FRAMEWORK FOR SELECTING PAVEMENT TYPES FOR LOW VOLUME PROVINCIAL ROADS

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Degree of Master of Science

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Sri Lanka

November, 2018

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Thesis submitted in partial fulfilment of the requirements for the degree

Master of Science

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November, 2018

DECLARATION

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……………………………………… Date:

Prof. J.M.S.J.Bandara

……………………………………… Date:

Dr. H.R.Pasindu

ABSTRACT

Low volume Roads are those that serve the daily social and economic needs of the locality. In developing countries, the main problem with low volume roads which are managed by local authorities 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. Fund allocation can be optimized to achieve better overall network performance if the decision making can be supported by up to date information of the road network condition.

Road roughness information is very useful for road agencies because it can be used to assess the road condition and be used in decision making process for maintenance planning and programming. But existing measurement technologies to measure road roughness like profilometer are very expensive and difficult to use with the prevailing constraints in the local road agencies. The development of smartphones with 3-Axis accelerometer allows it to take acceleration measurements in m/s^2 along each of x, y, z axes. In this research regression analysis was used to two find a relationship between roughness value (IRI) obtained from profilometer and resultant acceleration obtained from an android application called Androsensor. According to the results Resultant acceleration has a linear relationship with road roughness (IRI) and Engineers can use this relationship to estimate road surface condition based on accelerometer readings.

In developing countries planning decisions on maintenance and decisions on selecting pavement type are mostly taken based on feedback from local communities and subjective judgement made by the authority due to significant political and other interferences. Therefore it has been become the trend in the recent past in Sri Lanka 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 has it's many advantages in the point of view of the road user, when analysing 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. Therefore 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.

This research presents a methodology to select suitable pavement type for low volume roads in Sri Lanka. The main factors considered for framework are Traffic volume, Traffic composition, Land use, connectivity, terrain and weather.

Key Words: Low volume roads, Roughness, maintenance, pavement type

DEDICATION

To

My Loving Parents and Brothers.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my research supervisors, Prof. J.M.S.J. Bandara and Dr.H.R.Pasindu for offering me this immense opportunity to follow the master's research and continuous guidance throughout the research. Your encouragement and enormous support are highly appreciated. Further for providing opportunity to attend conferences workshops for knowledge enhancement and reviewing the papers amidst their busy schedule.

Further thank goes to the progress review committee member Mr. R.M.Amarasekara of the Road Development Authority for his comments to improve the research output and sparing his valuable time to attend the progress reviews amidst the busy schedule. Thank goes to Prof. Asoka Perera for his comments as a progress review committee member and facilitating the official process of the master's degree program as the research co-ordinator of the Department of Civil Engineering.

Thank goes to Prof.(Mrs.) Dileeka Dias, Dean Faculty of Graduate Studies and Prof. (Mrs.) Chintha Jayasinghe, Director Post Graduate Studies for facilitating the official process and conducting seminars and workshops at faculty and department level to enhance the research skills of the research students.

This research work would not have been possible if it wasn't for the comments and suggestions from academic and professional experts in respective fields. Therefore, I would like to convey my special thanks for Prof. W.K. Mampearachchi, Dr.Dimantha de Silva and Dr. Lesley Ekanayake for giving their time and expertise towards the successful completion of this research study.

Further I like to thank my colleagues in the Transportation Engineering Division for their continuous support, courage and comments given during the endeavours of the research.

Last but not least I would like to thank Ms. Chathuri Andrahennadi and Mrs. Melani Jayakody for their support in all official matters throughout this study.

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
ADB	Asian Development Bank
ADT	Average Daily Traffic
AHP	Analytic Hierarchy Process
BST	Bituminous Surface Treatment
CBP	Concrete Block Pavement
cIRI	Calculated International Roughness Index
CSD	Context Sensitive Design
DBST	Double Bituminous Surface Treatment
eIRI	Estimated International Roughness Index
ESA	Equivalent Standard Axles
HDM	Highway Development and Management
IMF	International Monetary Fund
IRI	International Roughness Index
LBU	Large Bus
LVR	Low Volume Roads
MG 1	Medium Truck
MG 2	Heavy Truck
NGO	Non- Governmental Organization
QCS	Quarter Car Simulation
PCI	Pavement Condition Index
PRDA	Provincial Road Development Authority
RDA	Road Development Authority

VIMS	Vehicle Intelligent Management System
Vpd	Vehicles per day

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CHAPTER 01 INTRODUCTION

1.1 Problem Statement and Background

Low volume Roads are those that serve the daily social and economic needs of the locality. 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 a engineering point of view, low volume roads need to be classified according to their functional characteristics such as traffic volume, traffic composition ,etc. (J R Cook, R C Petts, J Rolt, 2013)

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. Low volume roads are also classified as roads with average daily traffic less than 2000, according to Federal Highway Administration.

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. Pradeshiya sabhas and municipal councils and in some areas provincial road development authorities (PRDA) are responsible for maintaining the low volume road network in Sri Lanka. 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. (G.H.Clemmons and V.Saager, 2011)

It has been become the trend in the recent past in Sri Lanka to pave low volume roads in asphalt regardless of the traffic volume and the required condition of the road. Although asphalt roads has it’s 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.

At present we don’t have a decision making tool to select most appropriate pavement type for a selected low volume road in Sri Lanka. Not only in Sri Lanka, 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.

A significant amount of investment will require to maintain a low volume road network at an acceptable standard and it is increasingly challenging with the current economic situation in developing countries like Sri Lanka. Since available funding needs to be directed towards high priority projects, the rehabilitation costs for low volume roads is escalating as they often require full or partial reconstruction by the time they are improved due to extent deterioration. There should be a sustainable pavement management strategy to select the most appropriate surface type for a selected low volume road. (S.Landers, D.Mason and J.Macnaughton, 2014)

Therefore 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. The active involvement of local stakeholders and villagers is also important for 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 Z. et al, 2006)

It is vital to have objective method of assessing the road condition especially the surface conditions, to achieve the best outcome from the utilized funds. A database of the road network condition is essential for this that analysis could be done to give useful information for decision making (Maryvonne Plessis-Fraissard, 2007). Also, it is essential to have access to a proper inventory of the road network especially up to date road condition information so that to test the economic viability of projects, to allocate funds to different areas efficiently.

Collection of road condition data (usually measured through distress surveys) is generally expensive, time consuming and requires high level of manpower. There is no comprehensive database even for national roads in Sri Lanka. The other option of gathering roughness data using the profilometer has limitations in accessing narrow roads and very expensive though it can provide accurate information. At present only one profilometer is available in Sri Lanka. Therefore it is necessary to investigate low cost, practical methods to evaluate pavement condition of low volume roads.

1.2 Objectives of the Study

The main objective of the research is to develop a decision framework for selecting appropriate pavement types for low volume roads depending on weather, terrain, traffic and land use consideration.

Pavement roughness data collected from low volume roads were used to validate the research output. But existing pavement roughness collection methods used in Sri Lanka like Profilometer are expensive and difficult to use. It also has limitations in accessing narrow roads though it can provide accurate information. Therefore to develop a cost effective practical method to collect pavement condition data which can also be used in maintenance planning and programming of low volume roads is also an objective of this research.

1.3 Scope of Work

In this research, a methodology is developed to facilitate the process of selecting an appropriate surfacing type for a road or a particular segment of a road. The main factors considered for proposed framework are Traffic volume, Traffic composition, Land use, connectivity, terrain and weather. Expert opinion collected using a questionnaire survey and field data collected from selected low volume roads used as the main inputs for the development of framework.

The selection process is a three stage process consisting of screening stage, selection stage and validating stage. In selection stage, Scores are assigned for pavement types screened through the screening stage based on the attributes Life cycle cost, Maintenance requirement and Rider comfort. Scoring factors are determined from a questionnaire prepared to assess the experts opinion on suitability of the pavement type for the particular conditions based on past experience, and engineering judgement. Cost effective method to collect pavement roughness data was also developed using an android application called "Androsensor" to validate the research output.

CHAPTER 02 LITERATURE REVIEW

2.1 General

The main objective of this research is to develop a framework to facilitate the selection of most appropriate pavement types for low volume roads. A literature review and agency surveys (PRDA and local authorities) were carried to findout the factors used by local authorities in Sri Lanka to decide pavement types for low volume roads. Based on the survey's results none of those agencies use a proper guidelines or manual to select pavement types.

In recent times, the demands on the road network and available funding for road rehabilitation are greater than ever especially in developing countries. These demands, combined with growing public expectations for safety, performance, and quality of the road pavement and therefore road agencies need to maintain the highest practical level of service. To meet these demands, local road agencies all over the world are focusing on preservation and maintenance of existing roads, rather than expanding and widening of existing low volume road network. (Veeraragavan A. and Murali M.P, 2011).

Local road agencies all over the world face the challenge of how to maintain their low volume roads cost effectively. A review of the literature confirmed that there is a lack of guidance on maintaining, rehabilitating and determining suitable pavement types for low volume roads, rather than lack of funding. (Oien A. at el, 2005).

Most of the decision making tools developed in the past for identifying and prioritizing pavement rehabilitation and maintenance needs has focused mainly on high volume roads. It is difficult to use these tools for low volume roads because financial pressures are limiting the ability of local agencies (PRDA, Local authorities etc.) to maintain road surface conditions.

This Literature Review focuses on decision making tools used to select pavement types for low volume roads in other countries. The study also includes a review of existing guidelines or manuals to select pavement types and an assessment of key aspects to be considered.

2.2 Maintenance management of Low volume roads

2.2.1 Low volume road network in Sri Lanka

Although, different definitions exist on the typical traffic volumes, low volume Roads are generally defined as those that serve the daily social and economic needs of the locality. In developing countries, low volume roads are generally classified as those with an average daily traffic of less than 1000 or one million ESA (Equivalent standard axles). Federal Highway Administration classified roads with an ADT (Average Daily Traffic) less than 2000 as low volume roads.

The road network of Sri Lanka exceeds 150,000 kilometres in length and from these more than 70% are low volume roads. But they only carry less than 20% of the total traffic in Sri Lanka (Ministry of Highways, 2010). Local athorities such as the pradeshiya sabhas, urban councils and municipal councils are responsible for the rehabilitation and maintainence of more than 65,000 kilometres of low volume roads and other low volume roads are unclassified. Another few kilometers of low volume roads are maintained by Forest Department and Mahaweli Authority of Sri Lanka. (Ministry of Finance and Planning, 2010).

The pavement types of those low volume roads comprise of concrete roads, asphalt concrete roads, metal and tar, block paving and gravel. The vehicle composition of these roads 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. The operating speeds are limited to around 20-30 km/h due to geometric design constraints such as high radius of curvature, high gradients.

2.2.2 Challenges face in Maintenance of LVR

Many challenges have arisen in rural road construction due to various reasons such as inadequate funding, lack of proper construction technology and skilled labour, need of utility services due to urbanization. LVR agencies face many challenges when trying to provide the highest level of service possible for the available level of funding. In developing countries like Sri Lanka, a common issues in agencies are the lack of budget and the resources to maintain the road network properly (Chamorro and Tighe, 2009). Since the process of allocation of money for provincial level tasks from the central government varies due to different reasons as political influences funding may be insufficient to perform the required development in the area.

According to the Sector Assessment report of Additional Financing of National Highway Sector Project, the main reasons for the low quality and standards of provincial and rural road network in Sri Lanka are, lack of resources for periodic maintenance and lack of institutional capacity of the provincial and rural road agencies.

Furthermore low-volume roads management agencies face numerous challenges in maintenance decision making such as lack of human resources, lack of equipment and other technology (e.g. network inventory), external influence etc. (Mary R. Ebeling and Jason Bittner, 2007).

However the low volume roads has remained the poorest funded and least attended roads in Sri Lanka, despite over 70% of the entire road network in Sri Lanka are low volume roads (Shanthini, 2006).This is because the Pradeshiya Sabhas, urban councils and municipal councils, which are the local administrative institutions that are closest to the rural communities, are poorly funded by the government. The Pradeshiya Sabhas not only lack the funds required to construct and maintain the rural roads, they also lack of skilled personals to undertake such tasks, unlike in the case of RDA constructing the national highways.
As identified in the framework developed by C.M.Calvo, 1998 for better managing and financing local authority roads in Sub-Saharan Africa, the five main problems associated with low-volume roads maintenance are as follows.

Responsibilities of the government agencies and institutions are not clearly defined

In most of the developing countries like Sri Lanka, responsibilities of each institution or ministry are not clearly defined. Multiple agencies are involved in rehabilitating and maintaining low-volume rural roads. Moreover, many countries including Sri Lanka have repeatedly changed the administrative structure of government agencies overseeing low-volume roads, changing responsibility from one ministry to another, often producing little more than confusion. (C.M.Calvo, 1998). For example in Sri Lanka three ministries involved rehabilitation and maintenance of low-volume roads (Ministry of Highways and road development, Ministry of Provincial councils and local governments and Ministry of Social Empowerment and Welfare) producing more confusion during budget allocation.

Fragmentation of the Planning System

Even though local authorities and PRDA are often the legally responsible for the rehabilitation and maintenance of rural roads and provincial roads in their area respectively, rehabilitation and maintenance activities of some roads are planned at the central government level without any involvement of the respective local authority or PRDA. This happens especially during the foreign aided projects (ADB funded Integrated Road Investment Program etc.) in which the Road Development Authority is the implementing agency for the rehabilitation of low-volume roads. Also in Sri Lanka planning decisions on maintenance are mostly taken based on subjective judgment/ad-hoc decisions without a consistent objective basis due to significant political interferences.

Many developing countries including Sri Lanka fail to allocate financial resources efficiently for projects, especially because the people involved in administration and finance planning respond to biased incentives. Capital and maintenance expenditures fall under separate budgets, between which fungibility is limited. Capital budgets are typically supported by allocations from central government and through special projects like iRoad program and have also been favored by local politicians. Maintenance budgets are usually supported by taxes collected from local authority area and often insufficient for road maintenance. (C.M.Calvo, 1998).

Insufficient and Uncertain Maintenance Funding

There is an overall shortage of funds allocated for road maintenance in developing countries such as Sri Lanka. The shortage has been especially severe at the lowest levels of the network—allocations for the low volume roads maintained by local authorities commonly have been only 5−15 percent of requirements. (C.M.Calvo, 1998)

Further, central government funding allocations to local authorities are unpredictable and irregular. Local authorities are generally given an estimate of the budget resources they will receive in the next fiscal year so that they can make realistic plans. Unfortunately, actual receipts nearly always fall short of original estimates. (C.M.Calvo, 1998).

<u>Inadequate Local Capacity</u>

Local governments which have the responsibility of maintaining low-volume roads in Sri Lanka, have limitations in technical skills especially in assessing the maintenance requirement. Most of the pradeshiya sabhas and urban councils doesn't have qualified engineers in their staff. They rarely use experienced local consultants in planning and supervising rural transport infrastructure works, partly because of the small size of the contracts that local authorities can offer making it unattractive for experienced firms to mobilize in rural areas. Local governments' lack of contract management experience and the resultant lack of contracts act as powerful brakes to the involvement of both local consultants and experienced contractors in the road sector. (C.M.Calvo, 1998).

<u>Inappropriate Design Standards and Methods</u>

Transport policy and programs in many developing counties have focused on providing mobility for high-volume roads. This is the case, in part, because engineers have been trained using curricula and educational materials influenced by the requirements of high-wage industrial countries. (C.M.Calvo, 1998). Many foreign funding agencies like Asian Development Bank (ADB), World Bank etc. have also encouraged the use of design standards that are more suited to the levels of heavy motorized traffic. But in most low volume roads in Sri Lanka, Traffic composition consists of more than 80% of Motorcycles and Three wheelers. Inappropriate methods have also contributed to inefficient resource use.

It has been become the trend in the recent past in Sri Lanka to pave low volume roads in asphalt regardless of the traffic volume and the required condition of the road. Although asphalt roads has it's 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.

Fund allocation for LVR can be optimized if the decision making can be supported by up to date information of the road network condition. Unfortunately in Sri Lanka, There is no comprehensive database even for national roads. Planning decisions on maintenance are mostly taken based on subjective judgment/ad-hoc decisions without a consistent objective basis due to significant political and other interferences. It is essential to have access to a proper inventory of the road network especially up to date road condition information so that to allocate funds to different areas, and to ensure that projects are achieving the required results.

2.2.3 Community Participation for Road Maintenance

Local authorities (Pradeshiya sabhas, urban councils and municipal councils) and in some areas provincial road development authorities (PRDA) are responsible for maintaining the low volume road network in Sri Lanka. The main issues LVR agencies face maintaining the low volume road network are, lack of funding for maintenance and resources and lack of technical skills.

