SUSTAINABLE ASSET MANAGEMENT – SELECTING OPTIMAL MAINTENANCE STRATEGIES BASED ON MULTI-CRITERIA DECISION MAKING – A RESEARCH AGENDA

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ABSTRACT

Infrastructure maintenance is one of the largest maintenance sectors in Australia. For instance, according to the Department of Infrastructure and Transport (2015), the market value of road maintenance activities is $7.8 billion in 2013, accounting for 5.2% of the total road network value of $150 billion. Major infrastructure authorities in Australia hold the belief that the performances predicted from current maintenance planning do not fit their real behaviours and conditions. This has been proved to create a significant loss of productivity and a misallocation of maintenance resources (Chen and Martin, 2012). The aim of this project is to develop an innovative Life Cycle Assessment (LCA) approach through integrating cost, performance, and environmental impacts to achieve the optimal maintenance productivity for road assets. This approach integrates (1) life-cycle cost modelling; (2) performance calibration and evaluation; and (3) environmental impacts.

Keywords: Life cycle cost; road pavement; environmental sustainability; asset management.

INTRODUCTION

According to the Department of Infrastructure and Transport (2015), Australian governments spend more than $7 billion maintaining and renewing the road estate every year. There is also evidence of significant maintenance deficit when there is a 15% per annum reduction in road maintenance expenditure over the three years from 2014-2017 (Government of Western Australia, 2014). According to the Australian

Local Government Association (2013), there is a forecasted shortfall of $17 billion for maintenance and renewable expenditure for local roads across Australia between 2010 and 2024, representing 39% above the estimated funding availability for the corresponding period. As such, particular attention should be directed towards improving the whole life asset management processes and ensuring that adequate long-term funding strategies are in place in the infrastructure sector (GHD, 2015).

Definitions: In this paper, the term "infrastructure" refers to road assets and the term "asset management" is restricted to the maintenance management of road pavement. "Road user benefit and cost" refer to direct cost borne by the road users, such as fuel, wear and tear of vehicles, and travel time. Saved marginal cost is equal to benefit.

INDUSTRY PROBLEMS

LIFE CYCLE COST MODELLING

Existing life cycle costing (LCC) method is mainly based on an evaluation of the present worth cost (PWC) or equivalent uniform annual cost (EUAC) of asset management strategies. Although the LCC method can help evaluate the life cycle economic performance of asset, it is limited as many studies have reported that the user benefits and costs, an element which is not included in LCC method, accounts for a significant portion of the life cycle cost (Litman, 2002). Current life cycle cost is often minimized for the considered asset without considering the often significant cost for the users of the asset and without even considering the long-term effects of the decision (Thoft-Christensen, 2009). Life cycle cost benefit (LCCB) analysis is an extended LCC analysis which all indirect cost, such as user cost and benefit as well as externalities, are included. Thoft-Christensen (2009) also found that the main reason leading to the non-adoption of LCCB in infrastructure projects is that engineers in general do not understand or appreciate the probabilistic concepts behind LCCB analysis. As such, an in-depth understanding of the LCCB method and its application in the asset management aspect is necessary.

CALIBRATION OF PAVEMENT PERFORMANCE

The pavement management system (PMS), either in HDM–4 (a computer software for Highway Development and Maintenance Management System) or dTIMS (Deighton's Total Infrastructure Management System), is a complex function of combined effects of traffic and weather, which induce stresses and strains within the pavement layers. It should however be noted that, these models were derived from a broad empirical base and may be volatile in predicting the performance of road pavements in local conditions. Context, location and environment specific calibration is a necessity to achieve optimal asset management performance.

Based on the HDM-4 and dTIMS modelling of deterioration, pavement deterioration models are provided with a set of default calibration coefficients, which aims to help adjust the models for different climatic conditions (Henning et al., 2006). However, there are studies which find that simply adjusting the calibration coefficients does not help improve the prediction accuracy. A more accurate deterioration model is required by using local rather than global parameters. For example, Henning and Tapper (2004) found that some models, such as the roughness progression model, do not necessarily follow the model format as described by HDM-4 and dTIMS. Uncalibrated use would predict pavement performance that might not accurately match the observed values on road sections (Jain et al., 2005). As such, fundamental understanding of the pavement performance and deterioration with regional variation is imperative.

ENVIRONMENTAL CONSIDERATION IN ASSET MANAGEMENT

A significant number of environmental protection measures have emerged over the past few years. The concept of sustainable development calls for a change of the way about how assets and projects should be appropriate managed. As major infrastructure stakeholders, including Main Roads WA (MRWA) and Road and Maritime Services (MRS), are integrating sustainability in their organisational strategic plans, there is a definite urge to include sustainability factors in making asset management decisions. In recent years, there is also a shift of public demand and supply towards more environmentally friendly products (Faith-Ell et al., 2006). As such, calculating the emissions and waste is useful to understand the environmental impact of a certain maintenance strategy and the effectiveness of green procurement can be evaluated (Guistozzi et al., 2012).

WHAT WILL BE PROPOSED

Asset management is a complex problem including the analysis of the trade-off between economic, performance and environmental parameters, based on which the most satisfactory and efficient solution will be sought (Pohekar and Ramachandran, 2004). Asset inherits both internal uncertainties (e.g. the deterioration of pavements) and external uncertainties (e.g. the availability of maintenance resources). Managing assets in a complex and uncertain environmental requires integration, because different situations require different solutions. In addition, integrated consideration ensures efficiency because only what is needed (processes, tools, resources, etc.) is used (Fernandez and Fernandez, 2008). We therefore propose a multi-criteria decision making tool to integrate life cycle cost, performance and environmental considerations.

