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LIFE-CYCLE COST ANALYSIS OF RECLAIMED ASPHALT PAVEMENT FOR SUSTAINABLE ROAD REHABILITATION

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Abstract

The construction of pavements requires a significant amount of non-renewable materials and energy. Recycling of asphalt pavements is a valuable approach for technical, economic and environmental reasons. The use of reclaimed asphalt pavement (RAP) is being favoured over virgin materials due to increasing cost of asphalt, the scarcity of quality aggregates and the pressing need to preserve the environment. This paper present a life cycle cost analysis of recycled pavement material for sustainable road rehabilitation on JabulaniSelepe road in Bethal, Mpumalanga Province of South Africa. Long term cost effects of recycled materials was determined in pavement design; life-cycle cost analysis (LCCA) was carried out on recycled materials, alternative recycling materials and conventional method. The present worth of cost (PWOC) for recycling and conventional method was used to determine the most viable option for construction and maintenance. Agency cost, initial rehabilitation, maintenance, future and salvage cost while the users cost which include construction delays, accident cost, time and vehicle operating cost was done. The result showed that LCCA identifies recycled RAP as the lowest cost pavement alternative. The PWOC for RAP and alternative recycling material was 50.90% and 41.48% respectively when compared with conventional method. Thus, using large amount of RAP could turn these asphalt mixes into good alternative to hot mix asphalt in environmental terms and cost-effective means to road rehabilitation than that of a conventional project.

Keywords: Life-cycle cost, Reclaimed asphalt pavement, Recycling, Present worth of cost

Introduction

The incorporation of Reclaimed Asphalt Pavement (RAP) in road construction and the substitution for virgin material is perceived as an opportunity to save resources and avoid the impacts associated with their extraction and transportation. The use of by-products in road construction is important to divert loads that would be otherwise disposed of in landfills. A significant range of applications of different recycled materials in road construction has been identified that has the potential to accomplish such goals. Even if the economic assessment is favourable, some physical properties of the material and technical requirements established by the transportation agencies may limit the use of recycled materials. In most countries the total amount of reclaimed asphalt pavement (RAP) and the production [illegible] as the percentage of RAP used in the recycled mixtures (Widyatmoko and Elliot, 2002; McDaniel & Nantung, 2005; Decker, 1997; Valdes *et al.,* 2011; Silva *et al*., 2012; Celauro*et al*., 2010; Oliveira *et al*., 2012). In the laboratory it can be feasible to use the total recycling technology which reuses 100% RAP with an adequate performance. If a material fulfils the technical requirements but the life-time of the structure is reduced due to its use, a life cycle cost analysis can determine whether the use of virgin or recycled material is more advantageous (Chiu *et al*., 2008; Sayagh*et al*., 2010). The total cost of highway construction can be classified into three main categories: agency costs, user costs and social costs. Agency costs can be divided into initial construction costs and maintenance and rehabilitation (M & R) costs. Initial costs of highway are cost of designing, acquiring right of way and costs of pavement, bridges and tunnels. M & R costs are all the costs that are needed to maintain the serviceability of the highway facilities above standard limits. M & R activities include all the preservation, rehabilitation, restoration and reconstruction of pavements and other highway facilities. Highway administrators and transportation agencies bears all agency costs. Users are the sum of vehicle operating cost, time related cost, work zone costs and accident costs. Social costs are all the related environmental costs from construction and M & R which are related to the surrounding of the [illegible] Life-Cycle Cost (LCC) by definition means the total cost of initial project plus all anticipated costs for subsequent maintenance, repair or resurfacing over the life of the pavement. In a typical Life-Cycle Cost Analysis (LCCA), two or more alternate choices are available for an initial pavement design. Based on the initial pavement designs, the expected maintenance and rehabilitation over the design life are then determined and incorporated into a single, inflation adjusted, cost in order to evaluate and to compare the different options in a fair and consistent manner. As a result, when used in the pavement selection process, pavement engineers are able to choose the pavement type and design with the lowest cost in the long run.

