

Importance of Sustainability-Related Cost Components in Highway Infrastructure: Perspective of Stakeholders in Australia

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Abstract: Highway infrastructure development typically requires major capital input. Unless planned properly, such requirements can cause serious financial constraints for investors. The push for sustainability adds a new dimension to the complexity of evaluating highway projects. Finding environmentally and socially responsible solutions for highway construction will improve its potential for acceptance by the society and in many instances the infrastructure's life span. Even so, the prediction and determination of a project's long-term financial viability can be a precarious exercise. Existing studies in this area have not indicated details of how to identify and deal with costs incurred in pursuing sustainability measures in highway infrastructure. This paper provides insights into the major challenges of implementing sustainability in highway project development in terms of financial concerns and obligations. It discusses the results from recent research through a literature study and a questionnaire survey of key industry stakeholders involved in highway infrastructure development. The research identified critical cost components relating to sustainability measures based on perspectives of industry stakeholders. All stakeholders believe sustainability related costs are an integral part of the decision making. However, the importance rating of these costs is relative to each stakeholder's core business objectives. This will influence the way these cost components are dealt with during the evaluation of highway investment alternatives and financial implications. This research encourages positive thinking among the highway infrastructure practitioners about sustainability. It calls for the construction industry to maximize sustainability deliverables while ensuring financial viability over the life cycle of highway infrastructure projects. DOI: 10.1061/(ASCE)IS.1943-555X.0000152. © 2013 American Society of Civil Engineers.

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Introduction

Highway infrastructure development and regeneration are gaining significance in many countries such as the United States, China, and Australia. In coping with the export of resources and associated regional growth, the Australian government has set up various plans to accelerate road infrastructure development and improvement (Bureau of Transport and Communications Economics 2009). As the government commits to boosting the economy through national infrastructure projects, sustainability challenges need to be included in the equation. Sustainability is an evolving concept with changing implications and wide ranged interpretations in the built environment (Yang 2012). For highway infrastructure development, it calls for more resource-sufficient, cost-effective, environmentally-friendly, and socially-acceptable solutions in both the construction and operation phases (Jha et al. 2012; Ramaswami and Rudolph 2009; Šelih et al. 2008). In many ways, environmental and social sustainability is becoming a matter of responsibility and operational practice for industry stakeholders and the government. Sustainability endeavors in

highway development, for example, noise barrier installation, will require additional upfront capital input. This is often a concern for investors, owners, and other stakeholders. Recent financial studies in Australia have revealed that more than a third of Australian local governments are financially constrained (Price Waterhouse Coopers 2006). However, they have the ongoing task of working with the federal government to develop and maintain highway infrastructure. To do so, they must ensure that adequate funding is in place for the long term. Therefore, early insight into the financial picture of pursuing sustainability has become an essential strategy for astute infrastructure investors and stakeholders.

Making an investment decision can be complicated when cost components related to sustainability are unclear. As highway infrastructure usually has a long-term life span, the evaluation of investment alternatives and project options requires tools and a systematic approach. Engineering economics is considered as a valuable approach to deal with public-sector investment evaluation and it often involves benefit-cost analysis (BCA) and life-cycle cost analysis (LCCA) (Lee 2002). LCCA provides valuable considerations on time, value for money, and reduction of running costs over time, and conversion to a single current value or present worth for analysis (Ozbay et al. 2004). It can be used intermittently throughout the economic life of an asset, such as a highway. In theory, LCCA can be regarded as a subset of BCA, with the latter being widely recognized as a useful framework for assessing the positive and negative aspects of prospective actions and policies, and for making the economic implications' alternatives an explicit part of the decision-making process (Carter and Keeler 2008; Jang and Skibniewski 2009).

In today's environment, all engineering economics approaches should incorporate the principles of sustainability. However, the

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difficulties in *measuring sustainability* and the inconsistency in measurement standards often complicate the matter. Previous studies have shown ambiguities in identifying sustainability-related costs and impacts in highway development (Kendall et al. 2008; List 2007; Wilde et al. 2001; Zhang et al. 2008). Many previous studies tend to avoid such complexities by omitting social and environmental costs. This has resulted in a knowledge gap (Fig. 1).

Other problems also hinder the integration process. Collecting cost data is challenging because of the complexity of sustainability in highway projects. It often has different priorities, perspectives, and interpretations depending on the projects, organizations, and stakeholders. Costs related to environmental and social measures eventually involve *soft* factors that display inconsistency in measurement approaches (Surahyo and El-Diraby 2009). Existing BCA and LCCA models 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 (Chou et al. 2006; Gerbrandt and Berthelot 2007; List 2007; Madanu et al. 2009; Ugwu et al. 2005). Early attempts to address the new sustainability aspects differ significantly in their consideration of environmentally- and socially-related costs (Quinet 2004; Surahyo and El-Diraby 2009). Benefits and costs are often articulated in money terms, and are in sync with the time value of money, so that all flows of benefits and project costs over time are expressed on a common basis in terms of their *present value* (Lee 2002).

