The Importance of Environmental Issues and Costs in Life Cycle Cost Analysis (LCCA) for Highway Projects

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ABSTRACT: Sustainability has been increasingly recognised as an integral part of highway infrastructure development. In practice however, the fact that financial return is still a project's top priority for many, environmental aspects tend to be overlooked or considered as a burden, as they add to project costs. Sustainability and its implications have a far-reaching effect on each project over time. Therefore, with highway infrastructure's long-term life span and huge capital demand, the consideration of environmental cost/ benefit issues is more crucial in life-cycle cost analysis (LCCA). To date, there is little in existing literature studies on viable estimation methods for environmental costs. This situation presents the potential for focused studies on environmental costs and issues in the context of life-cycle cost analysis. This paper discusses a research project which aims to integrate the environmental cost elements and issues into a conceptual framework for life cycle costing analysis for highway projects. Cost elements and issues concerning the environment were first identified through literature. Through questionnaires, these environmental cost elements will be validated by practitioners before their consolidation into the extension of existing and worked models of life-cycle costing analysis (LCCA). A holistic decision support framework is being developed to assist highway infrastructure stakeholders to evaluate their investment decision. This will generate financial returns while maximising environmental benefits and sustainability outcome.

KEY WORDS: Environmental, life-cycle cost analysis, highway, infrastructure, decision support.

1. INTRODUCTION

The complexity of environmental issues can lead to unpredictable investment decisions among investors and other stakeholders. For many economists and researchers, life cycle costing (LCC) is a useful approach for mitigating and managing this problem. Life cycle cost analysis (LCCA) is a tool that attempts to identify and quantify all significant costs involved in acquiring, owing and operating physical assets over their useful lives (Woodward, 1997).

However, current LCC may not provide appropriate solutions due to its limitation in handling environmentally related costs (Gluch & Baumann, 2004). Surahyo and El-Diraby (2009) have highlighted that there are inconsistent estimation methods in current studies relating to environmental costs in highway projects. There is also an unclear boundary in identifying such costs in highway infrastructure. Gluch & Baumann (2004) emphasise that there are limitations on current LCCA models, so further improvement of LCC in handling the environmental context is needed. Since investors are always facing problems of ambiguity and making irrational decisions, there is a need for decision support tools that are able to identify environmentally related costs in highway projects.

This paper discusses a research project which investigated the level of importance of environment related cost elements and issues within highway projects. Environmental cost factors were explored on an integral basis through literature review and quantitative approaches. The most important ones, as ranked by industry experts, were then evaluated and integrated into an existing LCCA model for further development. The resulting model will provide valuable references and decision support tools to stakeholders for use in investments decisions for highway projects.

2. LCC CONCEPT IN THE ENVIRONMENTAL CONTEXT

The literature review suggested limitations with the use of most existing LCCA models (Gerbrandt & Berthelot, 2007; Hong & Hastak, 2007; Lagaros, 2007). One such limitation is the omission of environmental costs in the life cycle cost analysis in highway projects. Many LCCA methods and software have excluded environmental costs because such costs are normally difficult to measure and the values related with user and environmental issues are often disputed.

Time is also one of the limitations while applying the LCC concept. The consequences of an emission or impact may never end, even if the possibilities of following and modeling them decrease as time goes by. The depreciation of future impacts, by narrowing system borders or discounting as economists do, is particularly important to recognize when dealing with global warming effects or depletion of natural resources (Azar & Sterner, 1996).

Another dimension is the inconsistent estimation methods in handling environmental costs and impacts. Many LCCA researchers and practitioners argue that some existing studies use socio-economic approaches, while others use engineering approaches in estimating costs related to the environment issues. This argument shows inconsistency in the estimation methods, reflecting the disagreement about the extent of the impacts of a highway project on the surrounding environment.

Traditionally, LCCA models treat input variables as discrete, fixed values where a conservative "best guess" of the value of each input parameter is used to compute a single deterministic result. A sensitivity analysis is often performed to assess the effects of various input parameters on the model results. However, the sensitivity analysis does not necessarily reveal areas of uncertainty that may be a critical part of the decision making process. As a result, it is difficult to ascertain which alternative has the “true” lowest life-cycle cost (Walls Iii & Smith, 1998). Risk analysis could be used with LCCA concept to address the issue of uncertainty and could allow the decision-maker to weigh the probability of any particular outcome that may occur.

