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Framework for selecting pavement type for low volume roads

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Abstract

Low volume roads form a vital link in the road network which provides accessibility to the communities to meet their social and economic needs. One of the main issues faced by the authorities managing the low volume roads which is the lack of funding, technical and human resources to maintain the road network. One of the main reason for insufficient fund availability to maintain the road network is the poor selection of pavement type during road construction. Selection of an appropriate pavement type should consider the expected traffic levels, terrain and ground conditions and should also give consideration to the socio-environmental factors relevant to the area such as land use, economic activities, noise and dust generation, connectivity etc. If this is not carried out properly, the invested would not yield maximum benefits to the community. The study proposes a framework to select pavement types for low volume roads considering traffic, social, environmental characteristics. Several attributes were identified which should be incorporated when selecting a pavement type for a low volume road. These are, traffic volume, traffic composition, land use, connectivity, terrain and weather. Five different pavement types were assessed under life cycle cost, maintenance requirements and road user experience to evaluate which pavement types were most appropriate for the different combinations of attributes, which represent the transport, socio-environmental characteristics present at different road segments. The proposed framework provides a useful tool for planning level decision making for local highway agency for pavement type selection for a low volume road network.

Keywords: Low volume roads; asset management; pavements; life cycle cost

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1. Introduction

Low volume Roads (LVRs) are those that serve the daily social and economic needs of the locality. Different definitions exist also on the typical traffic volumes for low volume roads. According to Swedish National Road and Transport Research Institute low volume roads are defined as roads with less than 1000 vehicles per day. Guidelines developed for low-volume sealed roads in Southern Africa also adopt a 200-vehicles-per-day threshold (Pinard et al. 2003). Moya et al. (2011) suggested four volume classes under 450 ADT for management of Spain's LVRs and Edvardsson (2013) focused on roads carrying up to 1,000 vehicles per day in her investigation of Nordic literature on LVRs. In the United States, the American Association of State Highway and Transportation Officials developed geometric design guidelines for "very low-volume local roads" with average daily traffic (ADT) of 400 or less (AASHTO 2001).

In developing countries, the main problem with low volume roads which are managed by local road agencies is the lack of funding for maintenance and resources. The funds allocated to local authorities are largely insufficient to maintain low volume road network at good condition. Local councils and in some areas Provincial road development authorities (PRDA) are responsible for maintaining the low volume road network. In addition to lack of funding they have limitations in technical know-how of assessing the maintenance requirement. Therefore while the major road system was undergoing significant improvements, the local low volume roads were continuing to deteriorate. (Clemmons and Saager, 2011).

Paving roads with asphalt concrete or concrete pavements when the traffic and other related factors do not warrant it is also a concern in these road networks. For example, it has been become a practice in the recent past in Sri Lanka to construct low volume roads in asphalt concrete or concrete pavement regardless of the traffic volume and the required condition of the road. Although asphalt roads have its many advantages in 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. Similarly, in many developing countries planning decisions on low volume roads are mostly taken based on subjective judgment/ad-hoc decisions without a consistent objective basis due to significant political and other interferences.

In most of the countries the low volume roads are classified based on administrative or political criteria and not on the traffic or any other characteristics of the road. However, from an engineering point of view, low volume roads need to be classified according to their functional characteristics such as traffic volume, traffic composition etc. (Cook et. al. 2013).

The traditional approach of selecting pavement type for a low volume road based on providing the highest level of functionality at the least possible cost. Moreover, the user cost (vehicle operating cost) was not also given consideration in deciding pavement types (Howe and Richards, 1984). The transportation cost is the price that a nation pays for mobility over its design life (Das, 2013). The transportation costs consist of two major components namely agency cost and road user cost. Any pavement type selected should strike a balance between road user cost and agency cost and should minimize the total transportation cost.

Social and environmental impacts, traffic volume, land use and aesthetics have not always been in the forefront of selection criteria (Ahmed et.al., 2006). Rehabilitation of a rural low volume road be likely to have a greater environmental and socioeconomic impacts as compared to national roads because they connect rural villages and communities and serve as farm-to-market access roads (Ahmed et. al., 2006). Therefore, an active involvement of local residents is required during the process of pavement surface type selection.

Introduction of "Highway sufficiency ratings" by the Arizona state highway authorities in the United States in 1946 is the first quantitative selection criteria for deciding pavement type selection. The principle underlying Highway Sufficiency Ratings is that for a given level of traffic volume a road ought to possess certain structural, safety and service characteristics. The method of sufficiency ratings became popular because it provided a simple assessment procedure that were easily understood by political representatives and general public. (Howe J. and Richards P., 1984).

Considering the different parameters that There should be a sustainable pavement management strategy to select the most appropriate surface type for a selected low volume road (Landers et.al., 2014; Fraissard, 2007). Therefore, a suitable framework should be developed as a primary step to providing the context and a methodology by which pavement options may be assessed and selected for low volume roads. In addition to the technical aspects such as traffic loading levels, soil conditions and drainage factors other socio-environmental factors should also be given due consideration in the pavement type selection process. As Engineers, we may conclude that smooth pavement surface like asphalt will be universally acceptable, but it can be defied by local villagers who fear more use of low volume roads by long distance travelers, higher travel speeds and more disturbance. (Ahmed et al, 2006)

Therefore, it is important to have an objective method of assessing the road condition especially the surface conditions, to achieve the best outcome from the utilized funds considering the relevant factors. The present study proposes a framework to identify the pavement type considering traffic, soil, terrain, weather and socio-environmental factors.