This paper examines current views and practices of industry stakeholders in regard to integrating sustainability into the long-term financial predictions and evaluation for highway infrastructure projects. It discusses a research project that identifies the importance of sustainability-related cost components in highway infrastructure provisions. In the research, a range of cost components were identified and evaluated by Australian highway industry practitioners based on their real-life experiences. The most significant cost components were incorporated into new modules as part of a developing financial decision support model, expanded from existing studies to incorporate the costs associated with sustainability commitments. The research seeks to bridge some of the knowledge gaps between sustainability endeavours and long-term financial investment decisions in highway infrastructure in the Australian context.

Significance of Sustainability-Related Cost Components in Highway Investment

Highway projects are long-term assets. Strategic plans should set out capital expenditure requirements for the next 25–50 years to

maintain service levels and long-term financial viability (Gerbrandt and Berthelot 2007; Gransberg and Molenaar 2004). Cash-flow constraints at points in time should also be resolved through long-term financial planning. Decision tools are required to evaluate investment decisions.

Realizing the advantages of pursuing sustainability, a number of research projects have attempted to investigate topics that bridge the gap between sustainability and highway infrastructure. For example, Huang and Yeh (2008) have implemented an assessment rating framework for green highway projects. In the study, the framework has been developed to analyze and measure the achievement of sustainability in the highway infrastructure by using several indicators. Ugwu et al. (2006a, 2006b) found that there is a need for methods and techniques that would facilitate sustainability assessment and decision making at the various project level interfaces during the development phases of a project.

Although the sustainability concept is essential for current Australian highway infrastructure development, stakeholders also realize the importance of its long-term cost implications for investments. As decisions based solely on acquisition cost may not be effective in the long run, Surahyo and El-Diraby (2009) highlighted the need to assess both environmental and social costs in the construction, rehabilitation, and operational phases of highway development. There is consensus among stakeholders that sustainability endeavors will have an impact on the developmental costs of highway infrastructure.

As sustainability is being increasingly emphasized in highway infrastructure, effective management of highway investment has become a crucial issue as highway funding to address the shortfall of funds at all levels of government (Price Waterhouse Coopers 2006). In this regard, the engineering economics concept is applied in highway development to explore more efficient investments for stakeholders. It evaluates not only the initial construction cost of the highway infrastructure, but also all the associated maintenance costs during its service life.

The use of engineering economics in highway infrastructure seems established, but limitations in the current approaches still remain—they are not well established and do not cover some critical issues in highway development. Wilde et al. (2001) reported that consideration of the social impacts of road construction, including health impacts of pollution emission and noise, was conversely independent of other costs and that these elements had not been incorporated into engineering economics.

The existing approaches tend to omit costs incurred for pursuing sustainability matters in the engineering economics calculation in highway infrastructure projects. These sustainability-related cost components include agency, social, and environmental costs caused

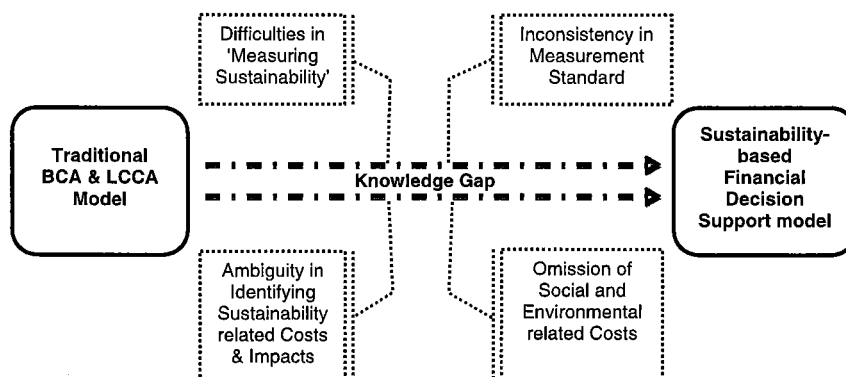


Fig. 1. Gap between traditional BCA and LCCA models and the need for a comprehensive financial decision support model

by the activities involved in highway construction and maintenance. As stated 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). These costs are increasingly important given that they will indirectly influence the financial budget for a long-term investment.

This study is motivated by the realization of the need and potential to incorporate sustainability-related cost components into the highway investment decision, in order to capture the full costs of highway development under the increased pressure to achieve sustainability. To this end, all projects of highway development, whether for capacity building, new access, or regeneration have an obligation to respond to these cost components.

Assessing Sustainability Costs for Highway Projects

Sustainability adds a new dimension to the evaluation of highway investments. However, the highway infrastructure sector's understanding of life-cycle costs remains limited (List 2007; Wilde et al. 2001; Zhang et al. 2008). Practitioners' imperfect perception of the merits of life-cycle costing and sustainability outcome appear to be the main cause (Chan et al. 2008; Cole and Sterner 2000).