A Canadian study by El-hakim *et al*. (2009) on the Life Cycle Cost (LCC) of a perpetual and a conventional section showed that for a design period of 50 years, the perpetual section, which costs 70% more during construction phase, has a 6.6% lower life-cycle cost. It was concluded that the cost of overlays and the reconstruction on conventional pavement are the main reasons for higher LCC of conventional pavements. Xu and Zhang (2009) analyzed the LCC of three asphalt pavement structures: flexible base perpetual asphalt pavement, semi-rigid base asphalt perpetual asphalt pavement and semi-rigid base asphalt pavement for LCC comparisons. The economic and social benefit of semi-rigid base perpetual asphalt pavement shows that it is the best option of highway construction in China. In a study carried out by Mandapaka*et al.* (2011), an attempt was made to evaluate and select an optimal M & R strategy for a designed flexible pavement by integrating LCCA and Mechanistic-Empirical design procedures. An 11.27 km long section of 4-lane highway 53, Lake County, California was considered. Three M & R strategies namely, Extended Pavement, Preservation (EPP), Preservation- Preservation-Rehabilitation (PPR) and Rehabilitation only (R) were evaluated. The various M & R strategies using Equivalent Uniform Annual Cost (EUAC) was employed. The LCCA demonstrated that EPP was the best economical alternative to maintain the pavement in a good usable condition for as long as 80 years of service. This paper present application of 100% recycled asphalt pavement material and determination of life cycle cost analysis for sustainable road rehabilitation on JabulaniSelepe road in Bethal, Mpumalanga Province of South Africa.

Materials and Methods

Location

The study was carried out on JabulaniSelepe road, Bethal, Mpumalanga Province, South Africa (fig. 1). Assessments were carried out to determine the extent of failure (visual assessment-figure 2), pavement analysis (structural, traffic and materials-figures 3 & 4) and recycling of 100% pavement materials and life cycle cost analysis in line with various specifications.

Pavement structure design

The road was constructed about 20 years without major rehabilitation. The road is about 251 metres and consists of three layers: 30 mm - asphalt concrete, 150 mm-base and 150 mm-sub-base. The characteristics of these materials were examined in accordance to TMH 1 and ASTM standards. The visual assessment was conducted according to TMH 9 and covers failures associated with surface, functional and structural. The information acquired from visual assessment was used to calculate Visual Condition Index (VCI) according to TRH 22. The VCI was used to indicate the actual condition of the road. The structural integrity of the road was done in line with TRH 22 which entails Benkelman beam, curvature metre and straight edge tests. Structural design and asphalt concrete was done according to TRH 4 and TRH 8 specification respectively. The pavement was design for traffic class E3; which is greater than 3 million and less than 10 million equivalent single axle loads. Base material was recycled with addition of 10% and 15% of virgin crushed stone material and alternative recycling method involved stabilizing the base material with 0.5, 0.8 and 1.0% of water polymer, while 0% was used as control. Reclaimed asphalt was used at 100% with softer bitumen of 50/70 penetration at 0, 0.3 and 0.6%. Laboratory results showed that the properties of 100% recycled asphalt material at 5.9% bitumen can be used in road rehabilitation.

Methodology

The LCCA presented herein were based on decision trees and Bayesian theory as suggested by specification (TRH 12) in assessing various probable outcomes within present worth of costs. Three alternatives were considered for the rehabilitation of the study road using present worth of cost (PWOC) as stipulated TRH 12. In PWOC method, all future costs are discounted to the present worth of costs using an acceptable discount rate. The costs incurred during the rehabilitation design period of the rehabilitation options were calculated using equation 1.

$$PWOC = P + \sum_{i=1}^{n} \left[A(1+r)^{-i} + S_n (1+r)^{-n} \right] \quad (1)$$

where: P = initial rehabilitation cost

A_i= relevant costs during the analysis period after i years

S_n= salvage value costs at the end of the analysis period n years later

n = analysis period

r = discount rate

The input data and specification for design and computation of LCCA are presented in Table 1. Agency costs which entailed rehabilitation, maintenance, future and salvage cost were determined using the market related rates in calculation. The maintenance and rehabilitation costs used in the analysis are based on current Rands, but adjustments due to inflation and discounting are taken into account and expressed in terms of net present value. Salvage cost was calculated based on the results of rehabilitation, maintenance, and future cost.

The following assumptions were used in life-cycle cost analysis:

i. The road user cost was not calculated because the traffic was diverted to the gravel shoulder of the road
ii. No plant cost for asphalt since both recycling and conventional method used the same plant and application technique
iii. 30 mm of hot mix recycled asphalt will be laid and 10 mm thick of rubberized asphalt to be laid over the reclaimed asphalt layer to improve the reliability of the pavement

iv. The estimated unit costs for the expected activities for South Africa location are based on 2013 Rands construction prices

Rehabilitation cost was based on structural and asphalt design. Maintenance cost was calculated under the assumptions that no operational maintenance will be required only resurfacing of 10 mm will be done every 10 years within the analysis period. Future cost was calculated with the assumption that the first resurfacing of 10 mm will be done after 10 years, rehabilitation of base and wearing course will be after 20 years and another reseal after 25 years.