Many industrial Countries like United States, Canada, Finland, Norway, and Sweden attempted to address this issue by providing legal instruments for private ownership of roads. Their main objective is to persuade local people (individuals, community organizations or villages) to accept responsibility for managing their own roads. Public funds can be used on a cost-share basis and there should be an incentive system, Training programs and technical assistance on road management and technical and financial over-sight to ensure accountability of public funds. (C.M.Calvo, 1998)

Local authorities or Provincial Road Development Authorities pay part of the construction and maintenance costs, and the users of the respective road section pay the balance. But there should be cost-sharing agreement and institutional arrangement between local authority and the individual or group of communities. In Finland they formed an act called “Road co-operative act”, In Onatario they form an organization called Local Road Board while in Lesotho they form a village development committee for this purpose.

Local communities need to be trained in planning, carrying out road construction and maintenance works, and dealing with unexpected problems during implementation. There is also need to ensure that road maintenance have carried out to minimum standards and public funds are properly accounted for road works. (C.M.Calvo, 1998)

Transferring managerial responsibility of low volume roads to local communities ensures that the roads receive regular maintenance and making it easier for local road agencies to maintain other roads under their jurisdiction. Local employment can be used to improve the efficiency of periodic and routine maintenance activities of these roads. Sweden local communities have managed to reduce their maintenance costs to about of half that spent by Sweden local governments. This savings partly due to lower maintenance standards and lower overheads. But some of the local communities have become so good at carrying out road maintenance that Swedish National Road Administration uses them to maintain some of the low volume roads on the national road network. (I.G.Heggie,P.Vickers, 1998).

This is not a new concept for Sri Lanka, since Sri Lanka has been well aware of the use of community-based, labour-intensive, low-cost road construction methods for a few decades now. The role of Non-Governmental Organizations (NGOs) in enhancing the community based low-volume road construction in Sri Lanka is noteworthy especially after the natural disasters like floods and Tsunami during the past. The government of Sri Lanka also assisted the rural communities in constructing the low-volume roads using the labour based technology, under the "Maga Neguma" rural road development programme initiated in 2004. (Shanthini, 2006)

2.2.4 Methods for Financing Low-Volume Roads

Lack of funds for road maintenance is a widespread problem in developing countries especially for low volume roads. Many Asian and African countries have invested heavily in road construction over the last fifty years. With the help of international funding agencies and donors like ADB and World Bank the aim was to increase the accessibility by producing proper low-volume road infrastructure. (C.F. Jaarsma, T. van Dijk , 2002).

However, in recent years the financial resources allocated in the road sector have been in dramatic discrepancy with the rapid growth of the road traffic. In most of the developing countries, the whole low-volume road network is funded with approximately 40% of the amount adequate road maintenance would need. For rural low-volume roads the situation is even worse. Only 20% of the total amount is funded. (C.F. Jaarsma, T. van Dijk , 2002).

As Nakagawa et al. (1998) observe, most advanced countries also continue to suffer from lack of funding for the maintenance of low volume roads. To solve this problem, it is important to establish a predictable and politically acceptable road maintenance funding methods. Therefore low volume road agencies are looking for additional financial resources. Co-financing by a public–private partnership and direct taxes for the road users are some examples that can be used. (C.F. Jaarsma, T. van Dijk , 2002)

In Sri Lanka low volume roads are maintained by funds allocated from central government and taxes collected from local authorities.In addition to that some low volume roads are rehabilitated through funds from World Bank,ADB,IMF, etc.

G.H.Clemmons and V.Saager, 2011 done a study on how washington country,Oregon financing their low volume roads.Washington country's annual low-volume road maintainence allocation is funded from vehicle registration fees,gas taxes and truck taxes.Gax taxes are the primary revenue source for low-volume road maintainence in Washington country,with little left over for road rehabilitation. In addition to that,every new development required to pay an amount called "Traffic Impact Fee" based on projected traffic increment to support road improvements in the area. Also all country residents need to pay a property tax and that will be used to fund major road improvements.

Further, a correlation was developed between traffic volume and annual maintainence cost based on the data collected from 20 gravel roads from cost records of past 20 years.A relationship was obtained using regression analysis as in the Figure 2.1 below.

Where, C is the average maintenance cost per mile per year and V is the traffic volume in Average Daily Traffic (ADT).

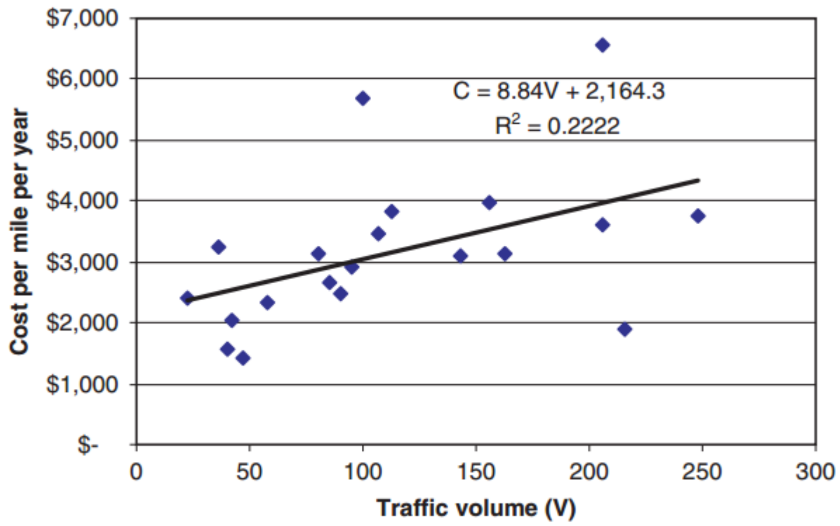


Figure 2.1: Correlation between Traffic Volume and annual maintenance cost

Another conclusion that can be obtained from the study is that it is cheaper to pave a road with Asphalt or DBST when the traffic volume increases rather than maintain it as a gravel surface. (G.H.Clemmons and V.Saager, 2011).

The benefits from improving low-volume road infrastructure is very limited, when a road link is important only for reaching a group of community or a village, serving little or no inter-local traffic. Therefore Rural road maintenance funding requires a specific taxation model that distributes costs according to benefits involved for the individual stakeholder. The distribution of maintenance costs among taxpayers within local authority area is often poorly funded.

A new model was developed by C.F. Jaarsma, T. van Dijk , (2002) using a case study in Netherlands. The Netherlands are even spending a greater proportion of funds on road maintenance. In the Netherlands, the three levels of road-networks: National government, provincial level and Municipal level each have a responsible administrative level similar to Sri Lanka. These administrations make both the policy concerning transportation and the decisions on where investments will be made. (C.F. Jaarsma, T. van Dijk , 2002).

However, the financial responsibility of the lower administrative levels is questionable also in Netherlands. On the basis of this basically budgetary neutral transfer of funding from locally collected taxes, one may state that, theoretically, lower administrative levels (Municipalities and other local authorities) are not financially responsible for their road management, for the money needed for local road management is indirectly paid by the national government.The basic steps of the model developed by C.F. Jaarsma, T. van Dijk to distribute maintainence costs between owners of the buildings and other users is summarized in the Figure 2.2 below.

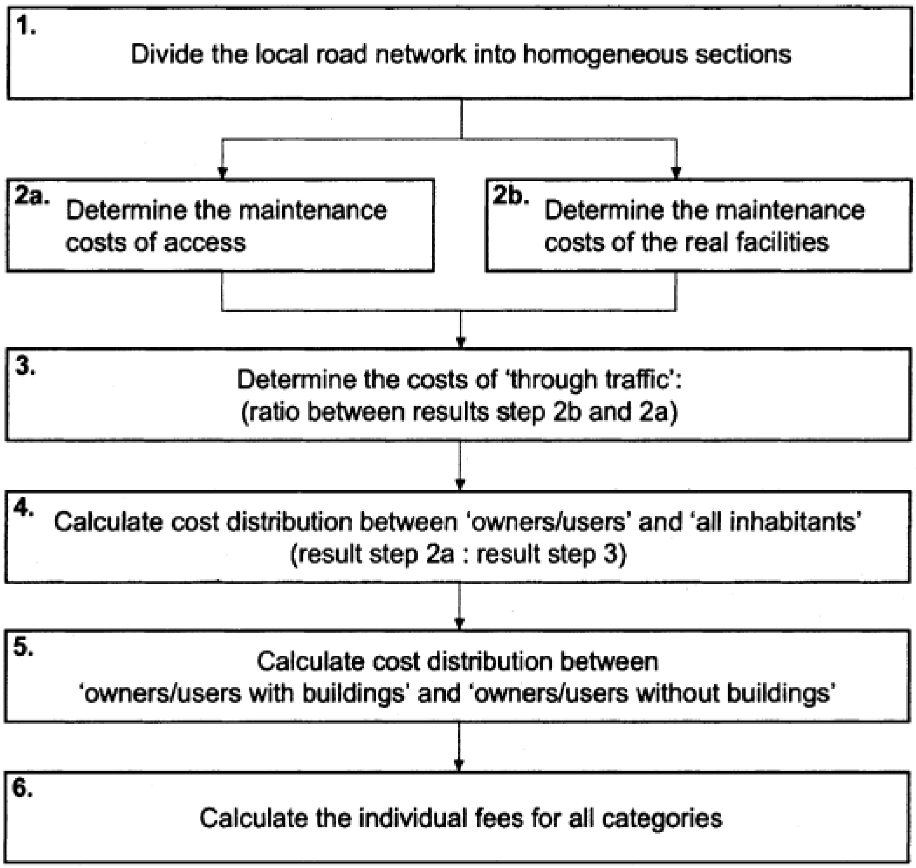


Figure 2.2: Summary of the model developed to distribute costs between specific users

The model developed by C.F. Jaarsma, T. van Dijk deals with the possibilities for increasing the financial capacity for the maintenance of low-volume roads, by charges based on specific profits without increasing taxes. In essence, the model emphasises that the basic facilities for reaching buildings and industries along a road should be paid by the owners of that buildings or industries.

User charge financing is one of the possible methods that can be used for financing of Low volume roads. The main idea coming from user charge financing is that people should pay for what they potentially use. Where expenses of the local authorities exceed the funds received from the central government, the deficit must be supplied by the taxpayers to the local authorities. (C.F. Jaarsma, T. van Dijk , 2002).

2.3 Existing Pavement type selection methods used in Other Countries

2.3.1 General

A Literature review was undertaken of current methods, practices and frameworks used by road agencies in other countries for selecting pavement surface types for low volume roads. Few agencies were found to be have comprehensive frameworks to select appropriate pavement type based on weighting methodologies incorporating multiple factors. Those existing frameworks are described in following paragraphs. Some agencies have volume thresholds which serve as a guide for various pavement surface types. Summary of those traffic volume criteria is presented in the Table 2.1 below. 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 Criteria for Road Surfacing (Selected Agencies)

Road Authority/Country	Traffic Volume Criteria
Nova Scotia	− Gravel if AADT (Average Annual Daily Traffic) <300, − DBST if AADT 300-500 − Asphalt if AADT>500
Manitoba	− All Primary Arterials should be paved in asphalt or concrete − Secondary Arterials − Bituminous surface Treatment if AADT<500 − Asphalt or Concrete if AADT>500 − Collectors − Bituminous surface Treatment if AADT 300-1000 − Asphalt or concrete if AADT>1000
Saskatchewan	− Primary Roads: Asphalt if Average Annual Daily Truck Volume > 50 − Secondary Roads: − Asphalt concrete if Average Annual Daily Truck Volume > 75

	– Gravel if Average Annual Daily Truck Volume 200-300
Ontario	– Hot Mix Asphalt for Arterials and Freeways – Secondary Highways: – Gravel if AADT <200 – DBST if AADT 200-1000 – Cold mixed asphalt if AADT 1000-1500 – Hot mix asphalt if AADT >1500
South Dakota	– Gravel if ADT <150 Vehicles/Day – Chip Seal if ADT =150-660 Vehicles/Day – Asphalt concrete if ADT >660 Vehicles/Day
Minnesota	– Road surface should be paved when ADT >200 Vehicles/Day
Missouri Cole County	– Road surface should be paved when ADT >125 Vehicles/Day
Kentucky Transportation Center	– Minimum ADT to justify paving is between 50 to 400 Vehicles/Day – Traffic composition should also be considered

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. Social and environmental impacts, traffic volume, land use and aesthetics have not always been in the forefront of selection criteria (Z.Ahmed,M.Maher,P.C.Marshall, 2006).

Rehabilitation of a rural low volume road be likely to 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 (Z.Ahmed,M.Maher,P.C.Marshall, 2006).Therefore active involvement of local residents is required during the process of pavement surface type selection.

The transportation cost is the price that a nation pays for mobility over its design life (Aswathy Das A, 2013). The transportation costs consists 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.

In the earlier days of road construction the emphasis was placed on design for the lowest construction cost. The costs of operating vehicles on the roads as well as inconvenience and discomfort to users was often neglected. (Howe J. and Richards P., 1984).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).

2.3.2 Surfacing criteria for Low volume roads developed based on Agency cost and User cost models

The transportation cost is the price that a nation pays for mobility over its design life (Aswathy Das A, 2013). The transportation costs consists of two major components namely agency cost and road user cost. Agency cost includes the cost that the respective local authority or Road Development Authority, have to incur for the rehabilitation and maintenance of low volume roads. Road user costs are the costs incurred directly or indirectly by the road users when using the road. Time and accident costs are also categorized under Road user cost but they are not directly traceable to a particular road because they can be influenced by many factors other than pavement condition.

A.S.Wolters, K.A.Zimmerman, D.L.Huft and P.A.Oien, 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.The factors considered for road surface type selection process in this study were 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 reults indicated that vehicle operating costs are higher on gravel roads than paved roads. Further there was no significant statistical relationship between crash occurance 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 occurances.

According to the analaysis 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 the figures 2.3 and 2.4 below. (A.S.Wolters,K.A.Zimmerman,D.L.Huft and P.A.Oien, 2005).

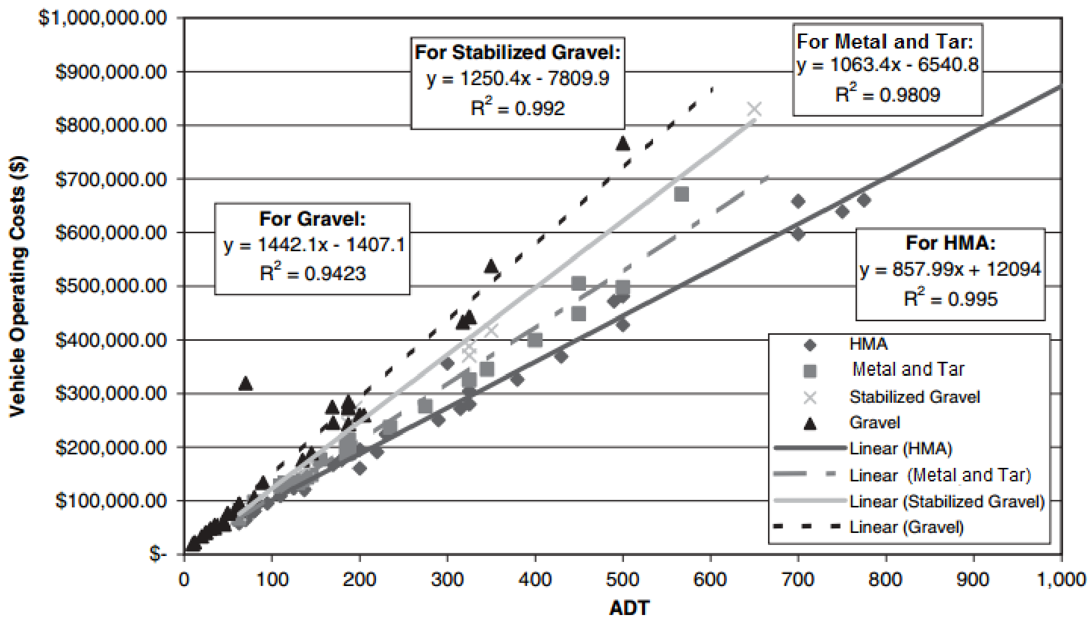


Figure 2.3 : 20 year vehicle operating cost comparison with traffic volume (ADT)

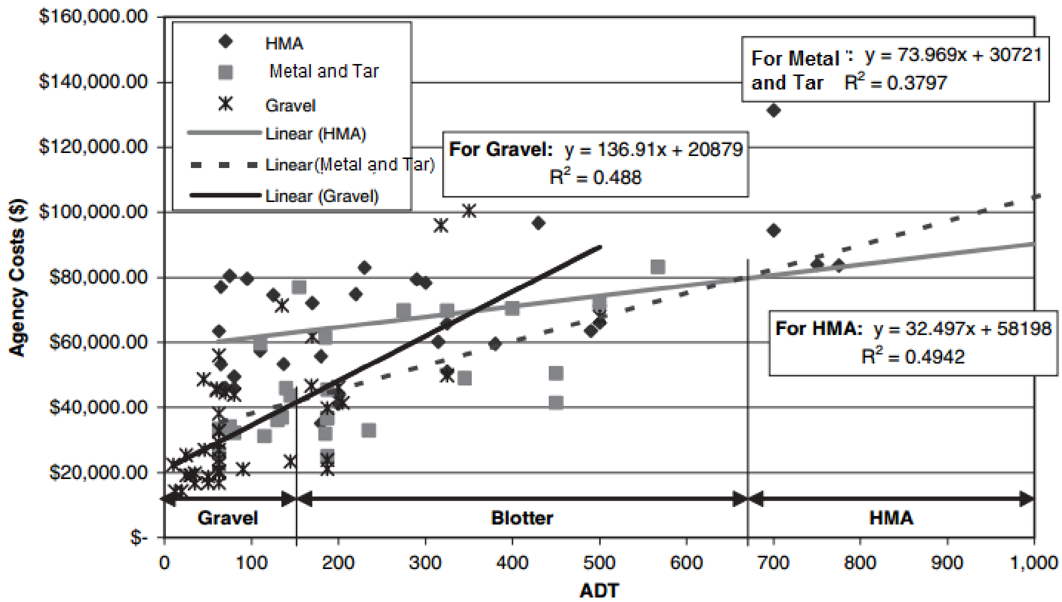


Figure 2.4: 20 year vehicle Agency cost comparison with traffic volume (ADT)

The New Brunswick department of transportation and infrastructure responsible for the rehabilitation and maintenance of roads in New Brunswick, Canada developed a sustainable pavement management strategy to select most appropriate surface type for each road. The process consisted of a two-staged screening approach, which included an initial screening criteria and a site specific screening criteria.(S.Landers, D.Mason and J.Macnaughton, 2014).