According to Quinet (2004), existing studies consider environmental impacts, primarily air pollution, noise and water pollution, and land use impacts as external costs. There also seems to be blurred boundaries in social and environmental costs for highway projects (Surahyo and El-Diraby 2009). Surahyo and El-Diraby (2009) highlighted the inconsistency in current estimation methods for highway construction, with a bias towards socioeconomic, technological, or engineering approaches. The complexity of sustainability and the broad implications and interests in financial issues made it difficult for past research to create consistent estimation methods.

Studies on sustainability-related cost components in highway infrastructure development continue to evolve (List 2007; Surahyo and El-Diraby 2009). While real-world perspectives of life-cycle costs remain scarcely reported, past studies have highlighted the need to consider appropriate methodologies in dealing with these issues.

Based on a review of recent literature, this paper suggests three categories of costs relating to sustainability measures and considerations: Agency costs such as those for initial construction, maintenance, pavement upgrade, and end-of-life costs (Bradbury et al. 2000; Rouse and Chiu 2008; Tighe 2001); Social costs such as items from vehicle operation, travel delay, social impact, and road accidents (Gilchrist and Allouche 2005; Gorman 2008; Surahyo and El-Diraby 2009; Winston and Langer 2006); and Environmental costs such as those dealing with noise, air quality, water quality, resource consumption and pollution damage from agency activities, and solid waste generation (Ahammed and Tighe 2008; Steen 2005; Surahyo and El-Diraby 2009; Ugwu et al. 2005).

These costs have been compared with and checked against Australian highway infrastructure characteristics and terminologies. With some minor adjustments, a set of key cost components relating to sustainability measures was established. The three main cost categories of agency, social, and environmental costs were expanded into 14 main factors with 42 subfactors for in-depth investigation. Table 1 shows the sustainability-related cost components for highway infrastructure. Surveys were conducted to study local infrastructure scenarios, collect opinions from practitioners, and develop a decision model for cost predictions and financial management.

Research Design and Development

Questionnaire surveys are effective in gathering information about the characteristics, actions, or opinions of a large group of people (Creswell 2009). In this research, a questionnaire survey was conducted to assess the importance of sustainability-related cost components in highway infrastructure. The questionnaire used in this research was based on the combination of the literature review, preliminary model development, and also the identification of sustainability-related cost components in highway infrastructure.

In this research, three main construction industry players involved in highway projects, namely, consulting companies, contractors, and government agencies from Australia were included. The respondents include senior practitioners and stakeholders who have substantial working experience in highway infrastructure projects. They play an important role in the construction industry because they are the decision makers in highway investments. Consequently, these stakeholders also have more concerns about the economic dimension of highway construction projects.

A pilot study was done with three academic and six industry experts. This helped finalize the 42 subfactors as sustainability-related cost components in the questionnaire survey. Targeted stakeholders included government and client representatives, builders, designers, project managers, quantity surveyors, planners, contractors, and subcontractors involved in highway projects. The questionnaire respondents were selected at random from industry databases in:

- The National Innovative Contractors Database by the Cooperative Research Centers for Construction Innovation;
- Directories from the Australian Institute of Quantity Surveyors; and
- Directories from 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 representative of the Australian construction industry stakeholders. Using the databases, 75 organizations throughout Australia are selected due to their recent involvement in highway projects. The questionnaire survey was administered online in 2011. Through random sampling among contacts listed in these organizations, 150 potential respondents were selected and approached for the questionnaire survey. Seventy-one questionnaires were returned with 9 incomplete. As a result, the useable response rate was 42% or 62 questionnaires. Of the 62 industry respondents, all of them were from the top (78%) and middle (22%) management level, holding positions such as general managers, finance directors, or project managers, respectively. All the participants had experience working in highway projects, with many over 20 years. The majority of participants were involved in highway design and construction activities (50%). A small number of participants were also involved in highway maintenance and extension works (19%); others engaged in smaller scale construction, extension, and maintenance works (31%). Most of the respondents came from the project management team (40%); others were client representatives, design consultants, and construction contractors (20% each). Together they serve as the decision makers in highway development and as such, have more experiences in the economic dimensions of highway projects. As highway development work is often at a national level and undertaken across state boundaries, the current geographical location of these respondents was not considered as important. Nevertheless, more than half (53%) of them also had work experience in government agencies throughout Australia. This background ensures the perspectives and viewpoints collected

Table 1. Sustainability-Related Cost Components for Highway Infrastructure (Adapted from Goh 2011)