The assessment and integration of environmental costs associated with the LCCA concept in highway projects is still a formidable challenge. However, a clear definition of the costs is needed so that everything of importance is included and no double counting occurs. Therefore, this research needs to disregard certain negligible costs and impacts and concentrate on the most important ones in highway investment.

3. ENVIRONMENTAL COSTS AND ISSUES IN HIGHWAY INFRASTRUCTURE

There is a huge coverage of studies related to environmental costs and issues in highway development. However, studies done from a LCC perspective still remain limited and they still face difficulties to reach the normal precision in costs estimation. But they still, at least, make the methodological issues more visible and practical rather than just a general discussion.

Most existing studies on cost allocation and investment evaluation for highway are primarily concerned with direct market costs, such as road construction and maintenance, travel time, vehicle operating costs and crash damages and how these vary depending on roadway conditions. Other types of studies incorporate environmental impacts, primarily air pollution, but sometimes also noise and water pollution and various categories of land use impacts. Some studies have only considered these as the external costs. The results of these studies often differ significantly, but this can be explained by the differences in their methodology and scope (Quinet, 2004).

While identifying environmental costs in highway investment, two situations are of interest in LCC: one is that of estimating the full life cycle cost of a project or decision, and another is that of trying to increase production efficiency and focusing on cost elements related to the environment. In the first case, only downstream costs are of interest. In the second case, all costs related to environmental issues 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. Environment related costs and issues that are considered essential in highway investment are classified into the following categories. (Table 1)

Table 1: Environmental impacts and costs in highway projects

ENVIRONMENTAL CATEGORY	FACTORS LEAD TO IMPACTS AND COSTS
Noise Pollution	• *Type of vehicle*. Motorcycles, heavy vehicles (trucks and buses), and vehicles with faulty exhaust systems produce high noise levels. • *Traffic speed, stops and inclines*. Lower speeds tend to produce less engine, wind and road noise. Engine noise is greatest when a vehicle is accelerating.. Aggressive driving, with faster acceleration and harder stopping, increases noise. • *Pavement condition and type*. Rougher surfaces tend to produce more tire noise, and certain pavement types emit less noise (Ahammed & Tighe, 2008). • *Barriers and distance.* Walls and other structures, trees, hills, distance and sound-resistant buildings (e.g., double-paned windows) tend to reduce noise impacts.
Air Pollution	• *Mobile Emission*: It is difficult to control given the reason that they are numerous and dispersed, and have relatively high damage costs because motor vehicles operate close to people. • *Transportation:* Transportation is a major contributor of many air pollutants. These shares are even higher in many areas were people congregate, such as cities, along highways and in tunnels.
Resource Consumption	• *Energy Security:* This includes economic and military costs associated with protecting access to petroleum resources. National security costs associated with defending petroleum supplies in the Middle East region are estimated to range from $6 to $60 billion annually (Romm & Curtis, 1996). • *Economic vulnerability:* dependence on imported petroleum makes a region vulnerability to economically harmful price shocks (sudden price increases) and supply disruptions. For example, the last three major oil price shocks were followed by an economic recession.

