)	0.3620
	Ground extraction costs	3.92 (0.92, 6)	0.1693
	Habitat disruption	3.84 (0.88, 7)	0.8053
	Land use	3.84 (0.98, 7)	−0.4772
	Waste management costs	3.84 (1.09, 7)	−0.9264
	Soil disturbance	3.79 (0.87, 10)	−2.4828
	CO2 emission	3.79 (1.14, 10)	−3.3523
	Extent of tree felling	3.77 (0.93, 12)	1.8748*
	Rough surface produce more tyre noise	3.73 (1.07, 13)	−0.1472
	Ecological damage	3.69 (0.99, 14)	−2.5144
	Environmental degradation	3.63 (1.02, 15)	−4.2399
	Air pollution effects on human health	3.63 (1.17, 15)	−0.8076
	Fuel consumption	3.40 (1.11, 17)	1.4248
	Vehicles engine acceleration noise	3.37 (1.19, 18)	0.2763
	Energy consumption	3.32 (1.01, 19)	2.6843*
	Driver attitudes	3.05 (1.30, 20)	2.9528*

N number of respondents, *SD* standard deviation

design safety. Highway construction, upgrade, maintenance and rehabilitation should all contribute to the improvement of road safety.

Traffic congestion (Mean = 4.00, 3.79) receives high importance ranking among the social category according to contractors and consultants. Heavy traffic tends to degrade the public realm (public spaces where people naturally interact) and in other ways reduce community cohesion (Litman 2007). Traffic congestions are becoming a major issue in many Australian capital cities and puts significant pressure to highway infrastructure development and renewal. Surplus funds are needed to ensure that renewal or extension works can take place. It is a challenge to highway stakeholders to optimise desired service levels while minimising life cycle costs.

Environmental cost components

Highway systems cause a mixture of impacts on the environment, and costs involved in environmental issues vary depending on the situation and project nature (Surahyo and El-Diraby 2009). Water pollution issues, including loss of wetland, and hydrological impacts, are ranked as the most important by the government agencies and local authorities. They 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.

Ground extraction costs, disposal of material costs, and waste management costs are the other top three environmental cost components ranked by the contractors and consultants. Solid waste is usually generated during the construction, maintenance and rehabilitation stages of highway infrastructure. This waste imposes a variety of environmental, human health and aesthetic costs. Some legislations and policies are designed to ensure that the disposal of materials is properly managed (Hao et al. 2007). Therefore, legislations make it mandatory for the stakeholder to prepare relevant budgets for managing waste.

Current LCCA practices

From their own work experiences, 62 % of the interviewees report LCCA practices in highway infrastructure projects. New, major and/or federal/state level highway projects usually apply LCCA. More recent projects tended to use LCCA. Those who report no LCCA applications are involved more with maintenance and upgrading works in regional areas. However, they did mention the utilisation of benefit-cost analysis in highway planning.

The interviewees agree on the need to apply LCCA to consider a wide range of uncertainties. It is also a top priority to ensure sufficient funds so that related services are delivered economically and sustainably into the future. Chan et al. (2008) believe highway infrastructure funding will continue to fall short of future infrastructure needs. Highways typically have a long-term life span and are usually designed for a life cycle period of 50 years (Gerbrandt and Berthelot 2007). In life cycle cost assessment, the analysis period depends on the nature of the project. Some studies stated that 20–30 years analysis periods were necessary for pavement (Li and Madanu 2009) while others suggest an analysis period of more than 35 years to include at least one major rehabilitation event for each alternative being considered (Santero et al. 2011). In this study, interviewees were asked about the appropriate analysis period of LCCA for highway infrastructure. Based on their experience and knowledge, they believe the applicable period of LCCA analysis is in the range of 30–50 years depending on pavement types and conditions.

This study found that the industry stakeholders rely on their expert opinions and past experiences to establish the life cycle assessment strategies for the alternatives, which specify the timing of rehabilitation, upgrading and reconstruction. An asset forecast life is a major influence on life cycle analysis (Santos and Ferreira 2013). An error in the forecast may cause a huge difference when predicting the costs for an asset such as highway infrastructure with a 50–60-year life span. This study found that to minimise errors, the utilisation of theoretical and historical data during the life cycle cost analysis is crucial. This finding is also supported by Arja et al. (2009), but is contrary to Li et al. (2013) who observed that descriptive decision-making studies have shown that individuals are not making rational decisions, especially when uncertainty is involved because of complex and long-term consequences, which is typical for highway investment decisions.