Sustainability criteria	Sustainable cost components (main factors)	Sustainable cost components (subfactors)	Factors that lead to the consideration of impacts and costs in highway infrastructure
Agency cost	Initial construction costs (Ugwu et al. 2006a, b) Maintenance costs (Hall et al. 2003; Wilde et al. 2001) Pavement upgrading costs (Gransberg 2009; Rouse and Chiu 2008) Pavement end-of-life costs (Aravind and Das 2007; Oliveira et al. 2005; Widyatmoko 2008)	Labor costs Material costs Plant and equipment costs Major maintenance costs Routine maintenance costs Rehabilitation costs Pavement extension costs Demolition costs Disposal costs Recycle and reuse costs	A number of general categories that should be considered when tabulating an estimate for initial construction, rehabilitation, and annual maintenance costs. All the cost items are viable options for construction and rehabilitation activities and should, accordingly, be considered as agency costs in the analysis of life-cycle costs for a highway pavement project. The initial construction items can be assigned quantities by the engineer to represent a particular design alternative, while unit costs can be provided for the other aspects of maintenance and rehabilitation activities. There has been a great deal of interest in the issue of the social costs in highway infrastructure development (Gorman 2008; Steen 2005; Surahyo and El-Diraby 2009; Winston and Langer 2006). The passions surrounding social costs have evoked far more shadow than light. At the center of this debate is the question of whether various modes of transportation are implicitly subsidized because they generate unpriced externalities, and to what extent this biases investment and usage decisions. On the other hand, the real social costs are typically not recovered when financing projects and are rarely used in charging for their use. Environmental issues in the current construction industry lead to an unforeseen capital investment for built assets. One problem is the complexity of these issues, which leads to unpredictable investment decisions among the investors. In identifying environmental costs in highway investment, two situations are of particular significance for LCCA: one is the estimation of the full life-cycle cost of a project or decision, and the other is the attempt to increase production efficiency and focus on cost components related to the environment. In the first case, only downstream costs are of interest. In the second case, all cost components related to environmental are of interest. When deciding upon which environment-related costs to include in the study, there are borders that need to be taken into account
Social cost	Vehicle operating costs (Goedecke et al. 2007; Kumar and Sutherland 2009) Travel delay Costs (Bartle and Devan 2006; Nguyen et al. 2008) Social impact Influence (Ahammed and Tighe 2008; Litman 2007; Surahyo and El-Diraby 2009) Accident cost (Chan et al. 2010a; Park et al. 2012; Partheeban et al. 2008)	Vehicle element costs Road tax and insurance costs Speed changing costs Traffic congestion costs Cost of resettling people Property devaluation Reduction of culture heritages and healthy landscapes Community cohesion Negative visual impact Economy value of damages Internal costs External costs	
Environmental cost	Solid waste generation cost (Abduli et al. 2011; Hanandeh and El-Zein 2010; Kolikkathara et al. 2010) Pollution damage by agency activities (Fischer 1999; Steen 2005) Resource consumption Noise pollution (Arenas 2008; Baldauf et al. 2008; Shukla et al. 2009) Air pollution (Chan et al. 2010a) Water pollution (Steen 2005; Surahyo and El-Diraby 2009)	Cost of dredge/excavate material Waste management costs Material disposal costs Land use costs Distraction to soil Extent of tree felling Habitat disruption and loss Ecology damage Environmental degradation Fuel consumption costs Energy consumption costs Cost of barriers Tire noise Engine noise Drivers' attitude Effects to human health Dust emission CO ₂ emission Loss of wetland Hydrological impacts	

through the survey are representative of the real-world scenarios and needs across Australia.

Statistical Measures and Analysis

Mean indexing and the t-test are widely used in exploratory and descriptive data analysis (Ahuja et al. 2009; Shehu and Akintoye 2010; Yang and Peng 2008). In the questionnaire survey, the level of importance was based on the respondents' professional judgment on a given 5-point Likert scale from 1 to 5 (where 1 was

not important at all and 5 was *very important*). Respondents were asked to consider the importance of the sustainability-related cost components based on project level considerations from their work experiences. Specific descriptions were used to define the questions to ensure that interviewees understood and responded accordingly. The critical rating was set at 3.75 representing *important* or *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 analyze 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 α greater than or equal to 0.7 as recommended (Chan et al. 2010; Yip Robin and Poon 2009). Yang and Peng (2008) suggest that in the early stages of research on predictor tests or hypothesized measures of a construct, reliability of α greater than or equal to 0.7 or higher will be adequate. In this research, $\alpha = 0.948$.

T -test analysis has been used by past studies to identify relative importance between variables (Ekanayake and Ofori 2004; Shehu and Akintoye 2010; Wong and Li 2006). The rule of the t -test in this survey analysis was that cost factors with a rank value larger than 3.75 were considered critical. The null hypothesis (H_0 : $\mu_1 < \mu_0$) against the alternative hypothesis (H_1 : $\mu_1 > \mu_0$) was tested, where μ_1 represented the critical rating above which the indicators were considered as *important*, and μ_0 represented the mean score of the survey that shows the rating below which the indicators were considered as *less important*. The value of μ_0 was fixed at 3.75. The decision rule was to reject H_0 when the result of the observed t -values (t_0) [Eq. (1)] was larger than the critical t -value (t_c) [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} = sample mean; SD/\sqrt{n} = estimated standard error different mean score (SD sampled standard deviation of difference score in the population; n = sample size (62 in this study); $n-1$ = degree of freedom; and α = significant level which is set at 5% (0.05).