2. Pavement type selection for low volume roads

Most highway agencies have developed different approaches to identify the most relevant type of pavement for different type of roads in the network. The most common differentiation is based on the traffic volume on the road and other factors include, land use, terrain, weather.

2.1. Traffic volume-based selection of pavement type

Some highway agencies have volume thresholds which serve as a guide for various pavement surface types. Summary of those traffic volume criteria is presented in Table 2.1. As evident, asphalt concrete option is adopted when traffic exceeds 500veh/day threshold and roads with traffic volume of more than 200 veh/day would be considered for paving. Most of the other remaining road agencies including Sri Lanka, doesn’t have a guide for selecting pavement surface types and pavement surface type is selected on a case-by-case basis.

Table 2.1. Traffic Volume Based Criteria for Road Surfacing

Road Authority/Country	Traffic Volume Criteria	Pavement type
Nova Scotia	AADT <300,	Gravel
	AADT 300-500	DBST
	AADT>500	Asphalt Concrete
South Dakota	ADT <150	Gravel
	ADT 150-660	Chip Seal
	ADT >660	Asphalt Concrete
Minnesota	ADT >200	Paved road surface
Missouri Cole County	ADT >125	Paved road surface
Kentucky	Minimum ADT 50 to 400	Paved roadway
Transportation Centre	Traffic composition should also be considered	

ADT – Average Daily Traffic, AADT – Average Annual Daily Traffic, DBST – Double Bitumen Surface Treatment

The National Road Master Plan 2007-2017 developed by Road Development Authority Sri Lanka (RDA, 2007) adopts a similar traffic volume-based selection process for road rehabilitation, resurfacing and improvement based on traffic volume and is presented below. For example, for rehabilitation pavement type selection for roads with AADT <1000, AADT 1000 - 3000, AADT 3000 – 10000, AADT > 10000, Single Bitumen Surface Treatment, Double Bitumen Surface Treatment, Asphalt Concrete (50mm) and Asphalt Concrete (80 mm) is proposed respectively.

There are other highway agencies which use both vehicle volume threshold as well as a road functional class to identify the appropriate pavement type (Landers et. al., 2014). Table 2.2 gives examples of different pavement type selection criteria adopted by highway agencies considering the functional hierarchy of the road and the traffic volume. This suggests that arterial type roads which are form the major links in the road network and are generally between regions/cities of country are paved using asphalt concrete/concrete irrespective of the traffic volume. The main reason would be these roads primary function is providing high mobility which requires a smooth durable pavement. For lower level road types such as collectors (secondary roads) or local roads pavement type is selected considering the traffic volume or the heavy vehicle volume. Based on the available information it is clear that the traffic volume-based criteria for pavement type selection varies significantly from highway agency to agency.

Table 2.2. Traffic Volume and Highway Functional Classification Based Criteria for Road Surfacing

Highway Agency	Functional Classification	Traffic Volume Criteria	Pavement type
Manitoba	Primary Arterials	-	Asphalt
	Secondary Arterials	AADT<500	SBST/DBST
		AADT>500	Asphalt / Concrete
	Collectors	AADT 300-1000	SBST/DBST
		AADT>1000	Asphalt concrete
Saskatchewan	Primary Roads	Average Annual Daily Truck Volume > 50	Asphalt
	Secondary Roads	Average Annual Daily Truck Volume > 75	Asphalt
Ontario	Arterials & Freeways	-	Hot mix asphalt
	Secondary Highways		
		AADT <200	Gravel
		AADT 200-1000	DBST
		AADT 1000-1500	Cold mix asphalt
		AADT >1500	Hot mix asphalt
New Brunswick department of transportation and infrastructure	Arterial	AADT > 1500	Asphalt
		AADT 300 – 1500 & Truck Volume > 300 AADT	Asphalt
		AADT 300 – 1500 & Truck Volume < 300 AADT	Chipseal
	Collector	AADT < 300	Chipseal
	Local	AADT < 300	Gravel

2.3.2 Surfacing criteria for Low volume roads developed based on agency cost and user cost models

Wolters et. al. (2005) developed a methodology to investigate pavement surfacing criteria for low volume roads in South Dakota. The research was focused on deciding the most economical pavement type from Hot mix Asphalt, blotter (Metal and tar) and gravel for low volume roads under a specific set of circumstances which included traffic volume (in vpd), truck traffic levels, terrain type and subgrade strength.

Agency costs, crash costs and vehicle operating costs were used for the model development and the results indicated that vehicle operating costs are higher on gravel roads than paved roads. Further there was no significant statistical relationship between crash occurrence and road surface type or Average Daily Traffic (ADT) because the factors such as pavement condition, environmental conditions, roadway geometrics, and careless driving can also contribute to crash occurrences. According to the analysis of Agency costs for different pavement types with ADT Gravel appeared to be most economical pavement surface type up to a traffic volume up of 150 vpd. Also, Metal and tar and hot mix asphalt was the most effective pavement surface types for traffic volumes of 150 to 600 vpd and more than 600 vpd, respectively, as indicated in Figure 2.1. (Wolters et. al., 2005).

