EXTENDING LIFE-CYCLE COSTING ANALYSIS FOR SUSTAINABILITY CONSIDERATIONS IN AUSTRALIAN ROAD INFRASTRUCTURE PROJECTS

Kai Chen Goh 1
Jay Yang 2

Keywords: Sustainability, life-cycle costing analysis, infrastructure, project costs.

Abstract
Among evolving definitions and various view points, sustainable development is essentially about making societal investments. These investments should be in synchronization with the natural environment, trends of social development, as well as organizational finance positions and local economies over a long time span. Traditionally in the eyes of clients, any project development must produce the highest level of profit margins, with some ad hoc consideration for other impacts. As all citizens of our society are becoming more aware of the sustainability concepts and new challenges such as the climate change, stakeholders of projects will demand answers to these issues when contemplating new built facilities. A large number of R&D projects have focused on the technical advancement and environmental assessment of products and built environments. It is necessary to place focus on cost/benefit issues, as no developers in the world would want to lose money by investing in built assets. For infrastructure projects, due to their significant cost of development and lengthy delivery time, presenting the full "money story" of going green is of vital importance. Traditional views of life-cycle costing analysis (LCCA) tend to focus on the pure economics of a construction project. Sustainability concepts are not broadly integrated with the current LCCA in the construction sector. To rectify this problem, this paper reports on the progress to date of a research aimed at developing and extending contemporary LCCA models in the evaluation of road infrastructure sustainability. The suggested new model development is based on sustainability indicators identified through previous research, and incorporating industry verified cost elements of sustainability measures. The on-going project is expected to produce a working model for sustainability life-cycle costing analysis for road infrastructure projects.

1. Introduction
Over the last few decades, sustainable development as a concept has been gaining popularity across various sectors including the construction industry. However, the practice of sustainability in the construction industry is still facing difficulties because of the globalization of the business environment, demographic change, environmental sustainability and climate change, new materials and technologies, information and communication technologies, and governance and regulation (Hampson and Brandon, 2004).
In support of a business sector to contribute to sustainable development, there is a need to create increasing economic values while using natural resources sustainably and making a broader contribution to society’s social aims and objectives (Bourdeau, 1999). This is a considerable expansion of the traditional concern of business with profitability and shareholder value as the only goal. There is also a greater need for tools to enable businesses to monitor, manage and report their performance in these respects.
Therefore, sustainable development is about making societal investments that are in synchronization with the natural environment and financial positions over a long horizon. In general sense for a client, the development of a construction project needs to be consistent with the benefits produced. Any built facility will cause certain degree of impacts to the natural environment. However, these impacts can be minimized by creating a more sustainability approach in its construction, operation, maintenance and replacement or disposal, which is consistent with cost benefits.
In Australia, the distribution of essential public services for maintaining human life, especially in highly crowded urban environments, is depending heavily on the infrastructure systems. According to Northern Economic Triangle Infrastructure Plan 2007-2012, Queensland state government in Australia will invest over 82 billion Australian dollars in the next 20 years, covering projects of transportation, gas delivery, water recycling and etc (Queensland, 2007). Large projects which are over 1 billion dollars in value each will take up almost 20 billion dollars in that 82 billion as a whole. In addition, numerous governments, professionals as well as researchers have put great enthusiasm into the development of criteria, tools, concepts, and assessment systems in an attempt to make infrastructure projects more sustainable (Dasgupta and Tam, 2010).

1 School of Urban Development, Queensland University of Technology, Brisbane, Australia, kai.goh@student.qut.edu.au
2 School of Urban Development, Queensland University of Technology, Brisbane, Australia, jay.yang@qut.edu.au
Although the sustainability concept is important to infrastructure development, the financial constraint is still one of the prime concerns to many infrastructure owners because of the huge capital requirement for project development. Understandably, the determination of costs is an essential part of the development process and a considerable element of the tools used by decision makers. According to List (2007), life-cycle cost analysis (LCCA) helps to ensure that these objectives are achieved. LCCA makes it possible for decision makers to evaluate competing initiatives and identify the most sustainable growth path for the common infrastructure. Besides, LCCA makes it possible to deal with the challenge of making choices about the allocation to spend on health care, environmental impact mitigation, national defence, transportation, and a wealth of other programs.