An appropriate discount rate is a crucial decision in a life cycle cost analysis. The industry stakeholders in dealing with LCCA evaluation use specific discount rates. Usually, the discounted rates are based on the standard of the Association of Australian and New Zealand Road transport and Traffic Authorities (Ausroad); however, an appropriate adjustment is needed to suit the project's environment. Therefore, this study shows that theoretical and historical data are significantly important for decision-makers to evaluate competing initiatives and find the most sustainable growth path for the highway infrastructure.

This study found that highway stakeholders have some general understanding of the LCCA approach, but their opinions have direct connection to their profession and organisation. They do agree on the need to incorporate sustainability issues into LCCA and improve current calculation methods. The following sections reveal how industry professionals deal with sustainability-related cost issues in their own practices.

Ways to quantify sustainability-related cost components

In terms of how to quantify sustainability-related cost components, all the interviewees mentioned that the industry is still working on it. Nevertheless, there is a strong desire to do so more quickly because of the uncertainties, environmental pressures, and limited funding from governments to maintain the level of services in the long run.

Due to the lack of quantitative means to transfer social and environmental issues into real costs, the practitioners have troubles to integrate these issues into current LCCA practice, despite their belief and intentions. The feedback from the interviewees indicates that in terms of agency cost categories, they are able to quantify these costs based on the existing models and programs. They also use historical data as a guideline in dealing with these costs. The social and environmental costs are still not very clear in the estimation methods. Some of the interviewees mentioned that they use a wrap-up cost, other mentioned using the environmental impact assessment as their guideline, and the rest said that it is very hard to convert each of the components into real costs money.

However, this study found that the attempts of life cycle cost analysis to translate these problems into a monetary unit may oversimplify reality. Neoclassical economic theory presupposes that all relevant aspects have a market value, that is, a price. The interview findings showed that there are items that are not possible to price. This leads to monetary calculations being incomplete with regard to socially and environmentally related cost components. Many economic theorists suggest different ways to put a price on social environmental items, for example through taxes (Matheson and Duke 2012; Sanchez and Hampson 2012; Sölveling et al. 2011; Stanley and Hensher 2011), but this study argues that it is impossible to catch all relevant aspects of these complex problems into one monetary figure. A similar finding was drawn from the research conducted by Surahyo and El-Diraby (2009). The monetarism of LCC consequently results in loss of important details which in turn limits the decision maker's possibility to obtain a comprehensive view of these problems.

Challenges of embedding sustainability-related costs

Many interviewees consider it very hard to convert each of the components into real costs. The following outlines two main domains contribute to the different challenges when emphasising sustainability-related cost components into LCCA practice:

- The omission of social and environmental costs in LCCA: This is caused by the difficulty of putting a dollar figure on each factor, the difficulty of quantifying social and environmental related costs and unclear impacts on the social and environmental issues.
- Uncertainty environment: This is caused by the lack of data in these areas; especially in identifying real cost values for the sustainability-related cost components, the assumptions needed in calculating and identifying these cost components, uncertainties of the future social and environmental impacts caused by highway infrastructure development, dynamic changes in the environment, the lack of techniques or models in evaluation sustainability-related costs and changes in the government policies and guidelines.

In an ideal sense, one hopes that a LCCA capable of assessing "sustainability" inclusions can translate social and environmental considerations into a one-dimensional monetary unit. However, this study found that any such attempt may oversimplify reality. There are items that are simply impossible to price. This leads to monetary calculations being incomplete. Many economic theorists suggest different ways to put a price on social environmental items, for example, through taxes (Glaeser and Kahn 2010; Köhler et al. 2010; Lipscy 2012). But this survey study found that it is unfeasible to harness all aspects of these complex problems into one monetary figure. A similar finding was drawn from the research of Surahyo and El-Diraby(2009). The total monetarism of life cycle cost consequently may result in the loss of important details which in turn limits the decision maker's possibility to obtain a comprehensive view of these problems.

Improving LCCA practices for highway sustainability

Despite of the many challenges, interviewees do believe that the current LCCA practices can be improved. Table 2 shows some of their suggestions for enhancing sustainability considerations in LCCA practice for highway projects.