The criticality of cost components in this study was examined 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 ($t_0 < t_c$), the H_0 that was *less important* and *not suitable* only was accepted.

Results

The questionnaire survey focused on identifying the critical cost components of sustainability measures that industry stakeholders believe should be incorporated 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. The questions were designed to identify the importance of these three categories of cost components in long-term financial management as highlighted in the literature review.

The three sections focus on different aspects of sustainability-related cost components when selecting a highway infrastructure project and making highway investment decisions. The agency, social, environmental cost component sections aim to explore the perspective of industry stakeholders' regarding the level of importance of these costs in highway investment. Meanwhile, the open questions seek to explore the comments and opinions of the stakeholders towards implementation of sustainability-related cost components in the long-term financial management of a highway. The supplement at the end of the questionnaire was

designed to gather information about the participants' background for statistical purposes.

The questionnaire was developed using a multiple-choice format. The questionnaire also included one open-ended question to allow respondents with relevant experience in highway development to submit additional comments and outline other problems they experienced in the long-term financial management of highway projects. Based on the data from the questionnaire survey, stakeholders' perspectives on the importance of cost components are presented in Table 2.

Sustainability-Related Cost Components: Perspective of Industry Stakeholders

The results indicate that the importance level of sustainability-related cost components according to the consultants were different than the importance level according to other stakeholders. Among the consultants, the highest rated costs were material costs (mean = 4.57), plant and equipment costs (mean = 4.36), and labor costs (mean = 4.07) in the agency category. Vehicle operating costs (mean = 3.79), traffic congestion (mean = 3.79), and road accident-economic value of damage (mean = 3.71) were the highest rated in the social category. Waste management (mean = 3.93), ground extraction (mean = 3.86), disposal of material costs (mean = 3.86), and hydrological impacts (mean = 3.86) were rated the highest in the environmental category.

For contractors, the most important cost components were those that threatened their profit level, with materials (mean = 4.50), plant and equipment (mean = 4.19), rehabilitation (mean = 3.94), and recycling costs (mean = 3.94) rated important in the agency category. The road accident-internal costs (mean = 4.25), traffic congestion (mean = 4.00), and external costs (mean = 3.88) were rated the most significant in the social category. The disposal of materials (mean = 4.13), ground extraction (mean = 4.06), and waste management costs (mean = 4.00) were classified as critical in the environmental category.

For government agencies and local authorities, the 10 costs rated highest in importance were those in the category of agency costs, namely, materials (mean = 4.30), major maintenance (mean = 4.24), and rehabilitation costs (mean = 4.21). In the social category, road accident costs, namely, internal costs (mean = 4.45), external costs (mean = 4.39), and the economic value of damage (mean = 4.00) were rated highest in importance. In the environmental category, hydrological impacts (mean = 4.36), loss of wetland (mean = 4.24), and cost of barriers (mean = 4.21) were the most important.

A general observation of the results is that the cost components rated most highly by the respondents tended to be those that were paramount to their specific business objectives. Analysis of the results reveals that the most important cost components were centered on three major sustainability aspects, namely, agency, social, and environmental cost issues. The following sections discuss these findings in detail.

Discussion

The most critical cost components in highway investments with sustainability objectives were identified. The results on the critical cost components were indicated by the t -values, which were higher than the cutoff t -value (1.6710) offering supporting evidence for the importance of these cost components. The top 10 rated cost components were identified and validated by industry stakeholders as shown in Fig. 2.

Table 2. Perceptions of Importance Level of Cost Components Related to Sustainability Measures by Industry Stakeholders