Current research on life cycle costing methods has mainly focused on commercial buildings (Aye et al., 2000). Moreover these research initiatives tend to focus on only the economics aspects, such as cashflows, of a construction project. There is noticeably poor coverage on the application of life-cycle costing methods in evaluating the economic view of sustainability in construction projects.

Thus, sustainable development is becoming the challenge for the current generation to take the responsibility of utilizing various essential resources that require satisfying the “needs” for present generation. The various resources including natural environment, raw materials, natural energy resources, qualitative values of society and culture, and capital resources exist to support and facilitate human life.

2. Road Infrastructure in Australia

Transport plays an important role in keeping the communities connected. Nowadays, people need transportation to have access to employment, education, lifestyle and cultural facilities. Conversely poor transport links can result in isolation, unemployment, low quality of life and inequality (Bickel et al., 2003). With the urban sprawl in many large cities during the twentieth century, road infrastructure has become increasingly important. This is because of the trend to suburban growth with relatively low densities has meant that cities have become physically larger, making it no longer practicable to walk or cycle to work, shops or the city centres. This poses a new challenge for public transport. At the same time there has been increased separation of urban activities and a movement out of the CBD (Central Business District). Today’s suburban areas are organised into specialised usages such as housing estates, shopping centres and industrial parks, often separated from each other and increasing the reliance on private transport.

According to the report from BTCE (2008), the Australian Government announced a one-off fund of $307.5 million to accelerate local road improvements. Road construction technologies and optimum construction expenditure are being closely considered by road authorities. The recent boom of export activities in the states of Queensland and Western Australia has not only resulted in significant population growth locally but also bottlenecks situations for railway and road infrastructure.

When a road construction program is developed strategically, society-wide efficiency and benefits can be achieved. For this reason it is important to determine the optimum level of maintenance and construction activities. In order to meet the national economic and social objectives, road infrastructure projects need to be planned well within given budgets in a cost-effective and efficient manner.

3. Sustainability in Construction and Transportation

Nowadays, there is an increasing demand for transport and mobility in our society. At the same time there is a concern for clean environment, preservation of nature, and the welfare of future generations. These conflicting desires have to be accommodated by policy makers in order to balance the positive and negative impacts of transport. Hence the current established concept of sustainable development is now taking on more issues regarding not only physical resources required for human existence, but also overall quality of the life for both present and future generations.

Several research projects have investigated different topics related to sustainability and transport infrastructure. Jonsson (2008) has implemented an appraisal framework in transportation system where the main elements of sustainability are taken into account. In the study, an appraisal framework has been developed to analyze and measure the achievement of sustainability in the transport sector by using several indicators. In addition, Gudmundsson (1999) found that indicators are “selected, targeted, and compressed variables that reflect public concerns and are of use to decision-makers.” These indicators are based on the selection of literature on social, environmental, health and sustainability.

Review of literature shows that past research were focusing on the indicators for sustainability criteria for transport sector based on the three aspects of sustainability, economic, environmental and social. In Australia, the International Council for Local Environmental Initiatives - Australia/New Zealand (ICLEI-A/NZ) has partnered with the Australian Greenhouse Office (AGO) and the VicHealth Foundation to deliver a resource package of tools, case studies and financial assistance to local government Cities for Climate Protection™ (CCP™) participants around Australia through the Sustainable Transport initiative. The aim of the initiative is to accelerate the implementation of sustainable transport systems and to demonstrate the strong and multiple benefits that arise from implementing sustainable transport actions (CCP, 2005). These indicators show that the sustainability plays an increasingly important role for Australian road infrastructure and transport link projects.
As sustainability issues are pursued in transportation infrastructure development, the economical bottom line, such as the cost effectiveness is still on top of the agenda for many stakeholders due to the significant level of financial commitment in these projects. Life-cycle costing analysis (LCCA) as a proven tool in other sectors of the industry is being highlighted as part of sustainability of transportation in the future.