Piyasena (2012) conducted a study to determine threshold traffic volumes under different climate conditions and subgrade conditions to upgrade road pavements in Sri Lanka. The analysis was based on the life cycle cost of each pavement type under traffic, climate (wet or dry), subgrade conditions. The study considered upgrade criteria for gravel, penetration macadam, surface dressing road types. For moderate soil conditions the threshold AADT for upgrading gravel road to penetration macadam surface or concrete pavement was 140 AADT and 310 AADT respectively. The threshold value for upgrading to concrete pavements reduced to 280 AADT under wet climatic conditions. Similarly, threshold for upgrading penetration macadam roads to surface dressing, asphalt concrete roads are 370 AADT and 900 AADT respectively and upgrading surface dressing pavements to asphalt concrete pavement is 1200 AADT. The values reduce by around 10% for wet climatic conditions. The study findings are comparable with the findings of Walters et. al (2005). Also, the threshold values for upgrading to asphalt concrete pavements are similar to those adopted by highway agencies as discussed in the earlier section.

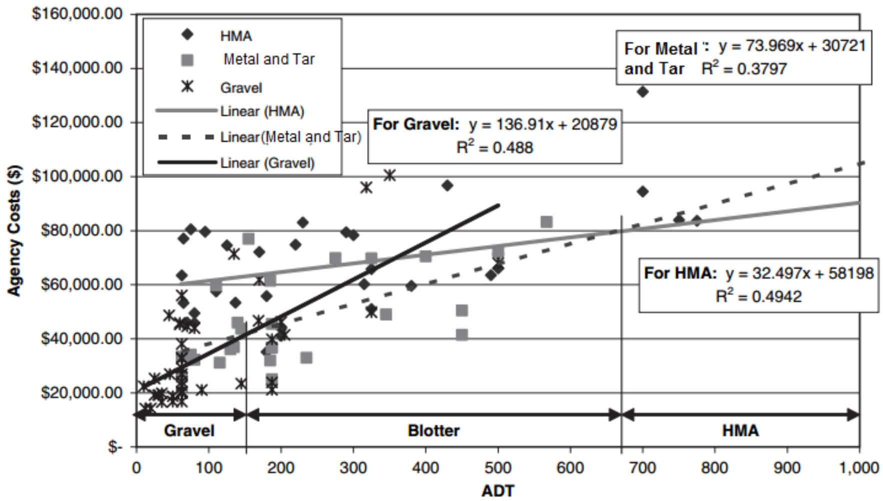

Fig. 2.1. 20 year vehicle Agency cost comparison with traffic volume (ADT) (Wolters et. al, 2005)

2.3.3 *Other approaches for pavement type selection*

Due to importance of incorporating socio-environmental factors in the pavement type selection process, purely quantifiable methods such defining AADT thresholds or life cycle cost analysis approach may not always yield the desired results. The main reason is that, most of the socio-environmental factors are not easily quantifiable or given an economic value. For example, the impact of dust generation from a road in a residential neighbourhood would not be incorporated in the approaches discussed in the sections 2.3.1 and 2.3.2. To address these shortcomings, multi-criteria analysis approach is adopted to determine the most appropriate pavement type.

Hein et. al. (2007) developed a model based on a numerical score to facilitate the selection of road surface type for low volume roads. Five selection factors were identified for scoring and factor weight was given for each factor. A description of those selection factors with the weights for each factor given by them is summarized in the Table 2.3 (The numbers in brackets are weights given for each factor).

Table 2.3. Description of main selecting factors and weights

Main factor	Selection	Associated factors and considerations	Main reason for inclusion of guidelines
Traffic (25)		• Daily Traffic volume in the road • Percentage of commercial vehicles (Trucks and Buses) • Expected vehicular growth • Road user costs • Functional classification of the road	To approximate road user costs

Impact on local residents (10)	• Number of houses along the sides of the road • Proximity of houses to the road • Loose or flying aggregate, dust • Environmental impacts • Smoother and quieter ride on an asphalt pavement • Expectations of the local residents regarding the pavement surface type. • Functional classification of the road	To characterize benefits incurred by nearby residents
Impact on local business activities (10)	• Presence of forestry, Mining or agricultural activities that results in large truck movement • Impact of load restrictions on local business activities • Number of commercial establishments along the route • Existence of tourist attractions and related facilities along the road	To characterize benefits to local businesses
Impact on long distance travel (10)	• Percentage of trips that have both the origin and the destination outside the local business area • Functional classification of the road • The need for alternative transportation corridors	To characterize benefits to long-distance travel
Agency costs (45)	• Initial construction costs for road pavements and drainage improvements • Future maintenance and rehabilitation costs • Pavement performance and constructability issues • Functional classification of the road	To characterize costs of providing and maintaining an upgraded road facility

The weights for each factor was calculated based on the results of questionnaire distributed between experts. The highest factor weight (45) was assigned to agency cost, while the lowest weights (10) were assigned to the impact on local business activities, impact on nearby residents, and the impact on long-distance travel.

Another method adopted by highway agencies to list of several criteria that includes both technical and socio-environmental factors. An example of such a site-specific screening criterion (Landers et. al., 2014) is given in Table 2.4. The site-specific screening criteria allows for the consideration of other roadway characteristics such as the presence of steep grades, the significance to tourism, connectivity to other roads in the network etc.

