Framework for Selecting Pavement Types for Low Volume Roads

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ABSTRACT: Low volume roads, have remained the least attended roads in Sri Lanka, although over 72% of the entire road network in Sri Lanka are low volume roads. The funds allocated by local authorities are insufficient to maintain at least 50% of existing low volume roads in good condition. It has been become the trend in the recent past to pave low volume roads in asphalt all over the country regardless of the traffic volume and the required condition of the road. Although asphalt roads have many advantages from the point of view of the road user, when analyzing the effective cost comparisons of life cycle cost this may not be the most suitable method available for some roads considering the limited funds available. A structured questionnaire was used to identify several issues associated with different road surfacing methods. Life cycle cost analysis was done to find the most suitable paving type for by using Net Present Value technique (NPV). According to that gravel has the highest NPV for 20 year design period while concrete block pavement has the lowest NPV. For a 10 year design period asphalt has the highest NPV.

1 INTRODUCTION

Low volume roads are generally classified as those with an average daily traffic of less than 300 or one million ESA. (equivalent to class T1/T2 in TRL Road Note 31 classification). Low volume roads, has remained the least attended roads in Sri Lanka, although over 72% of the entire road network in Sri Lanka are low volume roads. The funds allocated by local authorities are insufficient to maintain at least 50% of existing low volume roads in good condition. Therefore there is an increasing demand from the communities to upgrade these roads.

It has been become the trend in the recent past to pave low volume roads in asphalt all over the country regardless of the traffic volume and the required condition of the road. Although asphalt roads have many advantages from the point of view of the road user, when analyzing the effective cost comparisons of all life cycle cost this may not be the most suitable method available for some roads considering the limited funds available.

Furthermore these improved roads are not durable for the design period. The government has to improve them again after two or three years. Therefore rural people complained about the poor condition of these roads daily from all over the country. To address the serious backlog in maintenance, it will be necessary to increase the financial resources for road maintenance. At the same time, in order to ensure that funds are appropriately used for maintenance, there is a need to develop mechanisms that provide predictable and reliable resource allocations for road maintenance. Also there should be a cost effective framework to improve more low volume roads with the funds allocated.

2 METHODOLOGY

A structured questionnaire was used to identify several issues associated with different road surfacing methods. Information about noise, dust, motorist safety, pedestrian safety and environment-related factors such as emissions and erosion are gathered from the road side people during this study. The total number of roads considered for the survey was fifty, the low volume roads in seven provinces in Sri Lanka covering all six types of low-volume roads.

In order to see whether there was a relationship between different road surfacing methods and other aspects such as dust, noise, erosion, motorist safety and pedestrian safety, statistical tests of independence were carried out.

Both initial cost and maintenance cost (Life cycle cost) should be considered in order to determine the cost effective paving material (Kosgolla et al 2011). Therefore it is easier to use

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Net Present Value technique to determine the cost effective paving material. Twenty year and ten year design periods were considered to determine the most economical paving method.

3 LITERATURE REVIEW

The following types of road constructions are used in Srilanka for low volume roads. Some of them were popular in early days, but now they are rarely used. Some of them were recently introduced for the improvement of low volume roads (Priyantha N. A. A. 2011).

- Unsealed Earth roads
- Unsealed Gravel roads
- Asphalt paved roads
- Metalling and Tarring(DBST) roads
- Concrete roads
- Concrete block pavements

Shanthini (2006) has done a case study on greenhouse gas Emissions from Sri Lankan rural roads. Most of the emissions stem from the vehicular use on the rural roads as well as from the vehicles, such as tractors, tippers and trucks, used in the transport of materials required to construct the low volume road from places where the materials are available to the road site. Emissions also stem from rollers and excavators that are used at the road site during construction (Shanthini 2006).