RESEARCH METHOD

LIFE CYCLE COST

In this section, user benefit and cost will be included in the life cycle cost model. User benefit is usually measured by the reduced travel time (Jong and Bliemer, 2015). A comprehensive review of potential sources of user benefit will be conducted. Mathematical models, which incorporate all sources of user benefit due to improved pavement, will be developed. Previous studies on calculating user benefits, e.g. the value of time (VOT) model developed by Fosgerau and Hjorth (2007), will be useful for this project. The aggregation of all sources of user benefit will then be converted to the present value using a time-dependent annual discount rate.

Road user cost includes all the opportunity cost of travel rather than simply financial cost. Usually, road user cost includes travel time cost and vehicle operating cost (Thoft-Christensen, 2012). The mean value of such cost will be investigated using historical transportation data. For example, vehicle operating cost is highly related to a number of factors including speed and road conditions. There are four commonly used models, including the World Bank HDM – Road User Effect (RUE) model (see Bennett and Greenwood, 2001), the Texas Transportation RUC model (Daniels et al., 1999), the New Zealand vehicle operating cost model (Bennett, 2003) and the Cost Benefit Analysis (COBA) model adopted by England, Wales and Northern Ireland (UK Government, 2006). A new Integrated User Cost (IUC) model will be developed based on the vehicle operating cost model. The inclusion of specific user cost factors and the weighting of each factor in an Australian context will be investigated to develop the new IUC model. It will also integrates externalities, such as accident costs (see Liu and Xia, 2015). This will transform the cost-based methodology into a more holistic methodology.

ROAD PAVEMENT PERFORMANCE

Road pavement performance explores how well the data provided in the pavement performance prediction model represent the reality of current conditions and how well the predictions of the model fit the real behaviour. It is based on the calibration of the two models used in predicting road pavement performance, including road user effect (RUE) and road deterioration and works effect (RDWE) model.

The calibration of both RUE and RDWE models is based on a three-step procedure. A full review of the deterioration models, such as the models used in HDM-4, dTIMS and those developed by Austroads, will be conducted at the beginning of the project. This review will also identify the current calibration process and investigate possible calibration coefficient for each factor from relevant studies (i.e. desktop research). A simulation will be adopted to test whether by simply applying these relevant calibration coefficients, the predicted condition will match the current condition. Sample pavement segments will also be selected to accurately calculate the calibration coefficients for each factor.

ENVIRONMENTAL IMPACT

This section explains how environmental impacts, such as emissions and waste generated from asset management plans can be integrated into the asset management model.

A life cycle assessment of carbon emissions will be conducted. This assessment will be carried out to assess the emissions from maintenance activities. All inputs that will generate emissions will be recorded. Conversion factors for each emissions source will be investigated. Australian-specific conversion factors are preferred and the investigation of these conversion factors will be conducted. For example, conversion factors for different engine types will be examined based on the technical specifications including brake specific fuel consumption, horse power, etc. (Zhang, 2015).

There are various sources of waste from maintenance. The sub-topic will firstly identify the waste streams from maintenance activities of road assets. The quantity of each waste stream will then be determined. Once the quantities have been determined, the expected volume of waste will be calculated. The expected volume of waste from each waste stream will be calculated using a conversion factor. The estimation of the conversion factor is based on a regression model which is developed by considering user experience, industrial standard and various databases.

MULTI-CRITERIA DECISION MAKING

The development of the computerised tool is based on a multi-criteria decision making process, which aims at evaluating the trade-offs among life cycle cost and benefit, pavement performance and environmental considerations. The trade-offs can be evaluated using fuzzy set theory (Zimmermann, 2010), Analytical Hierarchy Process (AHP) (Chen, 2006) or other multi-criteria decision making methods (Liu et al., 2014). The integrated life cycle assessment tool (hereinafter referred to as the tool) can provide the optimal maintenance strategy in many sets of scenarios, such as pavement segments with varied requirements on cost, performance and environmental considerations. Multiple Attribute Value Technique (MAVT), as Multiple Criteria Decision Making (MCDM) technique, aims to provide support for decisions concerning multiple attributes by developing a scoring system (Belton and Stewart, 2002). The technique has three steps: (i) ascertaining the importance weight of each attribute; (ii) rating an option against each attribute; and (iii) aggregating the weights with the ratings. MAVT was suitable for this study because it gives more consistent rakings and the scores derived from the MAVT enable different types of structural frames to be ranked (Belton and Stewart, 2002).

CONCLUSIONS

This research will focus on establishing a new asset management model for road infrastructure which can capture the constantly changing requirements on economic, performance and environmental considerations. The proposed new model is expected to achieve a new maintenance management paradigm which can establish maintenance strategies that fit real behaviours and conditions of roads, achieve cost-effective maintenance and deliver environmental benefits. For asset owners or maintainers, the proposed approach can change the conventional methods of the road maintenance. Much more return on investment can be gained from the proposed approach. In the meanwhile, the technology provider can learn about the exact requirements among the business of road infrastructure maintenance and thus refine and improve the related technical supports to fulfil its market needs. Future studies will focus on the three industry problems as mentioned in the research agenda.

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