In order to embed sustainability in long-term financial management, there is a need for tools that are not only able to evaluate conventional cost items but also able to evaluate the importance of sustainability-related issues and impacts on the highway infrastructure investment decisions.

Table 2 Stakeholders' suggestions for enhancing sustainability in LCCA

Interviewee	Annotations
H3	"Full costs cannot be accurately determined; public survey may assist with attaining some information" (H3)
H5	"Not everything can be quantified; the use of multi-criteria evaluation methods may help in considering social and environmental impacts in highway projects" (H5)
H7	"Even though it is hard to put all these factors into real dollars, our experience and knowledge may also significantly contribute to the enhancement of sustainability" (H7)
H8	"...Engineering input is still a valuable part of the process..." (H8)
H11	"It would be good if we prepare our initial estimation, and it was our plan to develop a database that stores the initial estimation and the quality impacts. We have sorts of data and resources to check the assumptions" (H11)
H12	"It is really hard and we just based on our experience; we rely on people with experience, we are model driven, and we still need experts' input to improve on it" (H12)

Summary of findings and suggestions

Results of the questionnaire study and semi-structured interviews confirm the belief that sustainability-related costs as well as the benefits are an important part of the total assessment of highway projects. Most of the survey participants consider sustainability-related cost components are vital for highway investment decisions. The consideration of these costs is essential and must be integrated into LCCA for highway investment decisions. Critical cost components are those with t value higher than the cut-off at 1.6710. The industry suggested the top ten most critical cost components as shown in Table 3.

In the highway infrastructure sector of the construction industry, the understanding of life cycle costs is still evolving. While many practitioners have some general ideas, they have little assistance in how to apply LCCA. There is a general lack of tools or reliable methods in current practice. LCCA is usually only applied in large-scale and new highway infrastructure projects. But the industry is actively promoting LCCA and believes it is the right tool for long-term financial management.

Despite the difficulty, there are possible ways to quantify sustainability-related cost components. Some organisations employ existing models and software in quantifying

Table 3 Sustainability-related cost components in highway infrastructure

Sustainability criteria	Main cost components
Agency category	Material costs
	Plant and equipment costs
	Major maintenance costs
	Rehabilitation costs
Social category	Road accident- internal costs
	Road accident- economic value of damage
Environmental category	Hydrological impacts
	Loss of wetland
	Disposal of material costs
	Cost of barriers

the agency-related cost components, for example, the application of Highway design and maintenance standard model version 4 to quantify costs associated with construction and maintenance activities. There are a number of reasons for the lack of standard calculation methods for socially and environmentally related cost components. For example, there are no published calculation methods or models in dealing with these cost components; and they are too difficult to convert into real dollar value. Instead, these costs are often classified as external costs or wrap-up costs. For example, waste management costs are deemed as part of the construction costs.

There are three main challenges to the integration of sustainability-related cost components into LCCA practice—(a) the limited capacity of existing LCCA models; (b) poor quality of assumptions and data when dealing with sustainability costs; and (c) difficulties of examining long-term community and environmental issues and costs.

The interviewees of this research suggested the possible ways to improve the consideration of sustainability issues in LCCA practice. Multi-criteria evaluation and decision-making may help identify social and environmental effects therefore associated costs in highway infrastructure projects. Practical knowledge and past experiences may significantly contribute to the enhancement of sustainability in