Table 1 CO_2 emissions from different types of rural roads

Low volume road type	Emissions, in metric tons CO_2 per km of the road constructed
Earth road	0
Earth road with 0.8 m average embankment height	13.09
Gravel road of 3 m carriage way width	1.75
Gravel road on an embankment of 0.8 m average height	13.79
"Metalling and Tarring" road with 0.8 m embankment height	14.09
Concrete road with Grade 15 concrete and 150 mm thickness	83.9
Concrete road with Grade 20 concrete and 150 mm thickness	116.4

Table 1 summarises the emissions that stem from some of the road surfacing methods used in Sri Lanka. Going through the data provided in this table, one could see that CO_2 emission is considerably increased when an embankment is needed to make the rural road. Nevertheless, a road with an embankment still emits substantially less amount of CO_2 than a very simple concrete or asphalt road without an embankment. Most of the emissions accounted for in the making of a concrete road come from the manufacture of cement itself (Shanthini 2006).

4 RESULTS AND DISCUSSION

4.1. Issues associated with LVR's

The first part of this study focused mainly on identifying various issues associated with different road surfacing methods that are used for low volume roads. In order to see whether there was a relationship between different road surfacing methods and other aspects such as dust, noise, erosion and safety statistical tests of independence were carried out.

This method tests the independence of two variables using chi-square distribution. Let X and Y denote two categorical variables, X having i number of levels and Y having j number of levels. The ij possible combinations of outcomes could be displayed in a rectangular table having i rows for the categories of X and j columns for the categories of Y. As an example, the categorical variable X denotes the different types of methods used for road surfacing and Y denotes the levels for pedestrian safety.

Table 2 No. of responses for Safety of pedestrians

Road Surfacing (X)	Safety of pedestrians(Y)				
	Very poor	Poor	Average	Good	Excellent
Concrete	0	2	3	8	0
Asphalt	1	7	0	1	0
BST	0	2	5	5	0
CBP	0	0	0	6	1
Gravel	0	0	1	2	0
Earth	0	0	1	3	1
Total	1	11	10	26	2

The cells of the table represent the ij possible outcomes. Since i=6 and j=5 in this case, there are 30 possible outcomes. The observed values are denoted by O_{ij}, with n= Σij Oij denoting the total sample size.

The test of independence addresses the question of whether the pedestrian safety is

independent of road surfacing method. The hypotheses for this test of independence are as follows:

H_0: Pedestrian safety is "independent" from road surfacing method; and

H_1: Pedestrian safety is "not independent" from road surfacing method

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

Expected frequencies for the cells of the contingency table are calculated based on the assumption that the null hypothesis is true. Let e_{ij} denote the expected frequency for the contingency table in row i and column j.

Then, expected frequencies are calculated as,

e_{ij} = (Row i total) x (Column j total) / Sample size……..(1)

The test procedure for comparing observed frequencies and expected frequencies uses the following formula and a chi-square value is calculated.

$$\chi^2 = \sum\sum(O_{ij}-e_{ij})^2/e_{ij} \quad \text{.....(2)}$$

For this example, the value of the test statistic is $\chi^2 = 39.379$

With i rows and j columns in the contingency table, the test statistic has a chi-square distribution with (i-1)*(j-1) degrees of freedom.

At a 95% confidence level, the value shown in the table for 20 degrees of freedom is 31.41.Since the calculated χ^2 > the table value, the null hypothesis is rejected and it can be concluded that pedestrian safety is not independent from road surfacing material.

Likewise according to the statistical analysis safety of pedestrians, dust generation, noise, erosion and time taken to finish are not independent from the road surfacing method.

4.2. Quantitative Analysis

Quantitative analysis was done to analyze the information collected about the issues associated with the low volume roads.

Ranks are given for different road surfacing methods based on percentages of responses obtained from the questionnaire survey. Here rank one represents the best surfacing material and rank six represents the worst paving material in terms of above aspects (Table 3).

Table 3 Ranks of the road surfacing methods

Paving material	Rank			
	Safety of pedestrians	Dust	Noise	Erosion
Asphalt	6	1	2	1
Concrete	4	4	6	3
CBP	1	2	3	2
DBST	5	3	5	4
Gravel	3	6	4	5
Earth	2	5	1	6

4.3. Life Cycle Cost Comparison of Road Types

There are two major cost components associated with any type of road construction. They are initial construction cost and maintenance cost. Both initial cost and maintenance cost (Life cycle cost) should be considered in order to determine the cost effective paving method. Therefore it is easier to use Net Present Value technique to determine the cost effective paving method (Mampearachchi and Gunatilake 2014).