Sustainability indicators	Subcost components	Mean (SD, ranking)				<i>t</i> -value
		All (<i>N</i> = 62)	Government agencies and local authorities (<i>N</i> = 33)	Contractors (<i>N</i> = 15)	Consultants (<i>N</i> = 14)	
Agency cost components	Labor costs	3.87 (0.91, 5)	3.82 (0.77, 6)	3.88 (1.29, 5)	4.07 (0.83, 3)	1.0383
	Material costs	4.40 (0.74, 1)	4.30 (0.81, 1)	4.50 (0.65, 1)	4.57 (0.65, 1)	6.9164 ^a
	Plant and equipment costs	4.16 (0.77, 2)	4.09 (0.77, 4)	4.19 (0.91, 2)	4.36 (0.63, 2)	4.1927 ^a
	Major maintenance costs	4.06 (0.89, 3)	4.24 (0.83, 2)	3.81 (0.91, 6)	4.00 (0.96, 4)	2.7426 ^a
	Routine maintenance costs	3.84 (1.06, 6)	4.06 (1.00, 5)	3.44 (1.09, 8)	3.86 (1.10, 6)	0.6685
	Rehabilitation costs	4.06 (0.87, 3)	4.21 (0.65, 3)	3.94 (1.17, 3)	3.93 (1.00, 5)	2.8057 ^a
	Pavement extension costs	3.02 (1.02, 10)	3.09 (1.07, 9)	3.00 (1.00, 9)	2.86 (0.95, 9)	-5.6353
	Demolition costs	3.13 (1.18, 9)	3.24 (1.12, 7)	3.00 (1.12, 9)	2.86 (1.41, 9)	-4.1372
Social cost components	Recycle costs	3.44 (1.15, 7)	3.21 (0.99, 8)	3.94 (1.23, 3)	3.43 (1.34, 8)	-2.1226
	Dispose asphalt materials costs	3.29 (1.07, 8)	3.00 (1.00, 10)	3.63 (1.12, 7)	3.50 (1.02, 7)	-3.3851
	Vehicle operation costs	3.71 (1.07, 4)	3.67 (1.11, 5)	3.75 (1.20, 5)	3.79 (0.89, 1)	-0.3318
	Road tax and insurance	2.84 (1.15, 12)	2.79 (1.17, 12)	3.00 (1.24, 12)	2.86 (1.10, 11)	-6.1330
	Reduce speed through work zone	3.37 (1.30, 9)	3.18 (1.26, 10)	3.56 (1.33, 6)	3.64 (1.34, 4)	-2.0669
	Traffic congestion	3.71 (1.26, 4)	3.55 (1.23, 7)	4.00 (1.18, 2)	3.79 (1.42, 1)	-0.2826
	Resettling cost	3.53 (1.16, 6)	3.58 (1.30, 6)	3.44 (1.09, 7)	3.43 (0.94, 6)	-1.4152
	Property devaluation	3.03 (0.98, 11)	3.12 (1.11, 11)	3.06 (0.92, 10)	2.79 (0.70, 12)	-5.7471
	Reduction of culture heritage	3.50 (1.10, 7)	3.82 (1.16, 4)	3.06 (0.83, 10)	3.29 (1.07, 8)	-1.6068
	Community cohesion	3.40 (1.21, 8)	3.48 (1.28, 8)	3.38 (0.94, 8)	3.14 (1.35, 10)	-2.3109
	Negative visual impact	3.35 (0.95, 10)	3.39 (1.09, 9)	3.25 (0.51, 9)	3.29 (0.99, 8)	-3.0861
	Road accident—economic value of damage	4.10 (0.92, 2)	4.39 (0.79, 2)	3.81 (1.00, 4)	3.71 (0.99, 3)	3.2568 ^a
	Road accident—internal costs	4.23 (0.99, 1)	4.45 (1.79, 1)	4.25 (0.97, 1)	3.64 (1.22, 5)	3.7016 ^a
	Road accident—external costs	3.84 (1.14, 3)	4.00 (1.12, 3)	3.88 (1.00, 3)	3.43 (1.28, 6)	0.7091
	Ground extraction costs	3.92 (0.92, 6)	3.85 (0.87, 10)	4.06 (0.86, 2)	3.86 (1.10, 2)	1.4550
	Waste management costs	3.84 (1.09, 7)	3.70 (1.10, 16)	4.00 (0.97, 3)	3.93 (1.14, 1)	0.6501
Environmental cost components	Disposal of material costs	4.00 (1.05, 3)	3.97 (1.02, 7)	4.13 (0.97, 1)	3.86 (1.23, 3)	1.8670 ^a
	Land use	3.84 (0.98, 7)	4.06 (0.97, 4)	3.38 (0.94, 17)	3.71 (0.99, 6)	0.7231
	Soil disturbance	3.79 (0.87, 10)	3.82 (0.85, 13)	3.75 (0.88, 9)	3.64 (0.93, 9)	0.3620
	Extent of tree felling	3.77 (0.93, 12)	3.85 (1.00, 11)	3.63 (0.97, 12)	3.64 (0.74, 9)	0.1693
	Habitat disruption	3.84 (0.88, 7)	3.97 (0.92, 8)	3.69 (0.70, 10)	3.57 (0.94, 12)	0.8053
	Ecological damage	3.69 (0.99, 14)	3.85 (1.06, 11)	3.44 (0.85, 16)	3.50 (0.94, 13)	-0.4772
	Environmental degradation	3.63 (1.02, 15)	3.88 (1.05, 9)	3.38 (0.94, 17)	3.21 (0.89, 15)	-0.9264
	Fuel consumption	3.40 (1.11, 17)	3.33 (1.16, 18)	3.81 (0.66, 8)	3.07 (1.27, 17)	-2.4828
	Energy consumption	3.32 (1.01, 19)	3.30 (0.95, 19)	3.88 (0.39, 5)	2.71 (1.20, 19)	-3.3523
	Cost of barriers	3.98 (0.97, 4)	4.21 (0.96, 3)	3.69 (0.95, 10)	3.64 (0.93, 9)	1.8748 ^a
	Rough surface produce more tire noise	3.73 (1.07, 13)	4.00 (1.00, 5)	3.50 (0.94, 15)	3.21 (1.19, 15)	-0.1472
	Vehicles engine acceleration noise	3.37 (1.19, 18)	3.52 (1.28, 17)	3.25 (0.93, 19)	3.07 (1.21, 18)	-2.5144
	Driver attitudes	3.05 (1.30, 20)	3.15 (1.30, 20)	3.25 (1.09, 19)	2.50 (1.40, 20)	-4.2399
	Air pollution effects on human health	3.63 (1.17, 15)	3.79 (1.22, 14)	3.56 (1.08, 14)	3.29 (1.14, 14)	-0.8076
	Dust emission	3.94 (1.05, 5)	4.00 (1.12, 5)	3.94 (0.86, 4)	3.71 (1.07, 8)	1.4248
	CO ₂ emission	3.79 (1.14, 10)	3.73 (1.15, 15)	3.88 (1.04, 5)	3.79 (1.25, 5)	0.2763
	Loss of wetland	4.05 (0.88, 2)	4.24 (0.83, 2)	3.88 (0.92, 5)	3.71 (0.91, 6)	2.6843 ^a
	Hydrological impacts	4.08 (0.88, 1)	4.36 (0.82, 1)	3.63 (0.80, 12)	3.86 (0.95, 3)	2.9528 ^a