Table 2.4. Site specific screening criteria (ref. Landers at el. (2014))

Road Classification	Pavement Type selection Criteria
Arterial roads	This Criteria is developed only for low volume roads. Therefore, it does not apply for Arterial roads.
Collector roads	A metal and tar surfaced road can be asphalted wherever one or more of the following conditions satisfies: • When the road trace is traversed through a grade of 7% or more resulting construction stability issues; or • The existing pavement structure would result in a lower life-cycle cost for paving (e.g. locations with significant depths of asphalt where the cost of pulverization would offset the savings offered by bituminous surface treatment/chip seal).
Local roads	A metal and tar surfaced road can be asphalted wherever one or more of the following conditions satisfies: • When the road trace is traversed through a grade of 7% or more resulting construction stability issues; or • The existing pavement structure would result in a lower life-cycle cost for paving (e.g. locations with significant depths of asphalt where the cost of pulverization would offset the savings offered by surface treatment). A gravel surfaced road can be paved by Bituminous surface treatment or chip seal wherever one or more of the following conditions satisfies: • The road serves as a through road connecting two other provincially designated roads • The road provides direct access to a significant tourist destination

2.3.4 Context sensitive pavement design for low volume roads

Low volume roads have greater environmental and socioeconomic impacts as compared to national roads because they connect rural villages and communities and provide links to schools, temples, agricultural lands, wild life parks, etc. These impacts must be considered when selecting pavement types for Low volume roads to ensure that they do not disturb the delicate balance of traditional villages, forests and agricultural lands. Context-Sensitive Design (CSD) can be used in the design phase of low volume roads to address these impacts on low volume roads (National Cooperative Highway Research Program, 2002).

CSD is an interdisciplinary approach that involves all stakeholders to design a transportation facility that fits its physical setting and land use, while maintaining safety and mobility. Until recently, this approach was used only for geometric design of roads but in the recent past it has been used in pavement design and selecting pavement types for low volume roads. Ahmed Z. et al (2006) developed a methodology to select appropriate pavement surfacing for low volume roads based on engineering design factors such as structural capacity, durability and safety as well as non-conventional factors such as aesthetics, environmental and social impacts. Their proposed methodology involves applying weighting factors to a series of characteristics of low volume roads involved in selecting most appropriate pavement type.

The following factors were identified and subdivided into three categories.

1. Performance and Durability characteristics
   - Durability
   - Expected lifetime
   - Maintenance Requirements
   - Road Safety/Surface Characteristics
2. Constructability and Cost characteristics
   - Life-Cycle Cost
   - Availability of materials in the vicinity
   - Construction issues
   - Weather Limitations
3. Context Sensitivity and Environmental characteristics
   - Impacts on environment
   - Visual Quality
   - Context Compatibility

Design options that meet the structural requirements for particular conditions were compared using lifecycle cost analysis to find the most economical pavement type in the conventional pavement type selection process. It is noted that the pavement type selection process should also focused on other criteria such as functionality, serviceability, durability, rider comfort, environmental impacts and safety in addition to the life cycle costs based on the outcome from their research .

2.2. Research need for selecting optimum pavement type for low volume roads.

Based on the methods for pavement type selection reviewed in the study it is clear that most arterial type roads in the network would require asphalt concrete pavement irrespective of other factors. However, there is a significant variation in the decision criteria used for pavement type selection for other functional classes of roads with lower traffic volumes. Furthermore, pavement types such as block paving which very common in some countries is not discussed as a paving option in the methods discussed above.

It also appears that the incorporation of social and environmental factors is not adequately addressed in the pavement type selection. Pavement surface types that meet the structural requirements for particular conditions are compared using lifecycle cost analysis to find the most economical pavement type in the conventional pavement type selection process. However, life cycle cost analysis application in low volume road environment may not produce reliable output due several reasons, poor availability of data with respect to vehicle operating cost models for vehicle types for example, three-wheelers, tractors and min-trucks; the pavement deterioration models are not available for pavement types such as block paving and macadam type roads to accurately estimate future condition; and estimation of wider economic benefits/costs cannot be accurately quantified etc. Furthermore, the pavement type selection process should also have focused on other criteria such as functionality, serviceability, durability, rider comfort, environmental impacts and safety in addition to the life cycle costs. Thus, the roads constructed with the optimal pavement type that fulfills the structural, economic and social requirements. Therefore, there is a need to develop a methodology that considers technical, economic and socio-environmental factors that affect pavement type selection for road construction in a low volume road network in Sri Lanka.

3. Methodology

The paper proposes a framework to facilitate the process of selecting appropriate pavement types for low volume roads based on their characteristics. A low volume road network in Sri Lanka is used to illustrate the application of the framework for low volume road network. The selection process is a three-stage process consisting of screening stage, selection stage and validating stage. The alternative pavement types comprise of concrete roads, asphalt concrete roads, metal and tar, block paving and gravel roads. Expert opinion collected using a questionnaire survey and field data collected from low volume roads in different areas of the country used as the main inputs for the development of frame work.

3.1 Screening stage

The purpose of the screening stage is to identify a manageable number of pavement types that are best suited for a selected low volume road, based on a set of selected screening factors. The screening stage eliminates further consideration of all those pavement types that are clearly not applicable for a selected low volume road. Especially, the screening stage eliminate technically infeasible solutions for each scenario. After infeasible pavement types are removed from consideration, the remaining pavement types are carried forward in to the selection stage. Screening criteria used in the research is described in subsequent sections.