4.3.1. Net Present Value (NPV)

Net Present Value (NPV) analysis is most frequently used to determine the present value of future money. The initial cost takes place in the year zero. The annual maintenance cost from the year zero to "n" must be discounted to find the present value of those costs. The following equation is used to estimate the present value of each annual cost.

$$NPV = \sum \frac{Ai}{(1+i)^n} \quad \text{..... (3)}$$

Where A_i – cost in i^{th} year
i – Discounting factor
n- Number of years

In choosing between alternatives, the criterion is to select the one with lowest NPV.

In each of the road surfacing method Net Present Value (NPV) per square meter for design periods of twenty years and ten years were calculated to determine the cost-effective paving method. The results are as follows.

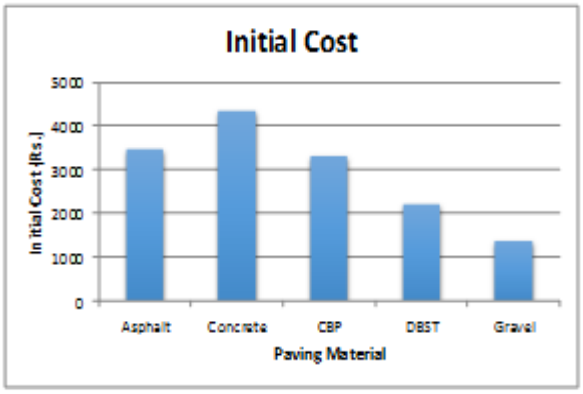

Fig. 1 Initial cost comparison of paving methods

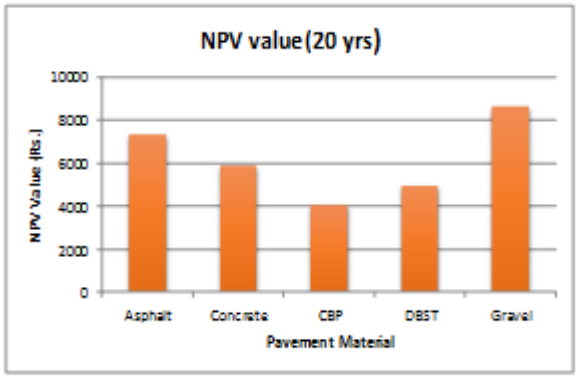

Fig. 2 NPV (20 years) comparison of paving methods

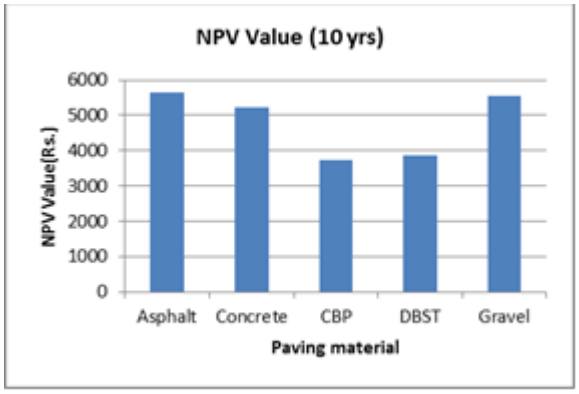

Fig. 3 NPV (10 years) comparison of paving methods

5 CONCLUSIONS AND RECOMMENDATIONS

Not only the cost, we had to consider various aspects such as noise, dust, safety and environment-related factors like emissions and erosion to determine cost effective paving method.

Although the initial cost of gravel road is lowest the NPV for design periods of 20 years and 10 years are high. Of the five paving materials gravel has the highest NPV for 20 years design period while concrete block pavement has the lowest NPV. Asphalt pavement has the highest NPV for 10 years design period.

Public opinion is also important when considering the cost effective paving method. Most people are satisfied with the design type of asphalt pavements, concrete block pavements and concrete roads. However very few persons who participated in the questioners were satisfied with the design type of gravel, earth and metalling and tarring roads.

Different road surfacing materials have pros and cons based on various aspects such as noise, dust, motorist safety, pedestrian safety and environment-related factors such as emissions and erosion.

Therefore designer should select suitable paving material for a particular road based on NPV, public opinion, local conditions such as ADT and various road related issues such as noise, dust, motorist safety, pedestrian safety and emissions.

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