Note: *N* = number of respondents.^a*t*-values, which is higher than cut of *t*-value (1.6710) indicating the significance of the indicators.

Agency Costs Category

Agency costs consist of all expenses generated by the highway agencies' activities throughout the overlay system lifetime. These typically include construction and preservation costs such as material, plant and equipment, and labor costs. Consultants were more concerned with the initial construction costs in highway development. They rated materials (mean = 4.57, rank = 1), plant and equipment (mean = 4.36, rank = 2), and labor costs (mean = 4.07, rank = 3) as the most important. Consultants are mostly involved at the front-end of project development and would therefore tend to focus on the initial costs rather than on the life-cycle benefits for

highway operation and maintenance. Conversely, the consultants in this study were less interested in cost items such as pavement extension (mean = 2.86, rank = 9) and demolition (mean = 2.86, rank = 9) as required in LCCA for highway projects. According to them, by the end of the pavement's life, major rehabilitation works are usually required to improve the pavement quality.

Respondents in the government agency group and local authority groups rated major maintenance (mean = 4.24) as the second most important cost, while the contractors rated rehabilitation costs (mean = 3.94) as the third most important in the agency costs category. Contractors reported that maintenance and rehabilitation activities often involve a significant cost throughout the highway life

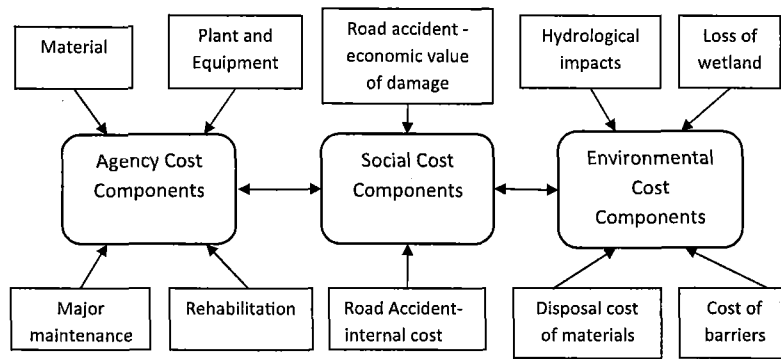


Fig. 2. Critical sustainability-related cost components in Australian highway infrastructure projects adapted from Goh (2011)

span. Rehabilitation activities are important to ensure the optimization of highway pavement performance (Chung et al. 2006). However, perhaps due to limited funding in today's economic climate, government agencies and local authorities considered that the greatest task in managing highway infrastructure was the prioritization of maintenance and repair expenditure. As highway infrastructures approach the end of their design lives, there is an increasing demand for new construction, rehabilitation, maintenance, and repairs to maintain service levels.

Some factors were more important than others according to different stakeholders. For example, costs for pavement recycling was ranked as the third most important factor according to contractors but only ranked eighth in importance by government agencies and local authorities (mean = 3.21) and consultants (mean = 3.43). According to Widyatmoko (2008), recycled materials are more cost-effective compared to conventional new materials. Recycled materials also provide similar performance in pavement. This shows that contractors, at the forefront of the work field, are increasingly concerned with economic advantage, placing an emphasis on recycled material.

Social Costs Category

In relation to road accidents—internal costs emerged as the most important theme in the social category. Government agencies and local authorities (mean = 4.45, rank = 1) and the contractor group (mean = 4.25, rank = 1) were most concerned with road safety. According to them, the main reason for highway infrastructure development was to improve community mobility and road safety. This is supported by past research. According to Park et al. (2012), the consideration of factors such as pavement width can significantly reduce the rate of road accidents. Highway construction needs to improve general access for the community while highway upgrades, maintenance, and rehabilitation should continue to improve road safety. Currently, decisions on highway design are often based on the safety of road users, rather than the available financial resources. Thus, road accident costs are a primary concern among the social aspects of LCCA for highway projects.