3.1.1 Alternative pavement surface type identification

Field Survey was conducted across low volume road agencies in Sri Lanka (Provincial Road Development Authorities, Local/Urban councils) to identify available pavement surface types that can be used for low volume roads. The identified pavement surface options were classified into five major types as follows.

a) Asphalt
b) Metal and Tar/DBST/Chip Seal
c) Concrete
d) Concrete Block Pavement
e) Gravel

3.1.2 Screening factors

Based on the literature review, the factors that has be used for selecting pavement surface type for low volume roads can be categorized into the following:

a) Traffic Volume –Roads with the high traffic volumes should be paved with a pavement type with a higher surface quality to provide the best level of service and to minimize road user costs
b) Commercial vehicles / Heavy vehicles – Additional strength will be required for roads with heavy vehicle movements to minimize damage to the road surface
c) Public Transport – Best level of service should be provided for roads that serve as bus routes to minimize road user costs
d) Adjacent Land Use / Development - Road users tend to have greater expectations regarding roads located in urban residential environments, gravel roads, which produce dust and metal and tar roads, which can result in flying stones are generally not suitable for densely populated areas. Roads that serve significant civic structures and residential areas should also have a higher surface quality. For roads located in agricultural/forest areas rustic surfacing are preferred.

e) Connectivity to national roads – Road users tend to have greater expectations regarding roads that served as connectivity roads between national roads, and should also provide best level of service to minimize road user costs.
f) Terrain– For roads traversed along mountainous terrains, gravel and chip seal surfacing can result in regular maintenance and resurfacing.
g) Weather – For roads susceptible to floods, Asphalt, chip seal and gravel surfacing are less acceptable. Concrete is preferred. For roads located in wet zone, unpaved surfacing (Gravel) can results in regular maintenance (Re gravelling).

Considering the significance and interconnection between above factors, four screening factors are identified that can be used for selecting pavement surface type for low volume roads as follows.

1. Traffic Volume
2. Traffic Composition
3. Land Use and Connectivity
4. Terrain and weather

3.1.2.1 Traffic volume

Traffic volume of the road in terms of Average Annual Daily Traffic (AADT) is a basic requirement to select appropriate pavement type for low volume roads. Screening based on traffic volume is effective for higher traffic volumes but does not reduce the list of preferable pavement types for low traffic volume roads. Based on the literature three traffic categories are identified for low volume roads as follows:

- Low - <600 vehicles per day
- Medium - 600-1200 vehicles per day
- High - > 1200 vehicles per day

3.1.2.2 Traffic composition

Composition of heavy vehicles and buses is also a significant requirement when selecting the appropriate pavement type for a particular low volume road. Vehicle composition of most of the low volume roads in Sri Lanka are predominantly comprised of motorcycles and three wheelers (up to 70% of the volume), there are few light trucks as well as tractors used for agricultural purposes and transport of goods. Those roads can be paved by using cost effective pavement surface types ignoring the high traffic volume. But roads that serve as bus routes should provide the best level of service ignoring the traffic volume and composition.

Low volume roads were classified in to three categories as follows:

- Heavy- Typical of collectors with significant trucks and buses: *Bus route, Number of buses per day > 6 or No. of heavy vehicles >75 per day*
- Medium- Typical of collectors with fewer trucks and buses: *Bus route, Number of buses per day < 6 or No. of heavy vehicles > 25 per day*
- Light – Typical of local streets with very few trucks: *Not a bus route or No. of heavy vehicles < 25 per day*

3.1.2.3 Land use

This screening criterion is related to the land use setting along the road, and is categorized based on,

- Residential: *Residential land use > 50% or No. of Civic structures along the road> 2 or if there are any factories along the road*
- Agricultural: *Agricultural land use > 50% or No. of civic structures along the road<2*

3.1.2.4 Terrain and weather

Roads that will require all-weather paved surface should be paved with a more durable materials. Usually unpaved surfacing are not practical for roads across mountainous terrain or susceptible to flooding.

- Wet Mountainous: *Wet zone Mountainous terrain or frequent flooding*
- Wet flat: *Wet zone flat terrain or flooding*
- Dry Flat: *Dry zone flat terrain or No flooding*

3.1.3 Initial screening matrix

The pavement surfacing types are screened based on their suitability for the different screening criteria. The decision on the suitability of each pavement type under the screening criteria were selected based on the results of the questionnaire survey and engineering judgment of the selected Engineers. Once all of the surface types are assessed for each screening criteria, any surfacing option that is not suitable for any of the selected screening criteria is removed from further consideration. The acceptable pavement types in Initial Screening Matrix was carried forward for further detailed evaluation in the next stage. This stage allows the low volume road agency to avoid performing a detailed evaluation for each individual surfacing listed in the surfacing catalogue and allows the engineers to focus on the most suitable surface types.

3.2 Selection stage

In the selection stage, a more detailed selection process is applied and the selection methodology is based on expert opinion. Those experts include total of 60 academics, engineers and professionals attached to universities, highway agencies, local authorities and rural road rehabilitation Projects. Those attached to road agencies are selected covering all provinces. Most of the engineers selected for the questionnaire survey are attached to Integrated Road Investment Program (The iRoads program improves the accessibility of the road network in rural areas of Sri Lanka, by rehabilitating more than 5600km of rural and provincial roads under ADB funding). The Selection Attributes, Screening Criteria, and Weighting Factors used for the research are detailed below.