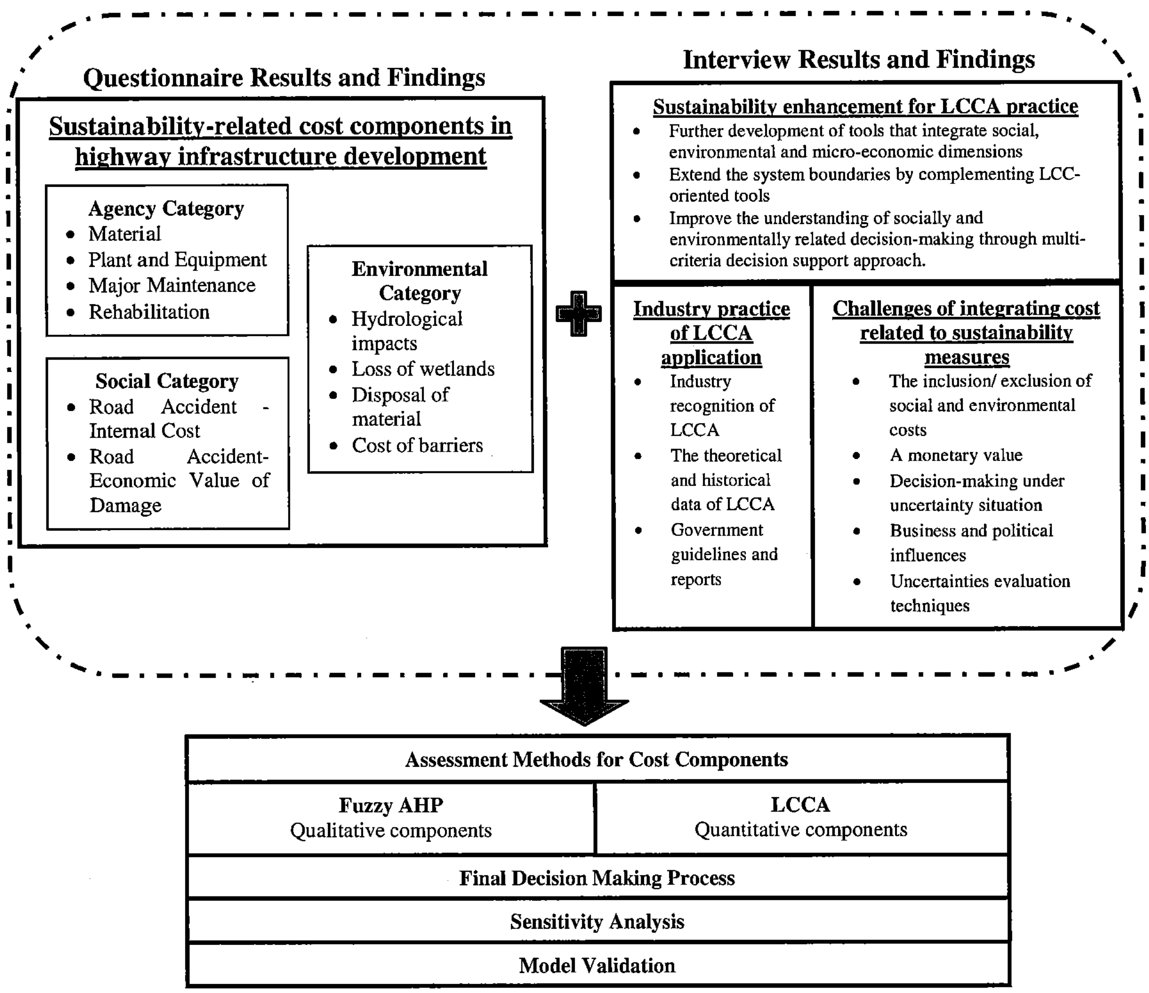

Fig. 1 Platform of overall scenario of long-term financial management in highway infrastructure

LCCA. More specific and in-house developed tools will also help in this respect.

Based on the processes of this research and findings from the surveys, a platform depicting the overall scenario of long-term financial management with sustainability objectives in highway infrastructure development can be established as shown in Fig. 1.

Using this platform, the research reported here advances onto the next stage—the development of a decision support model that incorporates fuzzy analytical hierarchy process, LCCA and sensitivity analysis. The on-going work aims to produce a procedure driven tool that can guide decision-makers to contemplate financial positions of embedding sustainability initiatives into highway projects.

Conclusion

The pursuit of sustainability in highway development can have long-term financial implications to the stakeholders involved. By understanding the current issues and critical cost components related to sustainability endeavours, we can develop and articulate strategies to improve and encourage the enhancement of highway infrastructure's long-term financial positions, while maximising sustainability deliverables. Feedbacks from the industry practitioners confirmed the importance of sustainability-related costs and suggest that highway investment decisions use scientific and systematic approaches such as the LCCA, particularly in dealing with sustainability issues. The authors propose a platform of LCCA considerations to assist practitioners' harness the various financial management scenarios and integrate them with sustainability objectives under a streamlined procedure. This provides the foundation for the development of a decision support model to evaluate costs associated with sustainability measures in highway projects. Future studies may also consider the inherent links between costs and risks for more tangible predictions on the gains as well as the commitments of pursuing sustainability in highway infrastructure.

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