The initial screening criteria was based on a given road's functional classification, daily traffic volumes, and daily truck volumes as indicated in figure 2.5 below.

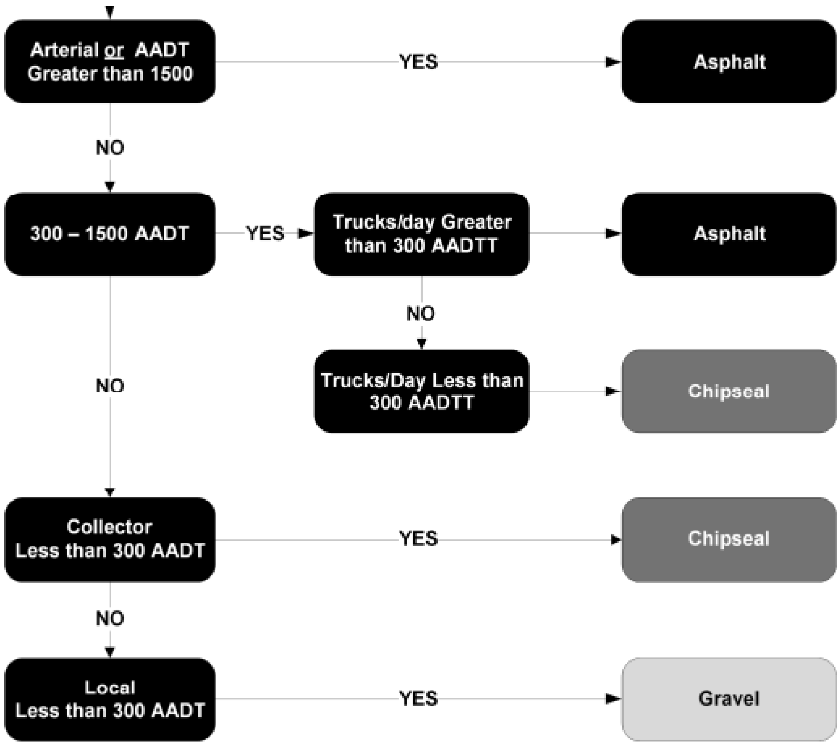


Figure 2.5: Initial Screening criteria developed by Landers, Mason, and McNaughton

The site specific screening criteria allows for the consideration of other roadway characteristics such as the presence of steep grades, the significance to tourism, etc. Those characteristics identified in site specific screening criteria is outlined in Table 2.2 below.

Table 2.2: Site specific screening criteria developed by Landers at el.

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; or • The road provides direct access to a significant tourist destination

D.K.Hein, D.J.Swan and J.J.Hajek, 2007 also 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 factors given by them is summarized in the Table 2.3 below. (The numbers in brackets are weights given for each factor)

Table 2.3: Description of main selecting factors and weights

Main Selection factor	**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. (D.K.Hein, D.J.Swan and J.J.Hajek, 2007)

The National Road Master Plan 2007-2017 developed by Road Development Authority presents a treatment selection process for each category of work (Rehabilitation, Resurfacing and Improvement) based on traffic volume and is presented in figure 2.6 below.

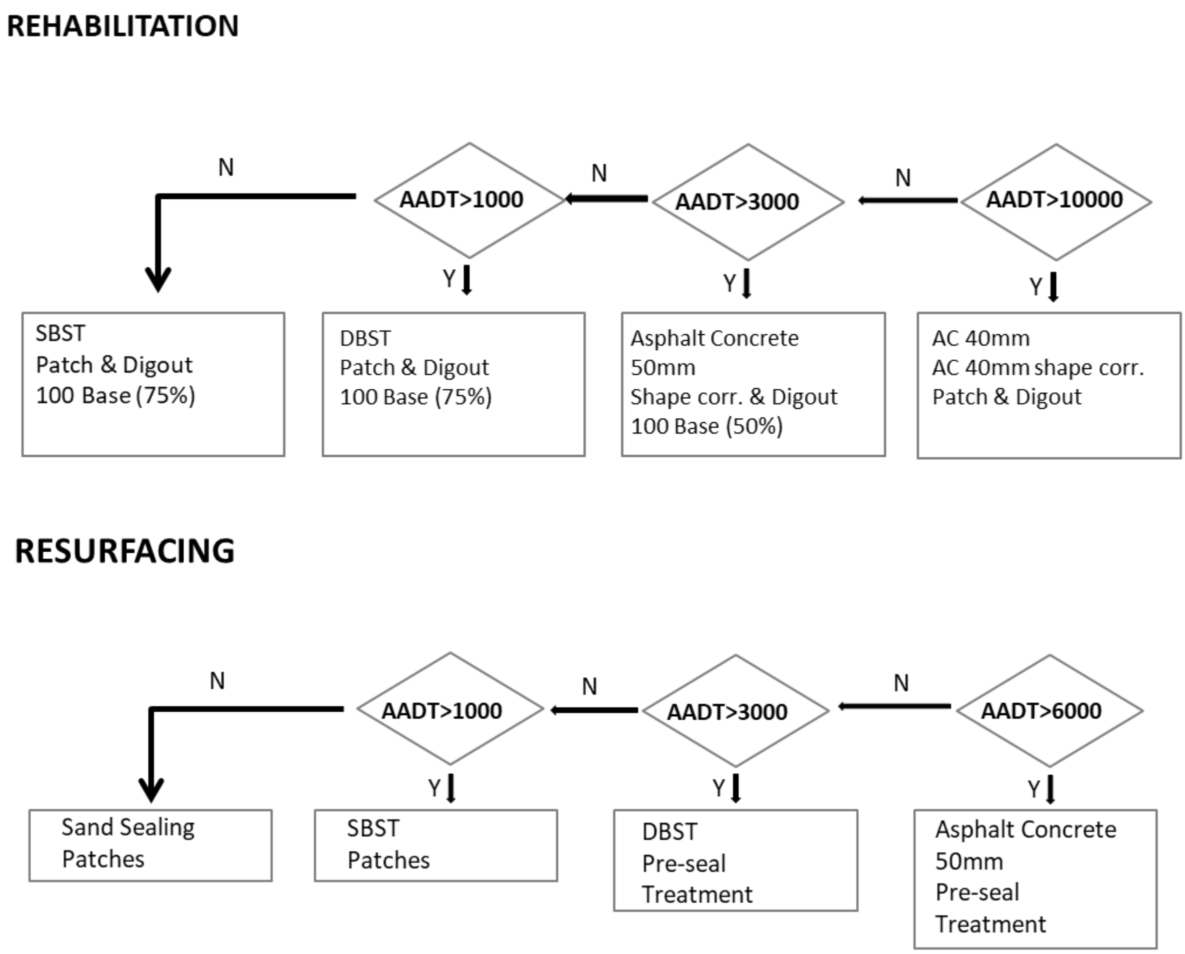


Figure 2.6: Decision Tree for Selecting Pavement Type
(Source: National Road Master Plan 2007-2017)

2.3.3 Context Sensitive Pavement Design for Low volume Roads

Low volume roads which cover more than 70% of the road network in Sri Lanka 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. (Z.Ahmed,M.Maher,P.C.Marshall, 2006).

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.

Ahmed Z. et al (2006) identified eleven characteristics of the roads subdivided into three categories in that research as given below.

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 .

2.4. Use of Roughness data for maintenance management of LVR

2.4.1 Pavement Roughness

Road roughness is a representation of its surface condition and is result of the irregularities in the pavement surface such as potholes, depressions, cracking, rutting, ravelling etc. International Roughness Index (IRI) is the globally accepted indicator to measure the road surface condition. Higher roughness or irregularities of the pavement can cause unpleasant driving comfort, increase in road user costs, and increase in fuel consumption damages to vehicle spare parts and sometimes cause road accidents. (Douangphachanh and Oneyama, 2013).

2.4.1.1 Importance of Road Roughness data for maintenance planning

In Sri Lanka, often maintenance decision making of low volume roads is done based on feedback from local communities and subjective assessment made by the authority. To achieve the best results from the funds available, it is essential to have objective method of assessing the condition of the road.

More than 70% of the Sri Lankan road network are low volume roads and these low volume roads are maintained by pradeshiya sabhas and municipal councils and in some areas provincial road development authorities. Therefore the road agencies need to cover a vast area of road network to conduct the pavement condition evaluations, using subjective rating methods would require full time allocation of engineers or senior technical officers to make assessments. This is not feasible option since most local agencies do not have the manpower to do so. At the same time making evaluation based on measured values will remove any bias or inconsistency that might occur with subjective ratings.

Road roughness is a result of unevenness of the road that is largely due to the distresses present on the road. Use of roughness information can give the road agencies useful information for decision making process in maintenance planning and programming.

In addition, the information is very important for road users because using such information, road users can avoid the bad roads ahead.

2.4.1.2 Impact of Roughness on Pavement Performance

The vibration caused by increased roughness affects the road user comfort level. Moreover it has an impact on vehicle operating costs. In the context of low volume roads it is important to assess the significance of roughness on operating speeds, vehicle operating costs etc. According to HDM-4 model developed by world bank (World Bank, 2015) the roughness impacts the fuel consumption, tire depreciation and repair and maintenance cost, for example vehicle operating cost for light trucks increase by approximately 20% when roughness increase from IRI 2 to 6 (Chatti and Zaabar, 2012). This is even more significant at higher IRI values. However, for smaller vehicles such as motor cycles and three wheelers the change in operating cost with roughness is very low less than 5%.

According to an analysis done by Islam S. and Buttlar W. (2014) road roughness was found to affect road user costs dramatically. The results of a comparison done between road user costs and agency costs showed that agency costs are very small compared to the roughness-related user costs over the life of the pavement (less than 4% of total costs).

Also several models for the effects of pavement surface condition on fuel consumption were developed as part of the Highway Development and Management software (HDM-4). According to the calibrated HDM-4 fuel consumption model developed by Zabeer I. and Chatti K.(2014) the effect of pavement roughness on fuel consumption increased by 1.75 for the van, 1.70 for the articulated truck, 1.60 for the medium car, 1.35 for the sport utility vehicle, and 1.15 for the light truck.

Wang et. al (2013) in their study on how roughness impacts flow speeds of roads, presents a regression model to depict how roughness impacts the average speed of vehicles.

$$y = 30.7368 + 1.0375RCI - 11.2421x_2 + 0.0062x_3^2 \quad (1)$$

$$RCI = 7.254 - 9.984 \log IRI \quad (2)$$

where, y is the average highway speed in kilometres per hour (km/h); x_2 is the ratio of traffic volume to the total capacity of roadway; x_3 is the speed limit, in km/h; IRI is the International Roughness Index, in m/km.

If typical values for a low volume road is substituted in the equation ($x_2 = 0.3$, $x_3 = 40$ km/h), this will give an average speed reduction of nearly 20% (41 km/h to 33 km/h) when the IRI increases from 2 to 12, the typical IRI values for low volume roads are in the range of 6-10 and for this range the reduction in speed is around 8%. This shows that marginal changes in roughness values at higher IRI levels often present in low volume roads the its impact on speed is not significant.

2.4.2 Pavement Roughness Data Collection

Road roughness can be computed in several ways depending on the accuracy of the measurements.

- Class 1: precision profilers - These are the highest standard of accuracy for calculating pavement roughness and are a series of accurately measured elevation points, closely spaced along the section e.g., dipstick, walking profilometer.
- Class 2: Other profilometer Methods- e.g. high speed laser profilometers.
- Class 3: Pavement roughness estimates from response type Measurements or simple profilers, which requires calibration.
- Class 4: subjective ratings - The Engineer physically drives along the road or makes a visual survey

Currently in Sri Lanka class 2 measurement technique, laser profilometer is used for roughness data collection of National roads (Figure 2.7) and at present only one profilometer is available. We can’t use that profilometer for the roughness measurement of low volume roads because it hardly covers the national road network in Sri Lanka. Also it is very expensive and requires high level of manpower like an engineer or a senior technical officer in addition to two traffic enumerators. It also has limitations in accessing narrow roads though it can provide accurate information.

Figure 2.7: Data Collection using laser Profilometer

Today smart phones have the capability of collecting information related to variation in road surface level which can be converted to road roughness measured as IRI (International Roughness Index). A number of smart phone applications are available but it is necessary to calibrate such models to suit local condition and vehicle used for data collection. The results of these can be considered as adequate for comparison of relative levels of road roughness which will be useful for maintenance decision making.

The smart phone apps based method is classified as a Class 3 measurement method. Compared to Class 1, 2 it has less accuracy and precision. However it is comparatively low cost. Compared to using subjective ratings it will give more consistent ratings on the roughness measurement and at the same time would not require the service of an experienced engineer or technical officer to make the evaluation.

2.4.3 Roughness Measurement with Smartphone Apps

At present, the technological advances in smart phones have given it the capability of collecting information related to variation in road surface level which can be converted to IRI values (International Roughness Index). A number of smart phone applications are available but it is necessary to calibrate such models to suit local condition and vehicle used for data collection. Smartphone based roughness measurement will only estimate a rough road roughness value in the form of index value which can be considered adequate for comparison of relative levels of road roughness for the purpose maintenance planning.

Smartphones is equipped with a 3-Axis accelerometer which gives the acceleration measurements in m/s^2 along each of x, y, z axes. Several studies have explored the use of standalone accelerometers and accelerometers that come with smartphones to detect road bumps and anomalies (Gonzalez et al. 2008); use a standalone accelerometer to fit in a simulation car and use it to assess road roughness condition (Douangphachanh and Oneyama, 2013).

Roadroid (Forslöf and Jones, 2015), a Swedish innovation developed in 2002 also use accelerometer and GPS applications in a smart phone to measure road roughness. (Figure 2.8).The Android application registers the vibrations from the road and correlates to the International Roughness Index (IRI). The Roadroid smart phone solution has two options for roughness data calculation.

(1) eIRI (estimated IRI)—based on a peak and RMS (root mean square) vibration analysis. The setup is fixed but made for three types of cars and is thought to compensate for speed between 20~100 km/h.

(2) cIRI (calculated IRI)—based on the QCS (quarter-car simulation) for sampling during a narrow speed range such as 60~80 km/h.

Douangphachanh and Oneyama (2013) developed a method to estimate road surface condition (roughness) from acceleration data collected from smartphones. They placed two different Android smartphones on two different vehicles and then drive each vehicle along many roads with different road surface conditions. Here they used Androsensor smart phone application and VIMS Vehicle Intelligent Management System to find out a correlation between acceleration data from smartphones and actual pavement surface condition.

Figure 2.8: Smart phone arrangement during roughness data collection

The main findings of their study includes,

a) Magnitude of acceleration has a linear relationship with road conditions.
b) There is a moderate difference in the relationships between magnitude of acceleration and pavement roughness for the two vehicles, while there is slight difference between the two smartphone devices that are fitted in the same vehicle.
c) The relationship between magnitude of acceleration and road condition is different significantly with the speed. That means the relationship between acceleration and the road roughness has a significant effect from speed and vehicle type, while it has a slight effect from the phone model.