	• *Higher world oil prices:* High U.S. demand increases international oil prices (the elasticity of world oil price with respect to U.S. demand is estimated at 0.3 to 1.1), imposing a financial cost on all oil consumers (Smith, 2009).
Pollution Damage from Agency Activities	• *Roadkills*: Animals killed directly by motor vehicles. Road kills are a major cause of death for many large mammals, including several threatened species. • *Road Aversion and other Behavioural Modifications*: Animals behaviour and movement patterns are affected by roads; become accustomed to roads, and are therefore more vulnerable to harmful interactions with humans. • *Population Fragmentation and Isolation*: By forming a barrier to species movement, roads prevent interaction and cross breeding between population groups of the same species. This reduces population health and genetic viability. • *Exotic Species Introduction:* Roads spread exotic species of plants and animals that compete with native species. Some introduced plants thrive in disturbed habitats along new roads, and spread into native habitat. Preventing this spreading is expensive. • *Pollution*: Road construction and use introduce noise, air and water pollutants. • *Impacts on Terrestrial Habitats*: Habitat disruption and loss. • *Impacts on Hydrology and Aquatic Habitats*: Road construction changes water quality and water quantity, stream channels, and groundwater. • *Access to Humans*: This includes hunters, poachers, and irresponsible visitors. • *Sprawl:* Increased road accessible stimulates development, stimulates demand for urban services, which stimulates more development, leading to a cycle of urbanization.
Solid Waste Generation Cost	• *Damage costs:* Inappropriate disposal of used tires, batteries, junked cars, oil and other harmful materials resulting from motor vehicle production and maintenance. • *Construction and Demolition Wastes:* surplus materials arising from any land excavation or formation, civil construction, roadwork, pavement maintenance or demolition activities. • *Waste from Motor Vehicles:* Motor vehicles produce various harmful waste products that can impose externalities. Motor vehicle wastes are the major source of moderate-risk wastes produced in typical jurisdictions (Giannouli, De Haan, Keller, & Samaras, 2007). • *Waste Management:* Planning for waste management is the process that involves many complex interactions such as transportation systems, land use, public health considerations and interdependencies in the system such as disposal and collection methods.
Water Pollution and Hydrologic Impacts	• *Impacts from Motor vehicles, roads and parking facilities:* These impacts impose various costs including polluted surface and ground water, contaminated drinking water, increased flooding and flood control costs, wildlife habitat damage, reduced fish stocks, loss of unique natural features, and aesthetic losses. • *Hydrologic Impacts:* They concentrate stormwater, causing increased flooding, scouring and siltation, reduce surface and groundwater recharge which lowers dry season flows, and create physical barriers to fish. • *Improper vehicles leak hazardous fluids:* Lubricating oils used in automobiles are burned in the engine or lost in drips and leaks onto the ground or into sewers lead to destruction to many aquatic species.

Highway projects take place in different physical, legal, and political environments; therefore, it is a challenge to develop a universal standard to calculate environmental costs. However, it is important to move towards having consistent and effective tools to support stakeholders in making financial decisions for highway investment. To that end, this paper presents the relative importance of environmental costs elements, as validated by highway industry practitioners, which can be incorporated into the proposed LCCA model for further development.

4. RESEARCH METHODOLOGY

Figure 1 shows the sustainability oriented LCCA model development process from literature review for highway projects. This study is emphasised on incorporating sustainability concept into LCCA. The costs related to sustainable measures in highway projects were identified and divided into three main categories namely agency, social and environmental cost and issues. In this paper, the relative importance of the costs and issues related to environmental elements were identified. Literature review has been carried out in environmental area. Accordingly, 20 environmentally related cost elements and issues in highway development were identified. This provides a platform of questionnaire survey formulation. To refine these cost elements and questions in the questionnaire survey, a pilot study was accomplished. This resulted in several improvements and changes to the questionnaire to improve the understanding of the questions by the participants before the final version of the questionnaire was developed. These environmentally related cost elements and issues have been widely discussed in previous studies on the subject. Therefore, this literature review shows a strong relationship between current industry practice and also the academic research path.

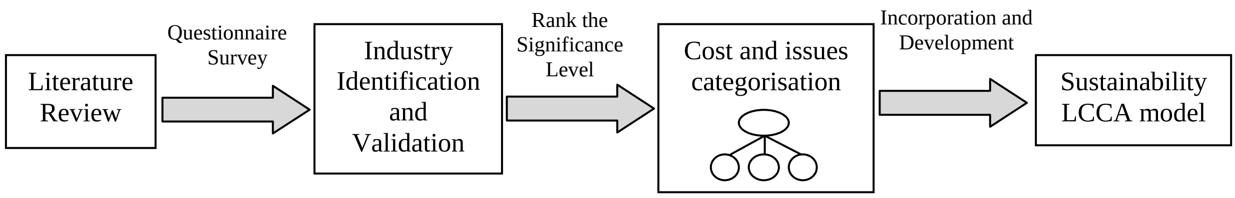

Figure 1: Workflow of sustainability LCC model development for highway projects

A total of 150 questionnaires were distributed together with a covering letter explaining the purpose of the study and assuring the participants of anonymity. Typical participants in this questionnaire survey are divided into three main categories, namely consultants, contractors, and local authority and government agencies. They are all the stakeholders, namely local authorities and government officers, project managers, engineers, quantity surveyors, planners, contractors and subcontractors involved in highway projects. Together they represent around 70 organisations involved in highway infrastructure development throughout Australia. They are professionally positioned at middle or higher management level in order to ensure a certain level of accuracy and credibility in the data collected. Invitations of participation were sent out through supporting e-mail, encouraging all potential participants, to take part in the questionnaire surveys.