3.2.1 Attributes used to rate pavement suitability

These attributes are selected from properties or characteristics of pavement surface types that can be used in the pavement type selection process. Three selection attributes were identified as given below:

a) Life Cycle Cost

The net present value of a pavement surfacing for a selected analysis period (usually 10-15 years) is used as the basis for this attribute. Agency costs, road user costs, expected maintenance costs, any required rehabilitation, and the time value of money were considered for the life cycle cost. It also depends on the durability and life expectancy of the particular surface type.

b) Maintenance Requirement

The frequency that periodic and routine maintenance interventions are required.

c) Road User Experience (RUE)

This selection attribute is a combination of several factors as follows.

- Safety
- Surface Characteristics
- Visual Quality –Appearance of the particular surfacing type and whether it is aesthetically pleasing or not
- Context Compatibility – How well a surfacing fits into the physical, cultural, historical, and/or visual context of the surrounding environment

3.2.2 Criteria used for rating

This criterion includes assigning of factors on how well a particular surface type ranks for each combination of screening factors (Traffic Volume, Traffic Composition, Land use, Terrain and Climate) based on each attribute used to rate pavement suitability. Each surfacing option is given a score based on the each of the above attributes. Factors used for rating (Scoring factors) are determined from a questionnaire prepared to access the experts' opinion on suitability of the pavement type for the particular conditions based on past experience, and engineering judgement.

The pavement surfacing criteria removed during the Screening stage are not considered when preparing the Questionnaire form. As shown in Table 3.1, "X" represents that pavement surfacing type removed during the screening stage.

Due to the complexity of questionnaire, with 54 (Total number of combinations for 3 categories each for Traffic volume, Traffic composition, Terrain and climate and 2 categories for Land use) combinations only 19 combinations are considered when preparing the questionnaire form. These 19 combinations are selected considering the most possible combinations in the low volume road network considered in the study.

The assigned score is between 1 and 10, with 1 indicating the worst or least desirable pavement type for each scenario and 10 indicating the best or most desirable pavement type with regard to that particular attribute. Pavement surface types are scored relative to the other surface types under consideration because it allows for greater differentiation between surfacing. Table 3.1 gives assigned average rating for each pavement type under the given criteria for the selected combination of attributes. For example, a concrete pavement would generally receive a higher rating under life cycle cost analysis and maintenance requirement under wet climatic conditions compared to asphalt concrete roads as they are more durable under those conditions.

Table 3.1 Ratings assigned to each pavement type under the selected combination of attributes

Selection Attribute					Lifecycle Cost					Maintenance Requirement					Road User Experience				
					Suitability of Pavement Type					Suitability of Pavement Type					Suitability of Pavement Type				
Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Gravel	Concrete	Concrete Blocks	Metal and Tar/DBST	Asphalt	Gravel	Concrete	Concrete Blocks	Metal and Tar/DBST	Asphalt	Gravel	Concrete	Concrete Blocks	Metal and Tar/DBST	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	8.35	8.15	X	3.65	X	9.6	7.85	X	4.7	X	4.2	6.55	X	9.15
2				Dry Flat	8.95	4.05	4.85	8.9	X	4.85	9.55	7.55	7.75	X	6.4	4.15	5.7	9.1	X
3			Agricultural	Dry Flat	9.6	5.1	4.65	7.7	X	6.2	9.6	7.35	8.05	X	9.5	3.8	5.25	8.3	X
4		Light	Residential	Wet Mountainous	8.25	4.05	5.4	9	X	3.05	9.25	9.2	9.2	X	6.1	4.8	7.45	8.75	X
5				Dry Flat	9.35	4.5	7.05	7.45	X	4.6	8.5	9.75	7.75	X	6.45	4.6	6.7	9.9	X
6			Agricultural	Dry Flat	10	4.2	6.75	6.95	X	5.6	9.15	9.35	7.9	X	8	4.55	6.05	8.55	X
7	Medium	Heavy	Residential	Wet Mountainous	X	8.3	6.4	X	6.6	X	9.9	6	X	5.9	X	3.3	5.2	X	9.6
8				Dry Flat	X	6.65	5.05	9.2	7.4	X	8.25	5.7	5.55	9.6	X	2.55	3.9	6.25	9.65
9			Agricultural	Dry Flat	X	6.4	4.75	9.3	6.85	X	8.1	5.4	6.6	9.45	X	3.05	4.1	6.45	9.7
10		Light	Residential	Wet Mountainous	X	8.25	7.95	X	4.5	X	9.7	8.4	X	5	X	4	6.2	X	9.2
11				Dry Flat	8.8	5.6	6.85	8.45	3.4	3.35	7.95	8.9	6.65	9.4	4.75	3.35	6	6.15	9.65
12			Agricultural	Dry Flat	9.75	4.5	5.1	7.85	3.5	5.5	8.4	7.3	7.45	9.1	6.3	3.55	5.3	7.2	9.75
13	Medium	Medium	Residential	Wet Mountainous	X	9.8	6.35	X	5.8	X	9.9	5.25	X	6.1	X	4.1	3.35	X	10
14				Dry Flat	X	7.15	6.4	8.7	6.45	X	7.55	5.5	6.35	10	X	3.05	4.8	6	9.95
15			Agricultural	Dry Flat	9.9	5.9	5.35	7.3	1.95	3.85	7.75	5.45	8.75	9.9	5.65	3.5	4.5	8.2	10
16	High	Heavy	Residential	Dry Flat	X	4.4	3.5	7.75	9.65	X	5.4	3.15	4.95	10	X	2.1	2.95	5.15	10
17			Agricultural	Dry Flat	X	4.3	3.2	8.85	8.75	X	5.5	3.15	5.7	9.8	X	2.55	3.3	5.4	10
18		Light	Residential	Wet Mountainous	X	5.75	8.1	X	6.1	X	6.6	7.25	X	9.55	X	2.75	5.2	X	10
19			Agricultural	Dry Flat	X	5.45	6.85	9.5	5.7	X	6.85	7.05	5.2	9.55	X	3.2	5.5	6.5	10

3.2.3 Weighting Factors

The weighting factors represent the relative importance of the selection attributes (Life cycle cost, Maintenance requirement, Rider comfort) for the decision making process, and are assigned based on past experience of different low volume road agencies (PRDA and local authorities). Also, weighting factors can be assigned by the design engineer of the relevant low volume road project or by the entire project team based on specific project details.