Shahidul Islam et al (2014) also proposed a method to estimate pavement roughness using vehicle vertical acceleration data collected from a smart phone application called Roughness Capture. At the same time an internal profiler fitted in a Honda CRV was used to collect profile data of the pavement for the validation of this application. He mounted a smartphone on the car dashboard with a standard car mount, and the Roughness Capture application was used to collect acceleration data, GPS location, and time stamp. Then, acceleration data were processed by an in-house MATLAB code to obtain pavement profile data and then the estimated pavement profile was analysed with ProVAL to estimate roughness according to the IRI.

The main outcomes of their research are,

a) For low to medium roughness values, IRI values measured with the smartphone application were similar to those collected with the inertial profiler and few outliers were observed.
b) The smart phone based system produced measured IRI values that were lower than those collected with the inertial profiler when roughness values are relatively high. A simple linear calibration can be used to bring the results into close correlation and can be easily accomplished in practice if necessary.
c) Vertical acceleration data collected by smartphones mounted in different vehicles will be dampened to varying degrees, because suspension systems vary widely from vehicle to vehicle.

2.4.4 Applicability of Smartphone App based Roughness Measurement for Low Volume Roads in Sri Lanka

Low volume roads represent more than 70% of the total length of roads, but only carry less than 20% of the total traffic in Sri Lanka (Ministry of Highways, 2010). Therefore the road agencies need to cover a vast area of road network to conduct the pavement condition evaluations, using subjective rating methods would require full time allocation of engineers or senior technical officers to make assessments. This is not feasible option since most local authorities do not have the manpower to do so. Using this method also allows the authorities to cover most of the network which may not be accessible using methods such as laser profilers, or axle mounted devices. Furthermore this will provide timely input for the agencies to plan their maintenance activities and to make preliminary estimates for budgeting purposes.

The next issue is, whether a high accurate and precise roughness measurement method is warranted for low volume roads. It’s a case of assessing the marginal benefits achieved for the additional resources employed for that, if the marginal benefits are not significant then it is not worthwhile allocating additional resources for that.

In terms of road user cost estimation for economic analysis based decision making, the key criteria would be vehicle operating costs and travel time savings. If these do not change significantly for marginal changes in roughness values at high IRI range (IRI 5-10) then there is no necessity to get very precise roughness measurement. Low volume roads do not carry high volumes of traffic, and a major portion of the volume comprise of three wheelers and motorcycles who's vehicle operating costs does not show the same sensitivity to roughness variation, at low speeds which was evident from HDM-4 model. Therefore marginal differences in roughness values and the resulting changes in total economic benefits (reduction in vehicle operating costs x number of vehicles by type) would not have any major impact of the overall road user cost estimation. Similarly the traffic speeds also is not sensitive to small variations in roughness values in low volume roads as a result do not have a significant impact of travel time saving value. Therefore we can conclude that pavement roughness values are not sensitive variable for economic analysis. Therefore opting for high accurate roughness measurement methods would not give significant marginal benefits in low volume roads in terms of road user cost analysis for economic analysis based maintenance decision making.

Therefore, although the smartphone application based roughness measurement methods lack the high accuracy and precision of the advanced measurement methods it will give an objective basis for the road agencies when making decisions with respect to maintenance planning.

2.5 Summary of the Literature Review

Key findings from the literature review regarding criteria and frameworks used for the selection of pavement surface type in other countries included:

- Most countries do not have comprehensive manual or a guideline for identifying most suitable pavement surface type even for their major roads; Most of them make their decisions on case by case basis;
- Most of the existing road surfacing manuals/guidelines are developed only for high volume(arterial) roads;

- Traffic volume is the predominant factor considered by low volume road agencies in other countries when selecting a pavement surface type;and
- Other factors commonly considered by road agencies include functional classification, agency costs, rural / urban setting, and impact on local residents, local business and long distance travel;

CHAPTER 03 METHODOLOGY

3.1 General

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. But 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.

A framework is developed to facilitate the process of selecting appropriate pavement types for low volume roads based on their characteristics. 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. The developed framework is presented in Figure 3.1 below.

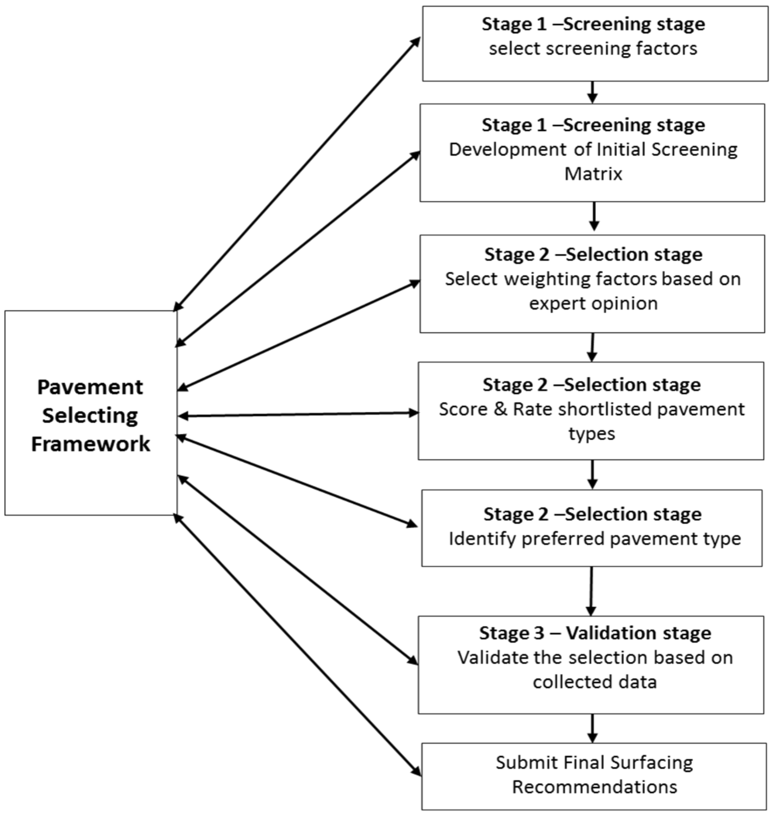


Figure 3.1: Pavement Surface Type selection process

The selection process is a three stage process consisting of screening stage, selection stage and validating stage. The proposed pavement types comprise of concrete roads, asphalt concrete roads, metal and tar, block paving and gravel roads.

3.2 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.

3.2.1 Pavement Surface Types

Field Survey was conducted across low volume road agencies (PRDA, Municipal/Urban councils and Pradeshiya sabhas) 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-
   40mm wearing Course and 40mm binder course with nominal maximum aggregate size of 20mm and bitumen binder with 60-70 penetration grade
b) Metal and Tar/DBST-
   Two seals of emulsion or hot bitumen without exposing first seal to traffic. Nominal maximum aggregate sizes for the first seal and second seal 20mm and 10mm respectively.
c) Concrete-
   Grade 25 concrete to a minimum thickness of 100mm with nominal maximum aggregate sizes of 37.5mm
d) Concrete Block Pavement-
   Paving with concrete inter locking paving blocks 225mm X 112.5mm X 80mm and strength 30N/mm^2 with soil compaction and 3"thick Quarry dust layer

e) Gravel –

Using gravel or blended soil to a minimum uniform thickness of 75mm

3.2.2 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 Traffic – 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.

- Traffic Volume
- Traffic Composition
- Land Use and Connectivity
- Terrain and weather

3.2.2.1 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 Very 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

3.2.2.2 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 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.

Based on the literature low volume roads were classified in to three categories as follows:

- Heavy- Typical of collectors with significant trucks and buses
  Public Bus route with Number of large buses per day > 6 or No. of heavy vehicles (LBU, MG1, MG2, Farm Vehicles, and Vehicles with more than 2 axles) along the road >75 per day
- Medium- Typical of collectors with fewer trucks and buses
  Public Bus route with Number of large buses per day < 6 or No. of heavy vehicles (LBU, MG1, MG2, Farm Vehicles, and Vehicles with more than 2 axles) along the road > 25 per day
- Light – Typical of local streets with very few trucks
  Not a public bus route or No. of heavy vehicles (LBU, MG1, MG2, Farm Vehicles, and Vehicles with more than 2 axles) < 25 per day

3.2.2.3 Land use

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

- Residential -
  Roads with predominantly residential land use (Residential land use > 50%) or No. of Civic structures (Schools, Hospitals and any other public institutions) and Industries along the road> 2
- Agricultural -
  Roads with predominantly agricultural or forest land use (Agricultural or forest land use > 50%) or No. of Civic structures (Schools, Hospitals and any other public institutions) and Industries along the road <2

3.2.2.4 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 Montainous

  Roads located in wet zone or Intermeadiate zone (located in area receiving annual rainfall in excess of 1750mm) and along a mountainous terrain (Gradient in between 8% and 15%) or subjected to frequent flooding

- Wet flat

  Roads located in wet zone or Intermeadiate zone (located in area receiving annual rainfall in excess of 1750mm) and along a flat terrain (Gradient less than 8%)or subjected to flooding

- Dry Flat

  Roads located in Dry zone (located in area receiving annual rainfall less than 1750mm) and along a flat terrain (Gradient less than 8%)or not subjected to flooding

3.2.3 Initial Screening Matrix

The pavement surfacing types are screened based on their suitability for the different screening criteria. Two designations are defined to assess the suitability of pavement types: Acceptable for use (1), and not acceptable (O). Table 3.1 below shows a typical initial screening matrix for identified five pavement surface types.

Table 3.1: Typical Initial screening Matrix

Road Surfacing Type	**Traffic Volume**			**Traffic Composition**			**Land use**		**Terrain and Climate**		
	Low	**Medium**	**High**	**Heavy**	**Medium**	**Light**	**Residential**	**Agricultural**	**Wet Mountainous**	**Wet Flat**	**Dry Flat**
Asphalt	1								O		1
Metal and Tar/DBST	1			O			1	1	O		
Concrete											
Concrete Blocks	O			O							
Gravel				O			O		O		

The final designation for each 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 (O) 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.

3.3 Selection Stage

In the selection stage, a more detailed selection process is applied and the selection methodology is based on expert opinion. Those experts includes total of 60 Academics, Engineers and Professionals attached to Universities, RDA, PRDA, 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 (iRoads Project). (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.

3.3.1 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) Rider Comfort

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

3.3.2 Criteria used for rating

This criteria 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 Questionnaire form used to obtain expert opinion is presented in Table 3.2 below. The pavement surfacing criteria removed during the Screening stage are not considered when preparing the Questionnaire form. As shown in Table 3.2, "X" represents those pavement surfacing criteria removed during the screening stage.

Only the most commonly available combinations for Traffic volume, Traffic Composition, Land use, Terrain and Weather categories in Sri Lankan provincial and rural road network are considered in this study. 19 combinations are selected when developing the pavement type selecting framework. They reflect vast majority of conditions that can be observed in our low volume roads.

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.

For example, if we assign score for the pavement type "Concrete" in terms of Maintenance requirement, for a selected combination,

1. If the assigned score is 1, it denotes that concrete is the least desirable pavement type for that combination in terms of maintenance requirement.
2. If the assigned score is around 5, it denotes that concrete is a desirable pavement type for that combination in terms of maintenance requirement. But, there can be more desirable pavement types than concrete.
3. If the assigned score is 10, it denotes that concrete is the most desirable pavement type for that combination in terms of maintenance requirement.

Table 3.2: Questionnaire survey form used to obtain expert's opinion

Selection Attribute					Lifecycle Cost					Maintenance Requirement					Rider Comfort				
Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Suitability of Pavement Type					Suitability of Pavement Type					Suitability of Pavement Type				
					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			X		X			X		X			X	
2				Dry Flat					X					X					X
3			Agricultural	Dry Flat					X					X					X
4		Light	Residential	Wet Mountainous					X					X				X	X
5				Dry Flat					X					X					X
6			Agricultural	Dry Flat					X					X					X
7	Medium	Heavy	Residential	Wet Mountainous	X			X		X			X		X			X	
8				Dry Flat	X					X					X				
9			Agricultural	Dry Flat	X					X					X				
10		Light	Residential	Wet Mountainous	X			X		X			X		X			X	
11				Dry Flat															
12			Agricultural	Dry Flat															
13		Medium	Residential	Wet Mountainous	X			X		X			X		X			X	
14				Dry Flat	X					X					X				
15			Agricultural	Dry Flat															
16	High	Heavy	Residential	Dry Flat	X					X					X				
17			Agricultural	Dry Flat	X					X					X				
18		Light	Residential	Wet Mountainous	X			X		X			X		X			X	
19			Agricultural	Dry Flat	X					X					X				

3.3.3 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 (Pradeshiya sabhas/ Urban councils/Municipal councils). The Questionnaire form used is given in Figure 3.2 below. Average values presented in Table 3.3 below were used for the final analysis.

Table 3.3: Average values used for final analysis

Criteria		More important	Intensity
A	**B**		
Life Cycle Cost	Maintenance Requirement	A	-1.1 or 1/1.1
Life Cycle Cost	Rider Comfort	A	-7 or 1/7
Maintenance Requirement	Rider Comfort	A	-5 or 1/5

Questionnaire Survey on Low Volume Roads

This survey is designed to collect expert opinion on the criteria considered to select most appropriate pavement type for low volume roads. The researcher has identified three (3) factors to be considered to select most appropriate pavement type. The objective of this survey is to identify the importance of those factors to select a pavement type for a low volume road.

This information is confidential and will only be used for academic purpose. Thank you in advance for your time and cooperation.

Please select one option from a row.

LCC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**MR**
LCC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**RC**
MR	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**RC**

LCC – Life Cycle Cost
MR - Maintenance Requirement
RC – Rider Comfort

Please refer the example done below.

Example-

Equal importance-
Both Factors contribute equally to select a pavement Type.

LCC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**MR**
LCC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**RC**
MR	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**RC**

Extreme importance-
Maintenance Requirement is favored very strongly over Rider Comfort.

Moderate importance-
Experience and judgment slightly favor Rider Comfort over Life Cycle Cost to select a pavement Type.

Figure 3.2: Questionnaire form used to assign Weighting factors

3.4. Validation Stage

Validation stage is required in research to evaluate the pavement selecting framework proposed and it deals with the justification of the research outputs with the industrial practice. There is a wide range of methods to validate a research outcome. (By statistical analysis, by comparison of research output with real industrial data, etc.). Roughness data collected from selected low volume roads were used for decision validating process of the research. Cost effective roughness computation method was developed using a smart phone application for roughness data collection of selected low volume roads.

3.4.1. Roughness Measurement of Selected Low volume Roads

The development of smartphones with 3-Axis accelerometer allows it to take acceleration measurements in m/s^2 along each of x, y, z axes. Past research on used of this technology has given evidence of the use of smartphones to measure road roughness. In this research an android application called "Androsensor" was used to develop a roughness computation method for low volume roads which can also be used in the maintenance decision making.

Androsensor is an application that is available for free download in Google Play Store. We can get several measurements from Androsensor application but for this experiment and studies, only acceleration data (x, y, and z) and location data (longitude, latitude, speed etc.) from GPS are used. In this research Regression analysis was used to obtain a relationship between resultant acceleration from Androsensor application and IRI values collected from Profilometer for same road sections.

3.4.2. Data Collection using smart phone

The smartphone installed with Androsensor application were fixed vertically on the windscreen of the vehicle in a steady position. Hence, we assume that the acceleration coordinates of the vehicle and smartphones are the same. A Toyota Hilux 4WD cab is used as the experimental vehicle for data collection, since most of the road agencies in Sri Lanka used this type of vehicles, as their field vehicles. A video camera is also used to capture the road surface and surrounding. This video clip is used for data checking and verification in case there is a need.

HTC Desire smart phone with an android version of 4.4 kit Kat is used for roughness data collection. Since, different road surface conditions cause vehicles to vibrate differently, the variation of the vibration can be captured by using a smartphone with acceleration sensors. We then drive the vehicle along the roads with different surface conditions. Graphical user Interface of Androsensor application and vehicle used for data collection is shown in figures 3.3 and 3.4 respectively.