Figure 1: Location of study area (www.safarinow.com)

Figure 2 Assessment of the pavement condition

Figure 3 Structural Assessment of the pavement section

Figure 4 Laboratory evaluations of the recycled pavement materials

Table 1 Life cycle cost analysis for the use of recycled pavement materials

LCCA	**Recycling (Rands)**	**Alternative (Rands)**	**Conventional (Rands)**
Rehabilitation	202628.59	171358.99	507748.79
Maintenance	185302.42	185302.85	185302.85
Future	382931.01	356661.41	693051.21
Salvage	473140.16	118887.14	462034.14
PWOC	326254.21	265876.31	640952.95

Table 2 pavement structure for life cycle cost analysis

Pavement Structure	Recycling	Alternative	Conventional
Wearing course	30 mm RAP	30 mm RAP	40 mm
Base	150 mm Of soiltech	150 mm of 10% Virgin material	150 mm G2
Sub-base	300 mm	200 mm G5	200 mm

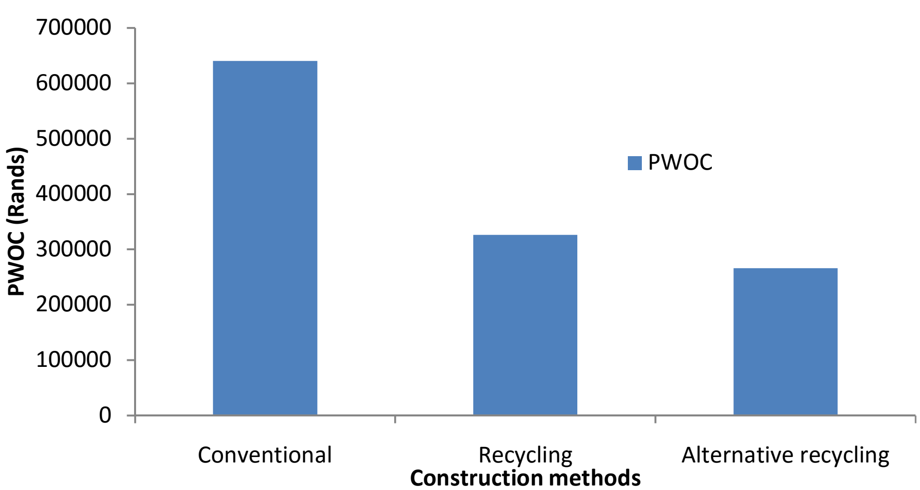

Figure 5 Present worth cost of the pavement material

Result and Discussion

The LCCA for the three pavement structure considered is as shown in Table 2. Maintenance cost is the same for all the three alternatives as a result of same application method. There is an increase in rehabilitation, future and salvage costs for alternative recycling, recycling and conventional method respectively. The reason why conventional method has the highest for rehabilitation is as a result of the new construction of asphalt concrete for the wearing course. As a result of recycling of pavement materials salvage value at the end of the analysis period is higher for recycling compared with either the conventional or alternative recycling method. Using large amount of RAP could turn these asphalt mixes into good alternative to hot mix asphalt in environmental terms and cost-effective means to road rehabilitation than that of a conventional method.

The present worth of cost of the three alternatives are shown in figure 5. The PWOC for recycling and alternative recycling methods are 50.90% and 41.48% respectively when compared with the conventional method.

Conclusion

The results of life cycle cost analysis of recycled pavement material and conventional pavement for sustainable road rehabilitation is presented in this paper. Life cycle cost analysis was carried out on recycled material, alternative recycling material and conventional method using present worth of cost to determine the most viable alternative for rehabilitation on JabulaniSelepe road in Mpumalanga Province of South Africa. There is a decreasing order with respect to cost of rehabilitation, future and salvage costs for conventional, recycling and alternative recycling method respectively. The use of high amount of RAP as reduces the maintenance cost and increase the salvage value making it a good alternative to hot mix asphalt in environmental terms and cost-effective means to road rehabilitation.

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