4. Life-Cycle Costing Analysis (LCCA) and Its Applications for Road Infrastructure

With increasing pressure on market share and internal growth, people have realised that the selection of the lowest initial cost option may not guarantee the economical advantage over other options for a construction organisation. Some of these organisations have referred to LCCA for economical evaluation of the project scenarios they have to face. LCCA seeks to optimise the cost of acquiring, owning and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life, using the present value technique (Woodward, 1997).

Several definitions of Life-Cycle Costing (LCC) exist. As useful as any and shorter than most, is the one according to White and Ostwald (1976), “The life-cycle cost of an item is the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life.” A typical structure and process flow of LCC can be illustrated as Figure 1.

Abraham and Dickson (1998) believe that life cycle costing studies show that the cost of owning and operating a system (ownership cost) can be quite significant and may often exceed acquisition costs. Thus, decisions based solely on acquisition cost may not turn out to be the best selection in the long term and this method can be effectively utilized to realize the benefits of long-term cost implications of sustainable development in infrastructure projects. Other literatures focus more on the conventional aspect of LCCA. Fuller and Petersen (1996) define LCC as the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system over a period of time. Furthermore, they define LCCA as an economic evaluation technique that determines the total cost of owning and operating a facility over its assumed life. Woodward (1997) identified six elements of LCCA: 1) initial capital costs; 2) life of the infrastructure; 3) the discount rate; 4) operating and maintenance costs; 5) information and feedback; and 6) uncertainty and sensitivity analysis. Likewise, the Royal Institution of Chartered Surveyors (RICS) defines the life cycle cost of an asset as the present value of the total cost of that asset over its operating life (including initial capital cost, occupation costs, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life).

The US Federal Highway Administration (FHWA) plays a major role in the research on life-cycle cost analysis (LCCA). It issues guidelines about how life-cycle cost analyses should be conducted, especially for feasibility studies on pavements. Other groups and individuals address the related topics life-cycle cost analysis on highway project (as illustrated by FHWA 2002, Walls and Smith 1998, Hawk 2003, Hegazy et al. 2004, and Persad and Bansal 2004). There are also research on comparisons between benefit-cost analysis and life-cycle cost analysis (Lee, 2002), assessments of the state-of-the-practice in the use of these tools (Ozbay, et al. 2004), and ideas about how uncertainty should be introduced, as in Tighe et al. (2001).

For the time being, Brilon (2000) proposes a comprehensive, economically based procedure for making decisions about capacity investment. Brilon suggests performing a ‘whole year analysis’ on the facility’s use so that the economic benefits from the capacity investments can be assessed. This same idea is adopted by Higgins et al. (2003) in an assessment of the level-of-service and delay performance of a freeway segment. Kittelson et al. (2004) incorporated these ideas into the guidance given to traffic engineers for assessing the benefits from marginal investments in highway capacity. However, these previous researches did not focus on sustainability in order to consider the economic benefits for the stakeholders.

Recently, sustainable development has added a new dimension to the evaluation of highway investments. It places an emphasis on analysing the entire life of a facility, from an environmental as well as an economic
perspective (List, 2007). Keoleian et al. (2005) developed an integrated life cycle assessment and cost model to evaluate infrastructure sustainability, and compare alternative materials and designs using environmental, economic and social indicators. Despite an increasing enthusiasm to propose the LCC approach as useful in the sustainable context, there is still a gap between theoretical concepts and real-life practice, as companies have not adopted LCCAs especially for infrastructure delivery. Previous researchers have not explained the underlying reasons to this gap. There is little actual incorporation of environmental factors and potential consequences in the LCC approach.

Based on the preliminary literature review, considerations on sustainable development and life cycle costing are beginning to take shape at international level research. However, the sustainability concepts are still not broadly integrated with the LCCA in the construction sector. For instance, in order to investigate how LCCA for road infrastructure investments might be made consistently with the premises of sustainable development, a broader, defensible sense of the benefits of LCCA need to be produced. A few previous research efforts have noted the importance of external costs as a result of environmental and other impact, but they did not account for them in calculating life-cycle costs therefore no further applications have been reported.