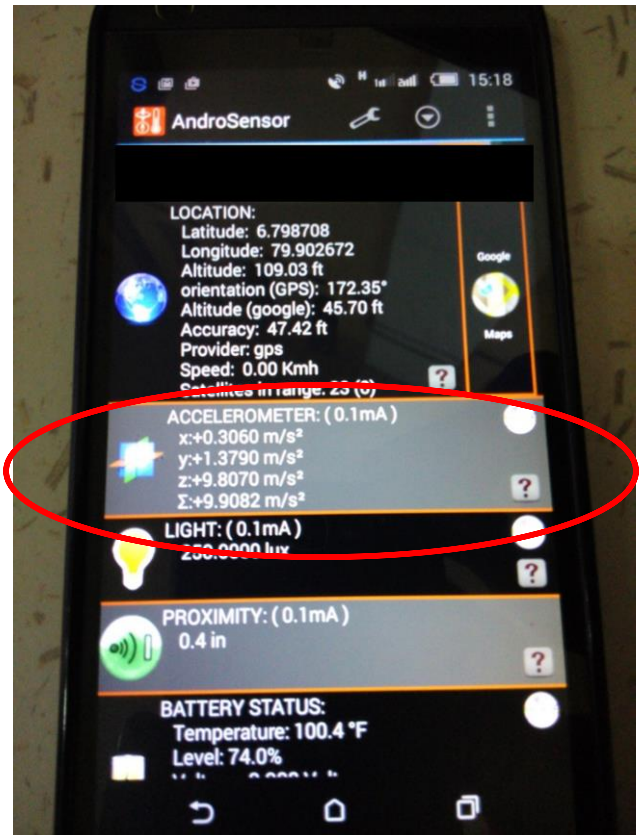


Figure 3.3: Roughness Data Collection using Androsensor Application

Figure 3.4: Toyota Hilux 4WD Cab used for data collection

45 national roads with different pavement surface conditions (including the Southern Expressway and Colombo-Katunayake Expressway) covering all climate conditions in Sri Lanka (wet, dry and intermediate) are selected for collecting roughness data. We drive the vehicle at different speeds along the same road and compared resultant acceleration values obtained to get the effect from speed of the vehicle.

3.4.3. Development of Cost Effective Pavement Roughness Data Collection Method

After obtaining the accelerometer data from Androsensor application, data was transferred to spread sheet files. Sample spread sheet of Accelerometer readings obtained from Androsensor Application is given in Table 3.4 below. Then those spread sheets were carefully checked manually to select only road sections that have complete data sets. Sections with incomplete data set are the sections that have no data from Androsensor. (i.e. when the vehicle speed is lesser or zero).

Recent Roughness data (IRI) of same roads collected from Profilometer was obtained from Planning division of Road Development Authority. Roughness data of 45 National roads including A & B class roads and Expressways was obtained. (Since the Roughness data collected from Profilometer is only available for national roads and Expressways). Then regression analysis is performed to identify a relationship between Average IRI values (collected from Profilometer) and resultant acceleration from Androsensor application for the same road sections. Resultant acceleration is the magnitude of resultant of the x, y and z accelerometer readings taken from Androsensor application for 100 m intervals. Data matching was done based on location readings (longitude and latitude).

Only the effect from vehicle type and speed of the vehicle are considered to develop this model because there was only a minor effect from the phone model to the relationship between magnitude of acceleration and road condition. (Douangphachanh and Oneyama, 2013). This can be used to give recommendation on the survey speed for road agencies when collecting roughness measurement using this method.

Table 3.4: Sample spread sheet of Accelerometer readings obtained from Androsensor Application

ACCELEROMETER X	ACCELEROMETER Y (	ACCELEROMETER Z	SOUND LEVEL	Latitude	Longitude	Altitude(m)	Speed(Kmh)
-2.604	12.257	-0.459	46.925	6.79853	79.91019	74.19	20.32
3.218	15.629	-1.992	42.486	6.79853	79.91019	74.19	20.32
-2.298	9.346	-1.225	40.021	6.79858	79.91018	73.55	20.27
-3.983	9.806	-1.225	39.655	6.79858	79.91018	73.55	20.27
1.072	11.645	-0.612	40.625	6.79864	79.91017	73.23	20.58
3.677	10.725	1.225	54.688	6.79864	79.91017	73.23	20.58
-3.677	9.806	3.984	54.475	6.79869	79.91016	72.9	21.79
0.306	10.112	0	45.435	6.79869	79.91016	72.9	21.79
0.306	11.185	0.919	47.473	6.79875	79.91015	72.9	22.1

Different relationships were obtained between the IRI values collected from Profilometer and resultant acceleration obtained from Accelerometer readings for different speed categories.(0-20 km/h, 20-30 km/h,30-40 km/h,40-50 km/h, 50-60km/h, More than 60km/h).

This study developed a relationship between acceleration measurements, collected by smartphones, and road roughness condition for local conditions. Since Toyota Hilux cab is used as the experiment vehicle to develop this model it is only valid for 4WD jeep/Cab type vehicles. However similar models can be developed for other vehicle types. The model developed will be used for the validation of the research output and it can be considered as adequate for comparison of relative levels of road roughness which will be useful for maintenance decision making of low volume roads.

3.4.4. Condition Indexes for Road Roughness (IRI)

At present, provincial road development authorities in Sri Lanka use subjective ratings to assess the pavement condition of low volume roads. The Engineers had to drive along the road physically to make a visual survey. This current practice is generally expensive, time consuming and requires high level of manpower since Engineers has to cover a vast network of low volume roads.

The minimum acceptable IRI values and road roughness condition indexes varies in different countries (Sousza, 2002) and is influenced by the type of maintenance treatment planned for the road and road type. For example IRI value less than 2 would be considered as good for major arterials due to higher operating speeds expected.

However this can be relaxed for low volume roads with lower operating speeds. Typically for low volume roads, pavement with IRI in the range of 7-10 is considered to be in moderate/poor condition and at a stage maintenance should be planned. Once these are established by the agency, they first select the roads that violate the threshold and then prioritize the roads for maintenance works for those roads based on the condition and the maintenance treatment planned.

Currently, a minimum acceptable IRI value or road condition indexes based on roughness are not developed even for national roads in Sri Lanka. Therefore, road roughness indexes used in Lao road management system is used as the basis to establish road condition index for low volume roads. Six road condition indexes are used in Lao road management system namely, Excellent(0≤IRI<2), Good(2≤IRI<4), Fair(4≤IRI<7), Poor(7≤IRI<10), Bad(10≤IRI<18) and Failed(IRI≥18).

Four condition indexes of road roughness are proposed to classify the road surfacing condition based on the IRI values obtained from smartphone application.

Proposed road condition indexes are given in Table 3.5 below.

Table 3.5: Road Condition Index

Road Condition Index	Average IRI
Good	0≤IRI<4
Fair	4≤IRI<7
Poor	7≤IRI<10
Bad or Impassable	IRI≥10

3.4.5. Field data collection of LVRs for Validation of the Research

About 95 low volume roads paved with different pavement surface materials such as Asphalt, Metal and Tar, Concrete, Concrete blocks and gravel were selected for validation of the research. Low volume Roads with different pavement surface conditions (good, average, poor, very poor, etc.) covering all climate zones in Sri Lanka (Dry and Wet) are selected for the data collection. Selected roads are within Anuradhapura, Vavuniya, Matara, Galle, Badulla, Kandy and Colombo districts.

The collected data can be categorized in to two categories.

1. Information required to classify the low volume road, based on the screening factors defined under 3.1.2 above (Traffic Volume, Traffic Composition, Land use, Terrain and climate)

Collected data includes,

a. Road Width(m)
b. Connection of the road at the start and end (A/B class road, C/D class road, Other minor road or dead end)
c. Land use along the road (Residential, Agricultural and Forest) and density
d. Whether it is a bus route or not, if yes number of buses per day
e. Whether the road is flooded regularly or not
f. Number of civic structures along the road (Hospitals, schools, Government institutions, temples, etc.)
g. Produces Served (Paddy, Vegetables, Tea, Fruits, Other)
h. Daily traffic flow along the road
i. Percentage of heavy vehicles
j. Terrain (Flat, Rolling or Mountainous) and Climatic zone (Dry or Wet)

2. Information required for the validation of the selection stage

Collected data includes,

a. Year of last rehabilitation of the road
b. Visual condition of the pavement surface (Good, Average, Bad, Impassable)
c. Average Roughness of the road section

Most of the selected roads were candidate roads to be improved under Integrated Road investment program (iRoads). 12 hour manually classified Traffic counts were obtained for these roads from the iRoads project and relevant provincial road development authorities. 12 hour traffic counts were conducted for roads if past traffic data is not available.

In addition acceleration measurements were taken along the road sections using Androsensor application. Resultant acceleration was computed and converted to the IRI value using the models developed between the resultant acceleration and IRI based on the survey vehicle speed.

3.4.6. Validation of the Framework using Roughness data of selected roads

Low volume roads are categorized in to each combination of screening factors (Traffic Volume, Traffic Composition, Land use, Terrain and Climate) based on their daily traffic flow, Percentage of heavy vehicles, Number of buses along the road per day, Land use along the road and density, Number of civic structures along the road ,Terrain and Climatic conditions.

Performance of the road surfacing materials for each combination were compared using Year of last rehabilitation, Visual condition of the pavement surface, Average IRI value along the road section with the desired pavement surfacing material for the relevant combination obtained from the developed framework.

CHAPTER 04 DATA ANALYSIS AND DISCUSSION

4.1 General

The results of the Surveys and analysis performed are presented in the sections below.

4.2 Screening Stage

4.2.1 Initial Screening Matrix

The Initial screening matrix developed to avoid performing a detailed evaluation for each individual surfacing and to allow the engineers to focus on the most suitable surface types is presented in Table 4.1 below. Selected pavement types from the Initial screening Matrix was carried forward to the selection stage.

Table 4.1: Initial screening Matrix

Road Surfacing Type	Traffic Volume			Traffic Composition			Land use		Terrain and Climate		
	Low	Medium	High	Heavy	Medium	Light	Residential	Agricultural	Wet Mountainous	Wet Flat	Dry Flat
Asphalt	O	1	1	I	1	1	1	1	1	1	1
Metal and Tar/DBST	1	1	1	1	I	1	1	1	O	1	1
Concrete	1	1	1	1	1	1	1	1	1	1	1
Concrete Blocks	1	1	1	1	1	1	1	1	1	1	1
Gravel	1	1	O	O	1	1	O	1	O	O	1

Note: Acceptable for use (1), and not acceptable (O)

4.3 Selection Stage

4.3.1 Results of the Questionnaire Survey

Expert opinion on suitability of pavement surface types for each combination of screening factors (Traffic Volume, Traffic Composition, Land use, Terrain and Climate) based on life cycle cost, maintenance requirement and rider comfort, collected using the Questionnaire survey is given below. Data was collected from a total of 60, and Average values of scores obtained for each pavement type for each combination is presented in Table 4.2 below. Some completed questionnaire forms are annexed as Appendix A.

Table 4.2: Average scores obtained from Questionnaire survey analysis

Selection Attribute					Lifecycle Cost					Maintenance Requirement					Rider Comfort				
					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	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

4.3.2 Weighting Factors

The weighting factors represent the relative importance of the selection attributes (Life cycle cost, Maintenance requirement, Rider comfort) were obtained based on pairwise comparison using AHP (Analytic Hierarchy Process). The values were obtained by interviewing 25 Engineers and average values obtained for each criteria is given in Table 4.3 below.

Table 4.3: Average values obtained from survey for each criteria

Criteria		More important	Intensity
A	**B**		
Life Cycle Cost	Maintenance Requirement	A	-1.1 or 1/1.1
Life Cycle Cost	Rider Comfort	A	-7 or 1/7
Maintenance Requirement	Rider Comfort	A	-5 or 1/5

The Comparison matrix (Reciprocal matrix) developed is given in Table 4.4 below.

Table 4.4: Comparison (Reciprocal) Matrix

Criteria	Life Cycle Cost	Maintenance Requirement	Rider Comfort
Life Cycle Cost	1	1.1	7
Maintenance Requirement	1/1.1	1	5
Rider Comfort	1/7	1/5	1
Sum	2.052	2.3	13

Sum of each column was also computed and values in the comparison matrix was divided by sum of respective column to obtain normalized relative weight. Normalized relative weights obtained are given in Table 4.5 below.

Table 4.5: Normalized relative weights

Criteria	Life Cycle Cost	Maintenance Requirement	Rider Comfort
Life Cycle Cost	0.49	0.48	0.54
Maintenance Requirement	0.44	0.43	0.38
Rider Comfort	0.07	0.09	0.08
Sum	1	1	1

The normalized principal Eigen vector (Priority vector) was obtained by averaging across the rows as given in Table 4.6 below.

Table 4.6: Normalized principal Eigen vector (Priority vector)

			Priority Vector	Priority Vector (%)
W =	1/3 X	0.487 + 0.478 + 0.5385	0.50	50
		0.443 + 0.435 + 0.3846	0.42	42
		0.070 + 0.0869 + 0.0769	0.08	8
Sum			1	100

Consistency Index (degree of consistency) was computed using the equation given below.

Consistency Index = $$CI = \frac{\lambda_{max} - n}{n - 1}$$

Principal Eigen value was obtained from the summation of products between each element of Eigen vector and the sum of columns of the reciprocal matrix as given below.

Principal Eigen Value = λ_{max} = (2.052 x 0.50) + (2.3 x 0.42) + (13 x 0.08)

= 3.03

n = Number of comparisons =3

Consistency Index = **CI** = (3.03-3) / (3-1) = 0.015

Random Consistency Index = **RI** = 0.58 (Assuming sample size of 500 matrices)

Consistency Ratio = $CR = \frac{CI}{RI}$ = 0.015/0.58 = 0.0258 = 2.58% < 10%

Consistency Ratio is smaller than 10%, therefore the inconsistency is acceptable.

Therefore, the weighing factors for the selection attributes are,

Life cycle cost = 50%

Maintenance requirement = 42%

Rider comfort = 8%

4.3.3 Final scores for each combination

Final scores of pavement types for each combination of Traffic category, Traffic Composition category, Land use category and Terrain and Climate category was obtained by multiplying Average scores obtained from Questionnaire survey analysis (Table 4.2) with relevant weighting factors as follows.

Final Score of pavement types for each Combination

$= \sum$ Average Score for each aspect X weighting factor for each aspect

(Life cycle cost, Maintenance Requirement, Rider comfort)

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

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 Rider comfort

4.3.4 Most Appropriate pavement type/types for each combination

Final scores of the pavement types for each combination were calculated as a percentage and given in Table 4.7 below. Most appropriate pavement type/ types are selected based on the percentages obtained for each pavement type for each combination.

Table 4.7: Final scores (as a percentage) and most appropriate pavement types for each combination

Selection Attribute					Final Priority Percentages (%)					Most Appropriate Pavement Type/Types
					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**	
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**	All Pavement types except Asphalt
3			Agricultural	Dry Flat	28.36	23.95	20.27	27.43	**X**	All Pavement types except Asphalt
4		Light	Residential	Wet Mountainous	20.75	22.16	25.19	**31.90**	**X**	Metal & Tar
5				Dry Flat	24.37	21.17	27.90	26.56	**X**	All Pavement types except Asphalt
6			Agricultural	Dry Flat	27.03	21.34	26.35	25.28	**X**	All Pavement types except Asphalt
7	Medium	Heavy	Residential	Wet Mountainous	**X**	**40.37**	28.87	**X**	30.75	Concrete
8				Dry Flat	**X**	**24.86**	18.58	**26.39**	**30.17**	Asphalt/ Metal and Tar/Concrete
9			Agricultural	Dry Flat	**X**	24.54	17.80	**28.43**	**29.23**	Asphalt/Metal and 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	All 05 Pavement Types
12			Agricultural	Dry Flat	22.78	17.96	17.89	22.59	18.78	All 05 Pavement Types
13	Medium	Medium	Residential	Wet Mountainous	**X**	**44.11**	29.35	**X**	26.54	Concrete
14				Dry Flat	**X**	24.46	20.61	**26.22**	**28.71**	Asphalt/Metal and 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
17			Agricultural	Dry Flat	**X**	19.13	13.06	29.74	**38.07**	Asphalt
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 and Tar

4.4 Validation Stage

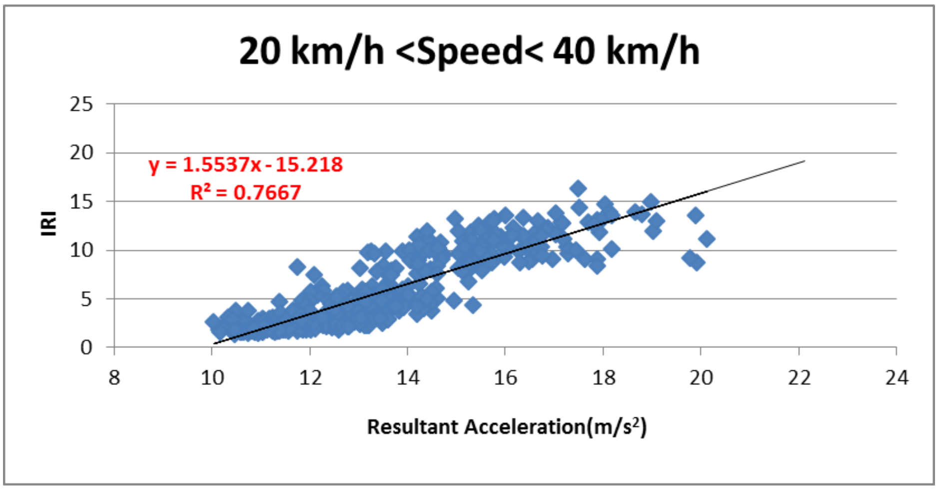
Validation stage is used to justify the selected most appropriate pavement types for each combination under the selection stage. Actual performance of the different pavement types with time for the each combination of Traffic, Traffic composition, land use, terrain and climate were compared with the results obtained in Table 4.7 above.