Based on the data collected, almost half of the participants are working in government agencies; most of them have more than 20 years of experience in highway projects. According to the nature of their organization, participants were divided into the following four groups: client representatives, project management consultants, design consultants, and construction contractors. The majority of participants are involved in highway design and construction activities. A small number of participants are also involved in maintenance and extension works for highway infrastructure; others are involving in construction, extension and maintenance works. Most of the participants are in the project management levels so they express their interest in emphasizing sustainability concepts in LCCA practice.

With strong support from stakeholders in highway industry, this study obtained a response rate of 42%. Out of a total of 150 questionnaires, 71 questionnaires had been collected and 9 questionnaires were not completed. As a result, the useable response 62 questionnaires (42%). Participants were asked to rate the importance of each cost element that related to life-cycle cost analysis in highway projects. The level of importance was based on their professional judgment on a given five-point likert-scale from 1 to 5 (where 1 is not important at all and 5 is very important). The environmentally related costs were then categorised based on their importance level as ranked by the respondents. These cost categories will be incorporated into the existing LCCA model for further development.

5. RESULTS AND DISCUSSION ON ENVIRONMENTAL COSTS AND ISSUES

Table 2 shows the overall rating for the most significant environmentally related cost elements and issues in the highway infrastructure projects. Results in this table shows the mean scores and respective ranks of importance level for overall cost elements. Environmental costs elements and issues that rated most importance comprise: hydrological impacts, loss of wetland, dust emission, cost of barriers, disposal of material cost and ground extraction cost.

From the results, it is understandable that the ranking for environmentally related cost elements is very specific in the context of highway infrastructure projects. Only those cost elements and issues ranked as significant for highway investment, ie, scoring 3.75 or 75% or above, have been incorporated into the preliminary LCCA model for further development. Low ranking of certain cost elements is rather relative to others which have been perceived as more important in this context.

Highway systems produce a mixture of impacts on the environment, and costs involved in environmental issues also vary depend on the situation and the natural of the project (Surahyo & El-Diraby, 2009). Based on Table 2, water pollution, such as lost of wetland, and hydrological impacts, are ranked the highest by the participants. They highlighted that these impacts impose various costs including those related to polluted surface 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 diffuse and cumulative.

Table 2: Survey analysis for sustainable 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*

Cost of barriers is also ranked as the third highest importance. Respondents mentioned that the construction of barriers is important to reduce noise impact and dust emission to the real estate near to the highway. Barriers, such as walls and other structures, trees, and hills, involve a huge portion of the cost during the construction stage, which is consistent with the viewpoint from literature review (Arenas, 2008). These barriers also involve maintenance costs during the highway infrastructure operation stage.

Finally, solid waste generation and management costs are other costs and issues have ranked significant, by the stakeholders, in the management of highway infrastructure. Solid waste is usually generated during the construction, maintenance and rehabilitation stages of highway infrastructure. This waste imposes a variety of environmental, human health, aesthetic, and financial costs. Some legislation and policies are designed to ensure that the disposal of materials is properly managed (Hao, Hills, & Huang, 2007). Consequently, legislation makes it mandatory for the stakeholder to prepare a relevant budget for managing the disposal of solid waste.

6. CONCLUSION

Highway infrastructure development is an integral part of the modern society. Yet it often has direct implications to the environment. Environmental issues usually involve unpredictable costs because of their complexity and uncertainty in relation to forecasting future consequences. These costs may cause the investors making an unreliable investment judgement on highway development. To solve such a problem, this research attempts to integrate environmental issues and costs in the proven Life Cycle Costing Analysis (LCCA) concept, to further develop a sustainability oriented LCCA model to aid the decision making on highway investment.

A questionnaire survey was conducted to explore the perceptions and concerns, as well we gathering agreeable compromises among industry experts in Australia. It helped explore the importance of various environmental cost elements in highway and identified those of immediate relevance and importance to be dealt with through LCCA. The results have shown a distinctive advantage of categorising the environmental cost elements and issues based on practitioners' perspectives and findings of past research. This survey served as an integral element of developing a sustainability oriented LCCA model capable of dealing with costs associated with environmental issues for highway investment.

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