5. A New Research Effort

In response to the shortfall of previous research, a study is being undertaken at the Queensland University of Technology, Australia. It aims to extend existing LCCA methods with a new framework that includes and emphasizes on sustainability aspects for road infrastructure projects. The new framework will incorporate cost implications of social impacts, environmental impacts, and other components that identified in this research. Also included in this framework are models that predict pavement performance, user costs and accident rates at work zones, and possible rehabilitation designs. The following research development plan is proposed (Figure 2).

![Figure 2 Research Design](image)

The first step of this research is to review the literature and Australian project reports related to the problem domain. Based on this review, the traditional life-cycle cost analysis (LCCA) model are refined and cost elements identified. Questionnaire-based surveys will help verify specific cost elements that emphasize sustainability issues in road infrastructure. The questionnaire design is based on the combination of the literature review on traditional LCCA model and preliminary model building, after incorporating sustainability cost elements identified from previous Australian road infrastructure projects. A new model of LCCA will then be developed based on results of the surveys and through seven stages of model building, namely problem identification and definition, system conceptualization, model formulation, analysis of model behavior, model evaluation, policy analysis, and model implementation. Finally to test and validate the new LCCA model, case studies will be made on the past projects and project/design briefings of future projects.

Progress to date in this research has identified cost elements for road infrastructure projects and a preliminary model has been developed from traditional models of available LCCA techniques. Based on the
literature review, there are some limitations associated with the use of most existing LCCA models. These models tend to ignore social and environmental costs obviously due to the difficulties of measuring such costs and the real values related with both are often disputed. In devising the new preliminary model, various cost components in road infrastructure projects were identified to fill the knowledge gap in LCCA. From this exercise, the research will identify then adopt the most appropriate traditional LCCA model in order to rebuild and expand it to produce the new sustainability life-cycle costing (LCCA) model (Figure 3).

Adopted Traditional Life-Cycle Costing Analysis (LCCA) model

- General Design Inputs
- Specific Design Inputs
- Calculate Agency and User Costs for Initial Construction
- Pavement Performance Prediction Models
- Maintenance/Rehabilitation Strategies
- Timing of Rehabilitation/Maintenance Events
- If No Maint/ Rehab Needs, More to Next Year
- If Not End of Analysis Period, Move to Next Year

Sustainable Cost Components and Issues

- Rehabilitation
- Maintenance
- Agency Cost
- Vehicle Operating Costs
- Travel Delay Costs
- Social Cost
- Insurances
- Accident
- Environmental Cost
- Upgrading
- End of Life
- Social Impact Cost
- Road Accident
- Noise
- Air Quality
- Recourse Consumption
- Pollution Damage from Agency Activities
- Solid Waste Generation

Figure 3. A New Model for Sustainability Life Cycle Cost Analysis of Road Infrastructure

6. Conclusions

Research on sustainable development of infrastructure projects is gaining popularity due to increasing public awareness of sustainability and unique nature of these projects. To date existing research have mostly focused on the environmental issues and sustainability assessment tools. Few research efforts were made to cover the economic and financial implications of developing road infrastructure as a result of pursuing sustainability. Despite extensive literature coverage on LCCs and some applications in the transport area, the authors have not identified practical solutions that will incorporate the necessary sustainability related issues and their cost implications to infrastructure projects. Therefore sustainability concepts are not broadly integrated with the current LCCA in the construction sector, particularly for road infrastructure, which is in high demand due to current economic development in Australia. The research reported in this paper explores tangible issues of sustainability in relation to Australian infrastructure. It intends to link the impact of these issues with cost implications through a new LCCA model for the overall evaluation of financial positions of road infrastructure projects. Based on locally identified sustainability indicators, the developing model has the potential to incorporate industry verified cost analysis techniques for sustainability measures, thus filling a void between a flurry of theoretical research and the lack of appropriate tools among practitioners.
References