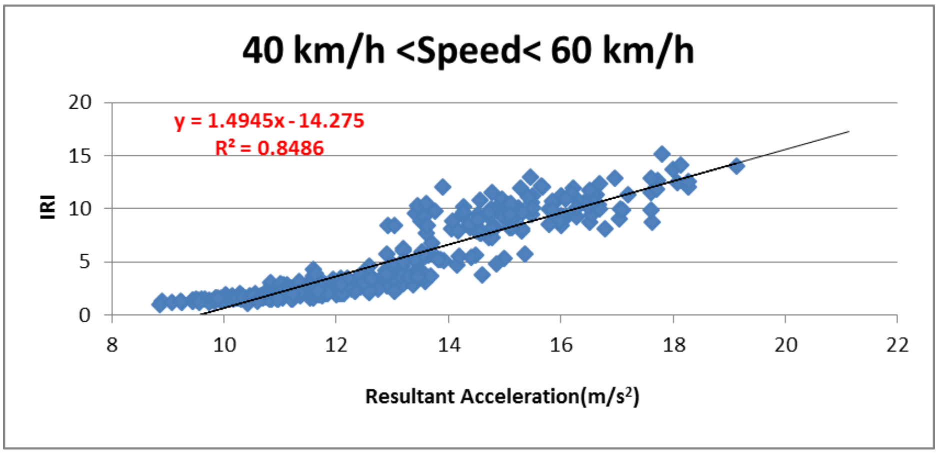
Pavement roughness measured by IRI is used as the basis to justify the final priority percentages obtained for the pavement types for selected combinations.

4.4.1 Cost Effective Pavement roughness computation method

The results of the regression analysis between resultant acceleration from Androsensor application and the average IRI value (collected from Profilometer) is given in figure 4.1 below.

According to the results, resultant acceleration measured in m/s^2 has a linear relationship with pavement roughness measured in IRI.





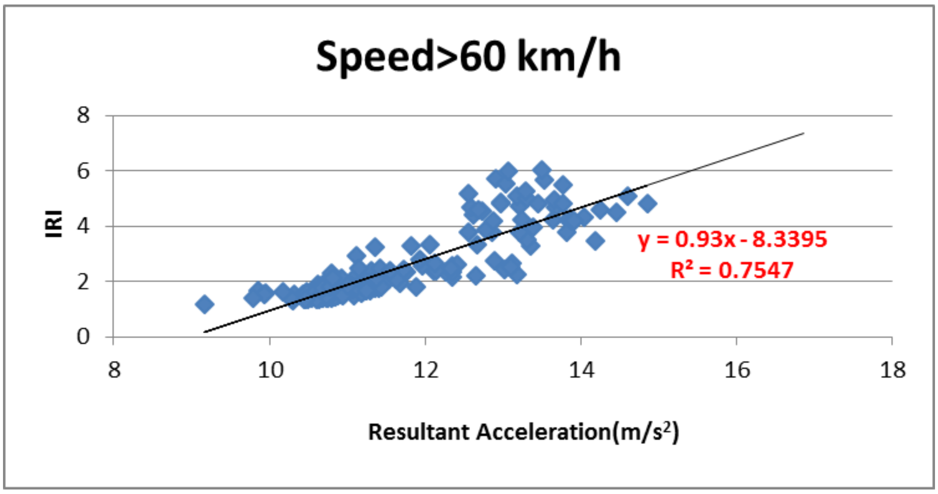


Figure 4.1: Relationship between resultant acceleration and road roughness with speed

Resultant acceleration shows different relationships for different speeds with the pavement roughness according to the coefficients of linear regressions obtained. Summary of regression analysis results is given in Table 4.8 below.

Table 4.8: Summary of Regression Analysis results

Speed of vehicle	Regression Equation	R square
Between 20 and 40 km/h	y = 1.5537 x – 15.218	0.7667
Between 40 and 60 km/h	y = 1.4945 x – 14.275	0.8486
More than 60 km/h	y = 0.93 x – 8.3395	0.7547

Where, x - resultant acceleration (m/s^2)

This smart phone based roughness computation method is valid for speeds between 20~100 km/h. However we can use this method for speeds less than 20 km/h. But results are not much accurate. (Lars Forslöf and Hans Jones).

Figure 13 above shows the linear relationships between the resultant acceleration and pavement roughness for each speed categories. Since all coefficient of determination (R-squared) values higher than 0.75, there is a very good correlation between resultant acceleration and pavement surface conditions.

Here, data were categorized in to three categories based on survey vehicle speed to obtain a relationship between the resultant acceleration and pavement roughness. If we consider, more categories better relationships could be obtained.

4.4.2 Comparison of IRI Values Obtained from Smart Phone Application with actual surface condition of roads

Sample of low volume roads with different pavement surfacing was selected for the comparison of IRI Values Obtained from Smart Phone Application with actual surface condition of roads. A panel of experts (Engineers) were asked to judge the present serviceability of these low volume roads. Observers were given an understanding about Present Serviceability rating (PSR) as given in Table 4.9 below.

Table 4.9: Road Conditions based on PSR

Present Serviceability Rating(PSR)	Road Condition
0.1 - 1.0	Excellent
1.0 - 2.0	Good
2.0 – 3.0	Fair
3.0 – 4.0	Poor
4.0 – 5.0	Bad or Impassable

Then the roughness obtained for those roads from smart phone application was compared with the observed ratings given by the panel of experts. Results of the comparison are presented in Table 4.10 below.

Table 4.10: Comparison of IRI obtained from Smartphone app with actual condition of roads

Hiralugama Road		
Pavement Type: Asphalt		
Road Geometry: Flat		
Drainage condition: Good		
Survey speed:53 km/h		
Average IRI: 2.23		
Road Condition: Good		
Nellikulama Road		
Pavement Type: Asphalt		
Road Geometry: Flat		
Drainage condition: bad		
Survey speed: 28 km/h		
Average IRI: 9.85		
Road Condition: Poor		
Pitaweliya Road		
Pavement Type: Concrete		
Road Geometry: Rolling		
Drainage condition: Fair		
Survey speed:23 km/h		
Average IRI: 4.17		
Road Condition: Fair		
Church Street		
Pavement Type: CBP		
Road Geometry: Flat		
Drainage condition: Good		
Survey speed:26 km/h		
Average IRI: 4.65		
Road Condition: Fair		
Ihalagama Rd		
Pavement Type: Gravel		
Road Geometry: Flat		
Drainage condition: poor		
Survey speed: 20 km/h		
Average IRI: 16.78		
Road Condition: Bad		
Eriyagama-Delnagama Rd		
Pavement Type: DBST		
Road Geometry: Flat		
Drainage condition: Bad		
Survey speed:35 km/h		
Average IRI: 8.25		
Road Condition: Poor		

As evident from Table 4.10 above, IRI values obtained from the analysis provides a reasonable assessment of the pavement condition, which can also provide useful inputs for pavement maintenance decision making. A lower IRI is obtained for the gravel road, which is in impassable condition, it must also be noted that the survey speed of the vehicle for the road is 20.14km/h which is at the lower limit of survey speeds applicable for this method. A similar format can be adapted to presenting the information related to the condition of the roads in the network.

This relationships can be used to estimate pavement roughness of the low volume roads and eventually, those estimated roughness values can be used to justify the selected pavement types for each combination under selection stage. Not only for the validation of this research, low volume road agencies in Sri Lanka such as PRDA and local authorities can also use above relationships to estimate road roughness of low volume roads under their authority based on accelerometer readings.

4.4.3 Benefits of Roughness measurements using smart phones

As mentioned earlier, although the smartphone based roughness measurement method lack the precision and accuracy of the roughness measurement using Profilometer it will give an objective basis for local authorities and PRDA, when making decisions with respect to maintenance planning.

There are several advantages of using smartphones for roughness measurements over Profilometer though it has a lesser accuracy.

1. Requires little training
2. Capital cost of equipment is minimal
3. Existing vehicles can be utilized
4. Easiness in Handling

The main benefit of this roughness measurement method is that Provincial Road authorities can use their own vehicle and smart phones to collect accelerometer data and to estimate road surface condition unlike in Profilometer based method where they require a separate equipment and vehicle for roughness measurements.

4.4.4 Field data collected for the validation of research

As described under 3.4.4 above, about 95 low volume roads with different surfacing types and in different conditions were selected for data collection. As mentioned in section 3.4.4 field data were collected for selected low volume roads under two categories. Field Data collected for each low volume road to classify the road based on the screening factors (Traffic Volume, Traffic Composition, Land use, Terrain and climate) are given in the Appendix B.

Some sample completed field data forms are annexed in Appendix C.

Categorization of low volume roads based on collected field data is given in Table 4.11 below.

Table 4.11: Categorization of low volume roads based on collected data

No.	Road Name	District	Road Surfacing	Screening Factors			
				Traffic Volume	Traffic Composition	Land use	Terrain and Climate
1	Welankulama-wewaldhigiliya Rd	Anuradhapura	Asphalt	Low	Light	Residential	Dry flat
2	Thalawa-Andaraweva Rd	Anuradhapura	Asphalt	High	Heavy	Residential	Wet flat
3	Senapura-Katiyawa Rd	Anuradhapura	Asphalt	Medium	Heavy	Residential	Wet flat
4	Athakada-Tonigala Rd	Anuradhapura	Asphalt	Medium	Medium	Residential	Dry flat
5	Welioya-Thammanawa Rd	Anuradhapura	Asphalt	Medium	Medium	Residential	Dry flat
6	Pothana-Ihalagama Rd	Anuradhapura	Asphalt	Medium	Medium	Agricultural	Dry flat
7	Rambewa-Rathmalgahaweva Rd	Anuradhapura	Asphalt	Medium	Medium	Residential	Dry flat
8	Athakada-Maligasweva Rd	Anuradhapura	Metal & Tar	Low	Medium	Agricultural	Wet flat
9	South channel bund Rd	Anuradhapura	Metal & Tar	Low	Medium	Residential	Dry flat
10	Left channel bund Rd	Anuradhapura	Metal & Tar	Low	Light	Agricultural	Wet Mountainous
11	Ihalagama-Thurukkurgama Rd	Anuradhapura	Gravel	Low	Light	Residential	Wet flat
12	Kalanchiya-Kapirikkagama Rd	Anuradhapura	Asphalt	Medium	Medium	Residential	Wet flat
13	Seppukulama-Pothana Rd	Anuradhapura	Gravel	Low	Light	Agricultural	Dry flat
14	Eriyagama-Adiranigama Rd	Anuradhapura	Metal & Tar	Medium	Light	Agricultural	Dry flat
15	Katukaliyawa Rd	Anuradhapura	Asphalt	Low	Medium	Residential	Dry flat

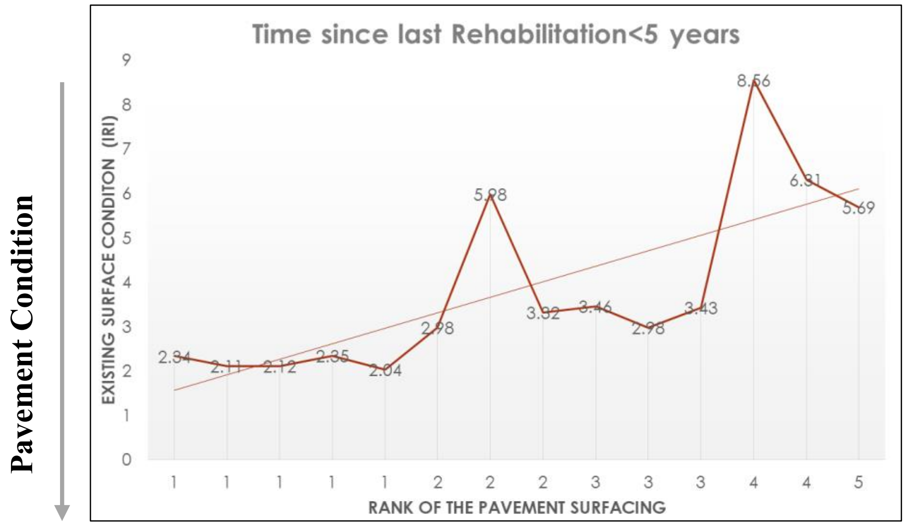
No.	Road Name	District	Road Surfacing	Screening Factors			
				Traffic Volume	Traffic Composition	Land use	Terrain and Climate
16	Seppukulama-Galenbindunuweva Rd	Anuradhapura	Asphalt	High	Heavy	Residential	Dry flat
17	Eppawala-Nellikulama Rd	Anuradhapura	Asphalt	Medium	Medium	Residential	Dry flat
18	Kirigollewa-Hirillugama Rd	Anuradhapura	Asphalt	Medium	Heavy	Residential	Dry flat
19	Navatkulam-Maraiyadithakulam Rd	Vavuniya	Gravel	Low	Medium	Residential	Wet flat
20	Santhasoolai to Mahakachchakodiya Rd	Vavuniya	Gravel	Low	Light	Agricultural	Wet flat
21	Sinnaputhukulam Rd	Vavuniya	Metal & Tar	Medium	Medium	Residential	Wet flat
22	Mahilankulam-Pallamadhu Rd	Vavuniya	Metal & Tar	Medium	Heavy	Residential	Dry flat
23	Omanthai-Elamaruthankulam Rd	Vavuniya	Gravel	Low	Medium	Agricultural	Wet flat
24	Madukande-Ireperiyakulam Rd	Vavuniya	Metal & Tar	Medium	Heavy	Residential	Dry flat
25	Koolankulam-Maraillupaikulam Rd	Vavuniya	Gravel	Low	Light	Agricultural	Wet flat
26	Kalnatinakulam-Asikulam Rd	Vavuniya	Metal & Tar	Low	Heavy	Residential	Dry flat
27	Malikai-Chemamadu Rd	Vavuniya	Gravel	Low	Medium	Agricultural	Wet flat
28	Elamaruthankulam-Samalankulam Rd	Vavuniya	Gravel	Low	Medium	Agricultural	Wet flat
29	Pandikeithakulam-Maraiyadiyhakulam Rd	Vavuniya	Gravel	Low	Medium	Agricultural	Wet flat
30	Rambaikulam-Palamoddai Rd	Vavuniya	Metal & Tar	Low	Medium	Agricultural	Dry flat
31	Weligama-Imaduwa Rd	Matara	Asphalt	High	Heavy	Residential	Wet flat
32	Jaburagoda-Koledanda Rd	Matara	Concrete	High	Light	Agricultural	Wet flat
33	Panchaliya-Borala Rd	Matara	Asphalt	Medium	Medium	Residential	Wet flat
34	Ibbawala-Panchaliya-Andugoda Rd	Matara	Asphalt	High	Light	Agricultural	Wet flat
35	Ibbawala-Ranamaduragama Rd	Matara	Asphalt	Low	Light	Agricultural	Wet flat
36	Wellawatta-Kammmalgoda Rd	Matara	Asphalt	Low	Light	Agricultural	Wet flat
37	Jaburagoda-Koledanda Rd	Matara	Asphalt	Medium	Medium	Residential	Wet flat