If we consider a particular low volume road, it is expected that some debate will be required between the design engineers to achieve consensus on the weighting factors to use. However, that type of debate can makes the pavement surface type selection process transparent. Weighting factors are assigned in terms of percentages and the total will be 100 percent. The higher the assigned weighting factor, the more important the attribute is considered to be in the overall selection process for a particular road.

In this research, weighting factors are assigned based on pairwise comparison using AHP(Analytic Hierarchy Process) and the values were obtained interviewing Engineers/Technical Officers attached to 5 provincial road development authorities (Southern, Western, Northern, North Central, Uva) and 20 local authorities (Local councils/ Urban councils). Therefore, the weighing factors for the selection attributes are,

- Life cycle cost = 50%
- Maintenance requirement = 42%

- Rider comfort = 8%

4. Pavement type Selection – Weighted Index Calculation

Final rating of pavement types for each combination of Traffic category, Traffic Composition category, Land use category and Terrain and Climate category was obtained by multiplying the average scores obtained from questionnaire survey analysis (see Table 3.2) with relevant weighting factors as follows.

Final Score of pavement types for each Combination

$= \sum 0.5\ A_1 + 0.42\ A_2 + 0.08\ A_3$

Whereas,

A_1 = Average score obtained for a particular surfacing type for a selected combination in terms of Life Cycle cost

A_2 = Average score obtained for the same surfacing type for a selected combination in terms of Maintenance Requirement

A_3 = Average score obtained for the same surfacing type for a selected combination in terms of Road user Experience

4.1 Appropriate pavement type for each combination of attributes

Final scores of the pavement types for each combination were calculated as a percentage and given in Table 4.1 below. The pavement type with the highest score (percentage) is selected as the most appropriate pavement type for respective combination. And the pavement type with the second highest score (percentage) is selected as the second most appropriate pavement type for the combination. For example, for low traffic volume road in a wet mountainous region with moderate level of heavy vehicle movement in a residential neighborhood, the most suitable pavement type would be concrete pavement followed by block paving. Whereas, for the same conditions in a dry climatic condition, the most suitable pavement type would be DBST followed by Gravel. For low - medium volume roads, in dry climatic condition with land use type ‘agricultural’ Gravel roads are selected as the preferred alternative.

Table 4.1 Computed Weighted Index for Each Pavement type and Selected Pavement Type

Selection Attribute					Final Priority Percentages (%)						
					Suitability of Pavement Type						
Combination	**Traffic Category**	**Traffic composition category**	**Land use category**	**Terrain and Climate**	**Gravel**	**Concrete**	**Concrete Blocks**	**Metal and Tar/DBST**	**Asphalt**	**Most Appropriate Pavement Type-1 (Highest Percentage)**	**Most Appropriate Pavement Type-2 (Second Highest Percentage)**
1	Low	Medium	Residential	Wet Mountainous	**X**	**40.78**	37.67	**X**	21.55	Concrete	Concrete Blocks
2				Dry Flat	25.20	22.85	21.71	**30.24**	**X**	Metal & Tar	Gravel
3			Agricultural	Dry Flat	**28.36**	23.95	20.27	27.43	**X**	Gravel	Metal & Tar
4		Light	Residential	Wet Mountainous	20.75	22.16	25.19	**31.90**	**X**	Metal & Tar	Concrete Blocks
5				Dry Flat	24.37	21.17	27.90	26.56	**X**	Concrete Blocks	Metal & Tar
6			Agricultural	Dry Flat	**27.03**	21.34	26.35	25.28	**X**	Gravel	Concrete Blocks
7	Medium	Heavy	Residential	Wet Mountainous	**X**	**40.37**	28.87	**X**	30.75	Concrete	Asphalt
8				Dry Flat	**X**	24.86	18.58	26.39	**30.17**	Asphalt	Metal & Tar
9			Agricultural	Dry Flat	**X**	24.54	17.80	28.43	**29.23**	Asphalt	Metal & Tar
10		Light	Residential	Wet Mountainous	**X**	**39.47**	37.04	**X**	23.49	Concrete	Concrete Blocks
11				Dry Flat	18.12	18.77	**22.37**	21.98	18.76	Concrete Blocks	Metal & Tar
12			Agricultural	Dry Flat	**22.78**	17.96	17.89	22.59	18.78	Gravel	Metal & Tar
13		Medium	Residential	Wet Mountainous	**X**	**44.11**	29.35	**X**	26.54	Concrete	Concrete Blocks
14				Dry Flat	**X**	24.46	20.61	26.22	**28.71**	Asphalt	Metal & Tar
15			Agricultural	Dry Flat	21.45	19.83	16.27	**24.37**	18.09	Metal & Tar	Gravel
16	High	Heavy	Residential	Dry Flat	**X**	19.22	13.71	26.38	**40.69**	Asphalt	Metal & Tar
17			Agricultural	Dry Flat	**X**	19.13	13.06	29.74	**38.07**	Asphalt	Metal & Tar
18		Light	Residential	Wet Mountainous	**X**	27.65	35.38	**X**	**36.97**	Asphalt	Concrete Blocks
19			Agricultural	Dry Flat	**X**	21.09	24.56	26.82	**27.53**	Asphalt	Metal & Tar