Vehicle operation (mean = 3.79, rank = 1) and traffic congestion (mean = 4.00, rank = 2) received high importance ratings among costs in the social category from the contractors and consultant groups. These costs indirectly influence the overall cost of a highway throughout its lifetime and should be taken into account in LCCA for highway projects. Heavy traffic tends to degrade the public realm (public spaces where people naturally interact) and in other ways reduces community cohesion (Litman 2007). Highway traffic certainly involves traffic delay costs to users who have

been mathematically modelled and evaluated based on simplifying assumptions (Jiang and Adeli 2003). While road users incur these costs, Wilde et al. (2001), Ozbay et al. (2004), and Eliasson (2009) believe that costs occurred in lost travel time may exceed an agency's construction cost by a substantial amount, particularly in urban areas.

Renewal and regeneration works are needed for highway infrastructure at some points in time and will require funds. It is a challenge for industry stakeholders to optimize the desired service levels while minimizing life-cycle costs for highway infrastructure.

Environmental Costs Category

Highway systems cause a number of impacts on the environment. Costs related to environmental problems vary depending on the situation and the nature of the project (Surahyo and El-Diraby 2009). Water pollution (such as hydrological impacts) (mean = 4.36, rank = 1) and loss of wetland (mean = 4.24, rank = 2) were rated as the most important costs by the participants representing government agencies and local authorities. Such problems can result in polluted surfaces and groundwater, contaminated drinking water, increased flooding and flood control, loss of unique natural features, and aesthetic losses. Quantifying these costs is challenging. For example, determining how many motor vehicles contribute to water pollution problems can be difficult since the impact is often diffused and cumulative.

Contractors and consultants rated waste management costs as significant (mean = 4.00, rank = 3) and (mean = 3.93, rank = 1), respectively. These costs are usually generated during the construction, maintenance, and rehabilitation stages of highway development. They are significant because engineers make early decisions on design configurations, construction methods/processes, and material specifications. Such decisions often have major impacts on the whole-of-life cost. Material reuse, recycling, and innovation in methods and processes will help reduce these costs. Legislation and policies can help ensure that the disposal of materials is properly managed (Hao et al. 2007). In some cases, legislation and carrying out proper planning makes it essential for stakeholders to prepare a relevant budget to manage the disposal of solid waste.

Research Limitations

The sampling process was enabled through industry databases typically listing senior managerial roles. This ensured a relatively high profile of respondents, which suited this research well as it

explored key stakeholder perceptions. In roles of senior to top managers, the respondents were asked to reflect on their years of experience and project level views, and to discard any performance indicators specific to each organization.

The limited number of contacts listed in industry databases has resulted in a small sample population, which presents a research limitation, as larger samples would normally yield more data to work from. However, this problem is offset by the seniority of the respondents, their associated broad viewpoints, and that they have made top in real rather than speculative projects. Nevertheless, future work could approach the issue with a wider range of practitioners. In addition to make the research results applicable to other countries, regional differences due to distinctive economic, cultural, and political environments can be prospective topics of study.

Conclusion

Sustainability has become one of the primary concerns within the construction industry. Compared to other sectors, the highway infrastructure sector also faces tough monetary challenges due to huge levels of funding required for the project life cycle. Stakeholders and investors need strategies to maintain financial viability as sustainability measures are increasingly introduced into the design, planning, construction, and operation phases. According to the industry practitioners, consideration of sustainability-related cost components through long-term financial management can significantly improve evaluation credibility for highway investments. It can also potentially reduce project risks and therefore, promote further sustainability input by the stakeholders.

Current literature on sustainability-related costs is mostly related to building construction. However, the complex and dynamic nature of highway projects translates to an even higher level of investment risk. Therefore, it is crucial to explore the relative importance of potential cost components and focus on the critical costs in order to improve long-term investment decision making. This study investigated these issues based on a survey of the perceptions, knowledge, and experience of Australian industry stakeholders.

The research reveals the most critical cost components in highway investments in the Australian infrastructure context. The perceptions of consultants and contractors are relatively similar. For example, both groups classify material, plant, and equipment costs as the top components in highway investment. There are some differences in the rating of the importance of cost components between stakeholders. Government agencies and local authorities have different opinions compared to the other groups. This can be explained by the fact that they are often the main investors in public highway infrastructure. Different professions and organizations have their own priority goals and needs, and such differences can affect the handling of these cost components in highway investment decisions. However, all stakeholders surveyed in this study firmly believe that sustainability-related cost components are vital to decision making for highway development.

The identified cost components are being further investigated through interviews and a case study, which aim to identify specific methods of predicting and controlling these costs. It is anticipated that new highway investment evaluation models can be formulated to predict holistic financial models and sustainability deliverables in highway infrastructure.

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