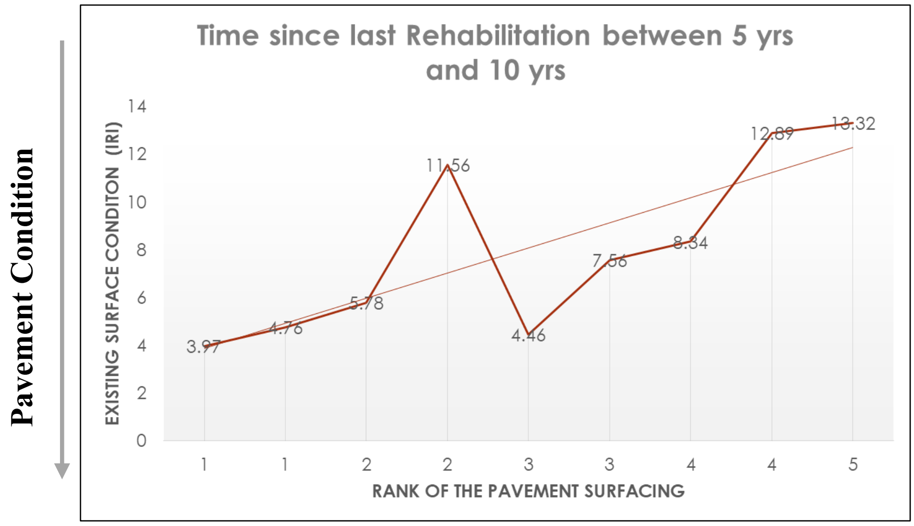
No.	Road Name	District	Road Surfacing	Screening Factors			
				Traffic Volume	Traffic Composition	Land use	Terrain and Climate
38	Kananke P.S - Dewalagoda Rd	Matara	Metal & Tar	Low	Light	Residential	Wet flat
39	Welipitiya-Udukawa Rd	Matara	Asphalt	High	Heavy	Residential	Wet flat
40	Welipitiya-Moonamalpa Rd	Matara	Asphalt	Medium	Medium	Agricultural	Wet flat
41	Pallala Rd	Matara	Asphalt	Low	Light	Residential	Wet flat
42	Pangirihena-Mayakaduwa Rd	Galle	Metal & Tar	Medium	Medium	Residential	Wet flat
43	Pitapola Rd	Badulla	Metal & Tar	Low	Heavy	Agricultural	Wet Mountainous
44	Taldena-Hunuketapitiya-Egodawela Rd	Badulla	Metal & Tar	Low	Medium	Agricultural	Wet flat
45	Soranathota Rd	Badulla	Asphalt	Medium	Heavy	Agricultural	Wet Mountainous
46	Madapathana Rd	Badulla	Concrete	Low	Light	Agricultural	Wet Mountainous
47	Hinnaragolla-Pitapola Rd	Badulla	Asphalt	Medium	Medium	Residential	Wet Mountainous
48	Etampitiya-Dehiwinna Rd	Badulla	Metal & Tar	Low	Medium	Residential	Wet Mountainous
49	Etampitiya-Ketawala-Keenakale Rd	Badulla	Asphalt	Medium	Medium	Residential	Wet Mountainous
50	Etampitiya-Abewela-Maligathenna Rd	Badulla	Metal & Tar	Medium	Medium	Agricultural	Wet Mountainous
51	Ketawala-Haliela Rd	Badulla	Asphalt	Medium	Heavy	Residential	Wet flat
52	Pitaweliya Rd	Badulla	Concrete	Low	Light	Residential	Wet Mountainous
53	Keppetipola Rd	Badulla	Metal & Tar	Low	Light	Residential	Wet flat
54	Kalupahana-Ohiya Rd	Badulla	Metal & Tar	Medium	Light	Agricultural	Wet Mountainous
55	Haldummulla-Nikapotha Rd	Badulla	Asphalt	Medium	Heavy	Residential	Wet Mountainous
56	Tambapillai Ave	Badulla	Metal & Tar	Low	Light	Agricultural	Wet Mountainous
57	Diyathalawe-Yahalabedda Rd	Badulla	Asphalt	Medium	Heavy	Agricultural	Wet flat
58	Moragolla Rd	Badulla	Asphalt	High	Heavy	Residential	Wet Mountainous
59	Galedanda Rd	Badulla	Asphalt	Medium	Heavy	Residential	Wet Mountainous
60	Mapanawatura Rd	Kandy	Asphalt	Medium	Medium	Residential	Wet Mountainous
61	Rangala Rd	Kandy	Asphalt	High	Heavy	Residential	Wet Mountainous
62	Karaliyadda-puthuhapuwa-werapitiya Rd	Kandy	Asphalt	Medium	Heavy	Residential	Wet Mountainous

No.	Road Name	District	Road Surfacing	Screening Factors			
				Traffic Volume	Traffic Composition	Land use	Terrain and Climate
63	Victoria Golf club Rd	Kandy	Asphalt	High	Heavy	Residential	Wet Mountainous
64	Milco Rd	Kandy	Asphalt	High	Heavy	Residential	Wet flat
65	Menikhinna-Kengalla Rd	Kandy	Asphalt	Medium	Heavy	Residential	Wet flat
66	Aswalapitiya Rd	Kandy	Concrete	Low	Light	Agricultural	Wet Mountainous
67	Moragahapitiyawatte Rd	Kandy	Metal & Tar	Low	Light	Residential	Wet flat
68	Uratiyagahawatte Rd	Kandy	Concrete	Low	Light	Residential	Wet flat
69	Nittawela Rd	Kandy	Asphalt	High	Medium	Residential	Wet Mountainous
70	Thurunusavigama Rd	Kandy	Asphalt	High	Medium	Residential	Wet flat
71	Mosque Rd	Kandy	Metal & Tar	Medium	Medium	Residential	Wet flat
72	Udamaluwa Rd	Kandy	Metal & Tar	Low	Light	Agricultural	Wet flat
73	Ampitiya-Gurudeniya Rd	Kandy	Asphalt	Medium	Heavy	Residential	Wet Mountainous
74	Ampitiya-Ratemulla Rd	Kandy	Metal & Tar	Medium	Light	Residential	Wet Mountainous
75	Polwatta Rd	Kandy	Concrete	Low	Light	Residential	Wet flat
76	Meekanuwa Rd	Kandy	Asphalt	Medium	Heavy	Residential	Wet Mountainous
77	Dangolla Rd	Kandy	Asphalt	High	Medium	Agricultural	Wet Mountainous
78	Edanduwava Rd	Kandy	Concrete	Low	Light	Agricultural	Wet Mountainous
79	Edanduwava Rd	Kandy	Metal & Tar	Low	Light	Residential	Wet Mountainous
80	Galwala Rd	Kandy	Asphalt	High	Medium	Residential	Wet flat
81	Kiribathkubura-Diyapalagoda Rd	Kandy	Asphalt	High	Heavy	Residential	Wet flat
82	Owala-Pinnagolla Rd	Kandy	Metal & Tar	Medium	Light	Residential	Wet Mountainous
83	Gonnoruwa-Muruthalawa Rd	Kandy	Asphalt	High	Heavy	Residential	Wet flat
84	Estate Rd	Galle	Asphalt	High	Medium	Residential	Wet flat
85	Kettarama Rd	Galle	Asphalt	Low	Light	Residential	Wet flat
86	Sri Saranapala Mw	Galle	Metal & Tar	Low	Light	Residential	Wet flat
87	Cemetry Rd	Galle	Concrete Blocks	Low	Light	Residential	Wet flat
88	Ambagahawatta Rd	Colombo	Concrete Blocks	Low	Light	Residential	Wet Mountainous
89	Herman Meigner Rd	Colombo	Metal & Tar	Medium	Light	Residential	Wet flat
90	Madanwila Rd	Colombo	Asphalt	High	Medium	Residential	Wet flat

No.	Road Name	District	Road Surfacing	Screening Factors			
				Traffic Volume	Traffic Composition	Land use	Terrain and Climate
91	Attygalle Housing lane	Colombo	Metal & Tar	Medium	Light	Residential	Wet Mountainous
92	Sarvodaya Rd	Colombo	Metal & Tar	Low	Light	Agricultural	Wet flat
93	Dewala Rd	Colombo	Asphalt	High	Heavy	Residential	Wet flat
94	Gangabada Rd	Colombo	Asphalt	High	Heavy	Residential	Wet flat
95	Church Rd	Colombo	Asphalt	High	Heavy	Residential	Wet flat

4.4.5 Comparison of surface Condition of roads with the ranks for Pavement Surfacing





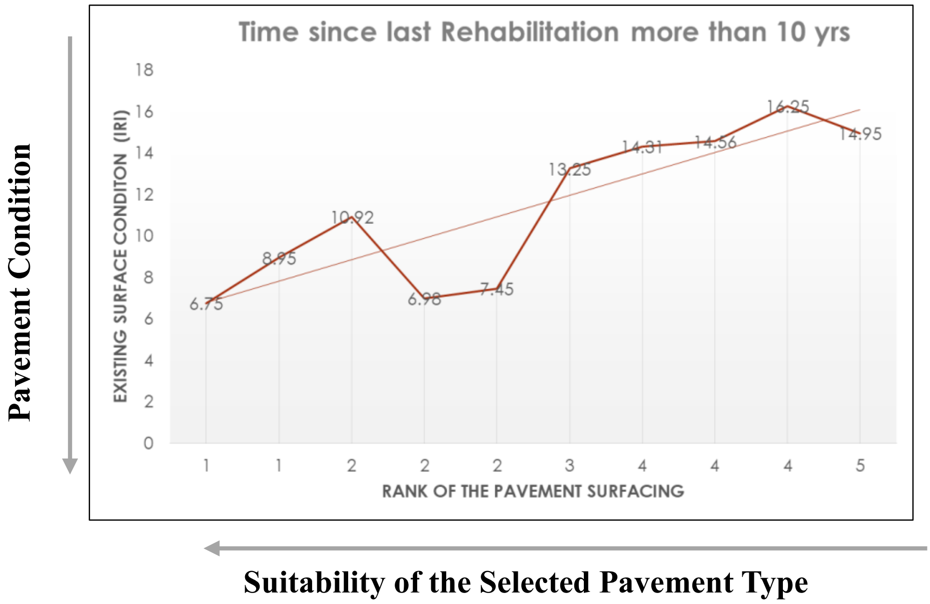


Figure 4.2: Comparison of surface Condition with the rank of Pavement Surfacing

Selected Low volume roads were classified in to three categories, based on the time duration since last rehabilitation: Roads rehabilitated within last 5 years, roads rehabilitated between last 5 years and 10 years, roads rehabilitated before last 10 years period. Then existing pavement condition of these low volume roads (IRI) was graphed against the rank of the pavement surfacing.

Accordingly, Roughness of the pavement is lower when the rank of the pavement surfacing is higher. If the rank of the pavement type is higher, surface condition will be better after a certain period. Therefore it can be concluded that ranks obtained for the pavement surfacing types in this research are realistic.

4.4.6 Comparison of the performance of selected low volume roads with the developed Framework

Actual performance of the different pavement types with time for the each combination of Traffic, Traffic composition, land use, terrain and climate is used as the basis to justify the pavement type selection framework developed in section 4.3.4. (Table 4.7).

First, selected low volume roads are categorized in to combinations as presented in Table 4.11 above. Resultant acceleration is calculated for each road and it was converted to Road roughness (IRI) using the relationships obtained in Table 4.8 above.

Road surface conditions are characterized based on the IRI value and road condition indexes defined in Table 3.5 above.

Since, there are repetitive combinations and similarity of the procedure, only a sample of roads (17 roads) are selected for the justification. Justification of the selected roads is presented in Table 4.12 below.

As evident from Table 4.12, Pavement type selection framework developed provide a reasonable guideline for low volume road agencies in Sri Lanka to select most appropriate pavement type for their low volume roads.

With the assumption that pavement widths and material thicknesses are not major considerations in low volume road design, this pavement type selection process can be used as the main design guideline for low volume roads in Sri Lanka. The future research would mainly address development of this framework integrating design width and design thickness in to consideration.

Table 4.12: Justification of the developed pavement type selection framework using field data

No.	Existing Road Surfacing	Resultant Acceleration (m/s^2)	Average IRI Value	Surface condition (Based on IRI)	Time Since last Rehabilitation/Major Repair	Combination				Suitability of Surfacing Type(According to the developed Framework)	Justification/Conclusion
						Traffic Volume	Traffic Composition	Land use	Terrain and Climate		
4	Asphalt	11.16	2.12	Good	2.5 years (Dec 2013)	Medium	Medium	Residential	Dry flat	Most Appropriate Pavement Type	Pavement is in good condition after 2.5 years, Selection is justified.
9	Metal & Tar	17.24	11.56	Bad	9 years (2007)	Low	Medium	Residential	Dry flat	Most Appropriate Pavement Type	Cannot be used for justification. Life time of Metal and tar pavement under these conditions is less than 9 years.
13	Gravel	11.71	2.98	Good	4 years (2012)	Low	Light	Agricultural	Dry flat	Most Appropriate Pavement Type	Even after 4 years, pavement is in good condition, Selection is justified.
14	Metal & Tar	13.86	6.32	Fair	6 years (2010)	Medium	Light	Agricultural	Dry flat	Most Appropriate Pavement Type	Pavement is in fair condition after 6 years, Selection is justified with maximum life time of 6 years.
16	Asphalt	16.82	10.92	Bad	12 years (2004)	High	Heavy	Residential	Dry flat	Most Appropriate Pavement Type	Pavement turned into Bad condition after 12 years, Selection is justified, with a maximum life time of 8-10 years under these conditions.
23	Gravel	12.02	3.46	Good	5 years (2011)	Low	Medium	Agricultural	Wet flat	Most Appropriate Pavement Type	Pavement type is in good condition, even after 5 years. Selection is justified.
25	Gravel	18.32	13.25	Bad	More than 15 years	Low	Light	Agricultural	Wet flat	Most Appropriate Pavement Type	Cannot be used for justification.
46	Concrete	14.14	6.75	Fair	12 years (2004)	Low	Light	Agricultural	Wet Mountainous	Most Appropriate Pavement Type	Even after 12 years, road pavement is in fair condition, Selection is justified with a maximum life time of about 12 yrs.
47	Asphalt	13.64	5.98	Fair	3 years (2013)	Medium	Medium	Residential	Wet Mountainous	Least Appropriate Pavement Type	Road Pavement turned in to fair condition within 3 years. Not a suitable pavement type. Selection is justified.

No.	Existing Road Surfacing	Resultant Acceleration (m/s^2)	Average IRI Value	Surface condition (Based on IRI)	Time Since last Rehabilitation/Major Repair	Combination				Suitability of Surfacing Type(According to the developed Framework)	Justification/Conclusion
						Traffic Volume	Traffic Composition	Land use	Terrain and Climate		
48	Metal & Tar	15.3	8.56	Poor	5years (2011)	Low	Medium	Residential	Wet Mountainous	Not a Suitable pavement type	Road Pavement turned in to poor condition within 5 years. Selection is justified.
51	Asphalt	18.9	14.15	Bad	8years (2008)	Medium	Heavy	Residential	Wet Mountainous	Least Appropriate Pavement Type	Road Pavement turned in to Bad condition within 8 years. Not an appropriate pavement type for these conditions. Selection is justified.
52	Concrete	12.86	4.76	Fair	7 years (2009)	Low	Light	Residential	Wet Mountainous	Second most Appropriate Pavement Type	Road Pavement turned in to Fair condition after 7 years. Selection is justified.
56	Metal & Tar	20.25	16.25	Bad/ Impassable	More than 15 years	Low	Light	Agricultural	Wet Mountainous	Not a Suitable pavement type	Road Pavement turned in to impassable after 15 years. Not an appropriate pavement type under these conditions. Selection is justified.
86	Metal & Tar	18.59	13.67	Bad	9 years (2007)	Low	Light	Residential	Wet Mountainous	Not a Suitable pavement type	Road Pavement turned in to bad condition just after 9 years. Not an appropriate pavement type under these conditions. Selection is justified.
87	Concrete Blocks	12.66	4.46	Fair	7 years (2009)	Low	Light	Residential	Wet flat	Most Appropriate Pavement Type	Road Pavement is in fair condition even after 7 years. Selection is justified.
88	Concrete Blocks	11.93	3.32	Good	2 years (2014)	Low	Light	Residential	Wet Mountainous	Second most Appropriate Pavement Type	Pavement is in good condition after 2 years, Selection is justified.
91	Metal & Tar	15.16	8.34	Poor	7 years (2009)	Medium	Light	Residential	Wet Mountainous	Not a Suitable pavement type	Road Pavement turned in to poor condition just after 7 years. Not an appropriate pavement type under these conditions. Selection is justified.

Note – The Justification is made based on the acceleration measurements obtained from December 2015- November 2016.

CHAPTER 05 CONCLUSIONS AND RECOMMENDATIONS

A Framework was developed to facilitate pavement type selection process for low volume roads based on their characteristics such as traffic volume, traffic composition, land use, terrain and climatic conditions. 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. The selection process is a three stage process consisting of screening stage, selection stage and validating stage.

The proposed pavement types comprise of concrete roads, asphalt concrete roads, metal and tar, block paving and gravel roads. Properties or characteristics of the pavement surfacing types such as lifecycle cost, maintenance requirement and rider comfort were also considered.

Actual performance of the different pavement surfacing with time for each combination was used to justify the developed pavement type selection framework. Roughness of the pavement surface measured by IRI was used to compare the actual performance of pavement surfacing with time.

Pavement roughness measurement method was developed using an android application to collect road condition data of low volume roads. Regression analysis was performed to identify a relationship between IRI and resultant acceleration from smart phone application. From the analysis, it has been found that acceleration data from smartphones has linear relationship with road roughness condition.

Not only for the validation of this research, IRI values obtained from the analysis provides a reasonable assessment of the pavement condition, which can also provide useful inputs for pavement maintenance decision making.