4.2 Results Validation

In order to validate the selected pavement types using the proposed method are the most appropriate type under the given conditions a roughness survey was carried out on a selected low volume road network covering the aforesaid combination of attributes. Roughness was measured using the smartphone-based roughness measurement app (Gamage et.al. 2016) which has been proven to give accurate estimates for roughness on low volume roads. The type of pavement, measured roughness values, age of the pavement, and the data representing the attributes used pavement type selection process was also compiled for the road segments in the sample.

Adopting the method proposed in the study, the pavement types that are suitable are identified for the attributes in the particular road segment. If the existing pavement type is similar to the pavement type with the highest weighted score (most appropriate pavement as given in Table 4.1) a suitability rank of 1 was assigned, similarly the lower ranks were assigned for other pavement types with lower weighted scores. The existing pavement performance was evaluated with respect to the age of the pavement and its IRI to assess whether there has been significantly high deterioration taken place. Based on this evaluation the existing pavement performance is deemed acceptable or not. For example, if an asphalt pavement showed IRI of 6-7 after 3 years, it is deemed un acceptable pavement performance level as it is apparent that there is significantly deterioration. If a gravel road has IRI of 10 years after 10 years it cannot be considered not acceptable since the pavement has reached its design life at that stage. Table 4.2 gives results of the validation study. The existing performance of the road was compared with pavement suitability rank assigned to it. For the selected sample road segments, it is evident that the roads with higher suitability rank (1) exhibited better pavement performance at their respective service life and pavement segments with lower rank have poor pavement performance.

Table 4.2 Results of validation analysis

	Existing Road Pavement type	IRI	Pavement age (years)	Traffic Volume	Traffic Composition	Land use	Terrain and Climate	Pavement suitability rank	Pavement performance considering the age and IRI	Comments
1	Asphalt	2.1	2.5	M	M	R	DF	1	Acceptable	
2	Metal & Tar	11.6	9	L	M	R	DF	1	-	Cannot be used for justification since pavement near its design life
3	Gravel	3.0	4	L	L	A	DF	1	Acceptable	
4	Metal & Tar	6.3	6	M	L	A	DF	1	Acceptable	
5	Asphalt	10.9	12	H	H	R	DF	1	Not Acceptable	Although the existing pavement type is the most suitable type for the given conditions, it has deteriorated significantly in 10 years
6	Gravel	3.5	5	L	M	A	WF	1	Acceptable	
7	Gravel	13.3	17	L	L	A	WF	1	-	Pavement exceeded its design life, cannot be used for comparison
8	Concrete	6.8	12	L	L	A	WM	1	Acceptable	
9	Asphalt	6.0	3	M	M	R	WM	3	Not Acceptable	The existing pavement type is the 3rd most suitable pavement type, therefore the conditions are not at the expected level after 3 years
10	Metal & Tar	8.6	5	L	M	R	WM	4	Not Acceptable	
11	Asphalt	14.2	8	M	H	R	WM	2	Not Acceptable	The existing pavement type is the 2nd most suitable pavement type, therefore the conditions are not at the expected level after 8 years
12	Concrete	4.8	7	L	L	R	WM	2	Acceptable	
13	Metal & Tar	16.3	17	L	L	A	WM	4	Not Acceptable	

14	Metal & Tar	13.7	9	L	L	R	WM	4	Not Acceptable
15	Block paving	4.5	7	L	L	R	WM	1	Acceptable
16	Concrete Blocks	3.3	2	L	L	R	WM	2	Acceptable
17	Metal & Tar	8.3	7	M	L	R	WM	4	Not Acceptable

Note: Traffic Volume: L – Low, M – Medium, H – High; Traffic Composition: L- Light, M – Medium, H – Heavy; Land use: R – Residential, A – Agriculture, Terrain and Climate: DF – Dry Flat, WF – Wet Flat, WM – Wet Mountainous.

5.0 Conclusion

The proposed framework provides a simple yet comprehensive framework for selecting pavement types for low volume road networks. It incorporates technical, economic, social and environmental factors in determining the pavement type. From the validation study it was evident that adoption of in appropriate pavement types for road construction would lead to faster deterioration of road pavement and reduced operational life. This leads increased operating cost for the road users, limits accessibility during wet weather conditions and environmental concerns such dust generation which an inconvenience to the community is. Therefore, selection of the appropriate pavement type is important to ensure the pavements constructed are economically viable and sustainable. The proposed method can be adopted for preliminary planning level decision making by local highway agencies.

The proposed framework can be easily customized to incorporate the decision criteria, pavement types that are most relevant to the particular highway agency which makes it adaptable to be implemented under varying resource and technical constraints. The method also helps engineers to make engineering decisions considering multitude of technical and non-technical factors which would results in solutions that are more acceptable to the community. This is mostly beneficial for highway agencies that do not have the resources and the information to carry out detailed life cycle costing analysis or other methods for pavement type selection that are data intensive.

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