There are several advantages of using smartphones for roughness measurements over Profilometer though it has a lesser accuracy. The main benefit of this roughness measurement method is that Provincial Road authorities can use their own vehicle and smart phones to collect accelerometer data and to estimate road surface condition unlike in Profilometer based method where they require a separate equipment and vehicle for roughness measurements.

The future research would mainly address developing a relationship of the acceleration data and road roughness for other vehicle types and explore approaches to estimate road roughness when the vehicle speed is lesser than 20 km/h, to be used in roads with geometric constraints or poor condition.
It is evident that, Pavement type selection framework developed provide a reasonable guideline for low volume road agencies in Sri Lanka to select most appropriate pavement type for their low volume roads. This pavement type selection process can be used as the design guideline for low volume roads in Sri Lanka, especially for local authorities.

The future research would mainly address development of pavement design guideline for low volume roads to provide design cross-section as based on the setting and characteristics of the road.

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APPENDIX A

SAMPLE COMPLETED QUESTIONNAIRE SURVEY FORMS

Director – Provincial Road Development Authority
(Sabaragamuwa Province)

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Life Cycle cost** of different pavement types.

10 -Most appropriate Pavement Type (Minimum Life Cycle Cost)
1 -Least appropriate pavement Type (Maximum Life Cycle Cost)

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Life Cycle Cost)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	7	8	X	10
2				Dry Flat		~~78~~	8	9	X
3			Agricultural	Dry Flat	10	8	5	9	X
4		Light	Residential	Wet Flat	4	6	4	X	X
5				Dry Flat	6	6	4	8	X
6			Agricultural	Dry Flat	10	6	4	7	X
7	Medium	Heavy	Residential	Wet Mountainous	X	8	9	X	10
8				Dry Flat	X	8	9	9	10
9			Agricultural	Dry Flat	X	8	9	10	6
10		Light	Residential	Wet Mountainous	X	7	5	X	6
11				Dry Flat	6	8	7	9	10
12			Agricultural	Dry Flat	9	5	4	10	6
13	Medium	Medium	Residential	Wet Mountainous	X	8	10	X	9
14				Dry Flat	X	8	7	10	9
15			Agricultural	Dry Flat	9	8	6	10	7
16	High	Heavy	Residential	Dry Flat	X	*3	*2	8	10
17			Agricultural	Dry Flat	X	*3	*2	10	8
18		Light	Residential	Wet Flat	X	*3	*3	X	7
19			Agricultural	Dry Flat	X	*4	*3	10	8

* Those values are based on the actual practice on Provincial roads this may be doubled if proper construction method is adopted.

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Maintenance Requirement** of different pavement types.

10 -Most appropriate Pavement Type (Minimal Requirement)
1 -Least appropriate pavement Type (Frequent Intervention)

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Maintenance Requirement)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	5	10	X	8
2				Dry Flat	8	10	9	7	X
3			Agricultural	Dry Flat	9	10	9	10	X
4		Light	Residential	Wet Flat		10	9	X	X
5				Dry Flat	9	10	9	10	X
6			Agricultural	Dry Flat	10	10	9	9	X
7	Medium	Heavy	Residential	Wet Mountainous	X	9	9	X	10
8				Dry Flat	X			8	10
9			Agricultural	Dry Flat	X	9	9	10	~~10~~ 8
10		Light	Residential	Wet Mountainous	X			X	
11				Dry Flat	2	*5	*3	9	6
12			Agricultural	Dry Flat	2	*5	*3	10	6
13	Medium	Medium	Residential	Wet Mountainous	X	8	7	X	9
14				Dry Flat	X	8	7	9	10
15			Agricultural	Dry Flat	1	8	7	10	9
16	High	Heavy	Residential	Dry Flat	X	*1	*4	9	10
17			Agricultural	Dry Flat	X	*1	*4	10	8
18		Light	Residential	Wet Flat	X	*2	*2	X	9
19			Agricultural	Dry Flat	X	*2	*2	10	9

* These unusual maintenance requir
is caused by the wrong construction
method.

PRDA (Sabaragamuwa)

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Rider Comfort** of different pavement types.

10 -Most appropriate Pavement Type
1 -Least appropriate pavement Type

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Rider Comfort)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	6	5	X	10 –
2				Dry Flat	2	6	5	8	X
3			Agricultural	Dry Flat	2	6	5	8	X
4		Light	Residential	Wet Flat	2	6	5	X	X
5				Dry Flat	2	6	5	8	X
6			Agricultural	Dry Flat	2	6	5	8	X
7	Medium	Heavy	Residential	Wet Mountainous	X	6	4	X	10 – 5
8				Dry Flat	X	6	4	7	10 – 5
9			Agricultural	Dry Flat	X	6	4	6	10 – 5
10		Light	Residential	Wet Mountainous	X	6	4	X	10 – 5
11				Dry Flat	2	6	4	7	10 – 5
12			Agricultural	Dry Flat	2	5	4	7	10 – 5
13	Medium	Medium	Residential	Wet Mountainous	X	5	4	X	10 – 5
14				Dry Flat	X	5	4	7	10 – 5
15			Agricultural	Dry Flat	2	5	4x	7	10 – 5
16	High	Heavy	Residential	Dry Flat	X	5	3*	5	10 – 5
17			Agricultural	Dry Flat	X	5	3*	5	10 – 5
18		Light	Residential	Wet Flat	X	5	3*	X	10 – 5
19			Agricultural	Dry Flat	X	5	3*	5	10 – 5

*Driving & rider Comfort gradually reduces in Asphat Payments

Deputy Municipal Engineer - Moratuwa Municipal Council

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Life Cycle cost** of different pavement types.

10 -Most appropriate Pavement Type (Minimum Life Cycle Cost)
1 -Least appropriate pavement Type (Maximum Life Cycle Cost)

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Life Cycle Cost)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	10	9	X	6
2				Dry Flat	8	7	8	10	X
3			Agricultural	Dry Flat	10	6	7	9	X
4		Light	Residential	Wet Flat	6	8	10	X	X
5				Dry Flat	9	6	8	10	X
6			Agricultural	Dry Flat	10	5	6	8	X
7	Medium	Heavy	Residential	Wet Mountainous	X	10	8	X	6
8				Dry Flat	X	6	7	10	6
9			Agricultural	Dry Flat	X	7	7	10	5
10		Light	Residential	Wet Mountainous	X	10	9	X	7
11				Dry Flat	9	6	7	10	7
12			Agricultural	Dry Flat	10	5	6	9	5
13	Medium	Medium	Residential	Wet Mountainous	X	10	8	X	7
14				Dry Flat	X	6	7	10	7
15			Agricultural	Dry Flat	9	5	6	10	5
16	High	Heavy	Residential	Dry Flat	X	8	9	6	10
17			Agricultural	Dry Flat	X	7	8	7	10
18		Light	Residential	Wet Flat	X	9	10	X	7
19			Agricultural	Dry Flat	X	8	9	10	6

MMC

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Maintenance Requirement** of different pavement types.

10 -Most appropriate Pavement Type (Minimal Requirement)
1 -Least appropriate pavement Type (Frequent Intervention)

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Maintenance Requirement)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	10	8	X	5
2				Dry Flat	7	8	9	10	X
3			Agricultural	Dry Flat	7	9	9	10	X
4		Light	Residential	Wet Flat	8	9	10	X	X
5				Dry Flat	8	9	9	10	X
6			Agricultural	Dry Flat	9	9	9	10	X
7	Medium	Heavy	Residential	Wet Mountainous	X	10	8	X	4
8				Dry Flat	X	9	8	7	10
9			Agricultural	Dry Flat	X	7	6	6	10
10		Light	Residential	Wet Mountainous	X	10	8	X	5
11				Dry Flat	6	8	9	8	10
12			Agricultural	Dry Flat	8	9	9	9	10
13	Medium	Medium	Residential	Wet Mountainous	X	10	8	X	6
14				Dry Flat	X	7	6	7	10
15			Agricultural	Dry Flat	7	9	8	9	10
16	High	Heavy	Residential	Dry Flat	X	9	7	6	10
17			Agricultural	Dry Flat	X	9	8	6	10
18		Light	Residential	Wet Flat	X	9	10	X	7
19			Agricultural	Dry Flat	X	9	10	5	7

Moratuwa Municipal Council

Please give a score (between 10 and 1) on appropriate pavement types for low volume roads with given characteristics based on **Rider Comfort** of different pavement types.

10 -Most appropriate Pavement Type
1 -Least appropriate pavement Type

Combination	Traffic Category	Traffic composition category	Land use category	Terrain and Climate	Most appropriate Pavement Type (Based on Rider Comfort)				
					Gravel	Concrete	Concrete blocks	Metal and Tar	Asphalt
1	Low	Medium	Residential	Wet Mountainous	X	6	10	X	8
2				Dry Flat	8	6	7	10	X
3			Agricultural	Dry Flat	10	6	7	8	X
4		Light	Residential	Wet Flat	10	6	7	X	X
5				Dry Flat	8	6	7	10	X
6			Agricultural	Dry Flat	10	6	7	8	X
7	Medium	Heavy	Residential	Wet Mountainous	X	5	8	X	10
8				Dry Flat	X	2	4	7	10
9			Agricultural	Dry Flat	X	3	5	7	10
10		Light	Residential	Wet Mountainous	X	6	10	X	8
11				Dry Flat	6	4	5	8	10
12			Agricultural	Dry Flat	7	5	6	8	10
13	Medium	Medium	Residential	Wet Mountainous	X	6	8	X	10
14				Dry Flat	X	5	6	7	10
15			Agricultural	Dry Flat	8	5	6	8	10
16	High	Heavy	Residential	Dry Flat	X	2	4	7	10
17			Agricultural	Dry Flat	X	4	6	7	10
18		Light	Residential	Wet Flat	X	3	5	X	10
19			Agricultural	Dry Flat	X	5	6	8	10

APPENDIX B

FIELD DATA COLLECTED FOR THE VALIDATION OF RESEARCH

No	Road Name	District	Road Width (m)	Road Surfacing	Connection		Landuse	Density of Landuse	Bus Route	Buses /Day	Climatic Zone	Flooding	Terrain	Produces Served	No.of Civic Structures						Traffic (12 hr)	No.of Heavy vehicles per day
					Start	End									Schools	Temples	Hospitals	Other	Factories	Total		
1	Welankulama-wewaldhigiliya Rd	Anuradhapura	3	Asphalt	A/B class Rd	A/B Class Rd	Resident/Forest	Average	No	0	Dry	Never	Flat	None		2				2	292	12
2	Thalawa-Andaraweva Rd	Anuradhapura	5.25	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Average	yes	16	Dry	Sometimes	Flat	Paddy	2	2	1	3		8	1278	99
3	Senapura-Katiyawa Rd	Anuradhapura	3.5	Asphalt	A/B class Rd	C/D class Rd	Residenti/Agri	Average	yes	2	Dry	Sometimes	Flat	Paddy	1	2		1		4	1007	87
4	Athakada-Tonigala Rd	Anuradhapura	3.2	Asphalt	A/B class Rd	A/B Class Rd	Residenti/Agri	Low	yes	6	Dry	Never	Flat	Paddy	4	4				8	649	24
5	Welioya-Thammanawa Rd	Anuradhapura	3.2	Asphalt	C/D class Rd	A/B Class Rd	Residenti/Agri	Low	yes	6	Dry	Never	Flat	Paddy	4	3	1	2		10	963	17
6	Pothana-Ihalagama Rd	Anuradhapura	4.5	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Low	yes	6	Dry	Never	Flat	Vegetables		1				1	1071	49
7	Rambewa-Rathmalgahaweva Rd	Anuradhapura	3.75	Asphalt	A/B class Rd	A/B Class Rd	Residenti/Agri	Low	yes	4	Dry	Never	Flat	Paddy	2	2		1		5	927	31
8	Athakada-Maligasweva Rd	Anuradhapura	2.2	Metal & Tar	A/B class Rd	A/B Class Rd	Residenti/Agri	Low	yes	4	Dry	Sometimes	Flat	Paddy/veg	1	1				2	475	8
9	South channel bund Rd	Anuradhapura	3	Metal & Tar	A/B class Rd	C/D class Rd	Residenti/Agri	Average	yes	4	Dry	Never	Flat	Paddy	1	1		1		3	348	7
10	Left channel bund Rd	Anuradhapura	3.75	Metal & Tar	A/B class Rd	C/D class Rd	Residenti/Agri	Low	No	0	Dry	Frequently	Flat	Paddy		1				1	520	9
11	Ihalagama-Thurukkurgama Rd	Anuradhapura	3.2	Gravel	C/D class Rd	C/D class Rd	Agri/Forest		No	0	Dry	Sometimes	Flat	Paddy	1	2				3	185	0
12	Kalanchiya-Kapirikkagama Rd	Anuradhapura	3.8	Asphalt	C/D class Rd	C/D class Rd	Residenti/Agri	Low	yes	6	Dry	Sometimes	Flat	Paddy/veg	1	3				4	808	33
13	Seppukulama-Pothana Rd	Anuradhapura	3	Gravel	C/D class Rd	C/D class Rd	Agri/Forest		No	0	Dry	Never	Flat	Paddy						0	243	4
14	Eriyagama-Adiranigama Rd	Anuradhapura	3.5	Metal & Tar	A/B class Rd	A/B class Rd	Residenti/Agri	Low	No	0	Dry	Never	Flat	Paddy	1	1				2	823	25
15	Katukaliyawa Rd	Anuradhapura	3.5	Asphalt	C/D class Rd	Other Rd	Res/Agri/Forest	Low	yes	6	Dry	Never	Flat	Paddy/veg	2	3				5	198	7
16	Seppukulama-Galenbindunuweva Rd	Anuradhapura	4.5	Asphalt	A/B class Rd	C/D class Rd	Res/Agri/Forest	Average	yes	12	Dry	Never	Flat	Paddy	2	2	1	2		7	1234	77
17	Eppawala-Nellikulama Rd	Anuradhapura	4.5	Asphalt	A/B class Rd	Other Rd	Residential	Average	yes	6	Dry	Never	Flat	None	1	2		3		6	810	43
18	Kirigollewa-Hirillugama Rd	Anuradhapura	3	Asphalt	A/B class Rd	A/B class Rd	Res/Agri/Forest	Low	yes	8	Dry	Never	Flat	Paddy/veg	2	2		1		5	944	26
19	Navatkulam-Maraiyadithakulam Rd	Vavuniya	3	Gravel	C/D class Rd	C/D class Rd	Agri/Forest		yes	4	Dry	Sometimes	Flat	Veg	2	1				3	411	5
20	Santhasoolai to Mahakachchakodiya Rd	Vavuniya	3	Gravel	A/B class Rd	Other Rd	Agri/Forest		No	0	Dry	Sometimes	Flat	Veg/Fruits		1				1	238	3
21	Sinnaputhukulam Rd	Vavuniya	3.5	Metal & Tar	A/B class Rd	C/D class Rd	Residenti/Agri	Average	yes	7	Dry	Sometimes	Flat	Paddy	4	3		2		9	978	28
22	Mahilankulam-Pallamadhu Rd	Vavuniya	3.2	Metal & Tar	A/B class Rd	A/B class Rd	Residenti/Agri	Low	yes	12	Dry	Never	Flat	Paddy	2	2				4	986	23
23	Omanthai-Elamaruthankulam Rd	Vavuniya	4	Gravel	A/B class Rd	C/D class Rd	Residenti/Agri	Low	yes	4	Dry	Sometimes	Flat	Paddy				1		1	350	8
24	Madukande-Ireperiyakulam Rd	Vavuniya	3.2	Metal & Tar	A/B class Rd	A/B class Rd	Residenti/Agri	Low	yes	10	Dry	Never	Flat	Paddy/veg	3	5	1	1		10	753	19
25	Koolankulam-Maraillupaikulam Rd	Vavuniya	2.3	Gravel	C/D class Rd	C/D class Rd	Agri/Forest		No	0	Dry	Sometimes	Flat	Paddy						0	268	0
26	Kalnatinakulam-Asikulam Rd	Vavuniya	2.5	Metal & Tar	C/D class Rd	C/D class Rd	Residenti/Agri	Low	yes	7	Dry	Never	Flat	Paddy	2	3		1		6	446	11
27	Malikai-Chemamadu Rd	Vavuniya	2.8	Gravel	C/D class Rd	C/D class Rd	Agri		yes	4	Dry	Sometimes	Flat	Paddy/veg		1	1			2	324	6
28	Elamaruthankulam-Samalankulam Rd	Vavuniya	2.5	Gravel	C/D class Rd	Dead End	Res/Agri/Forest	Low	yes	4	Dry	Sometimes	Flat	Veg	1					1	178	5
29	Pandikeithakulam-Maraiyadiyhakulam Rd	Vavuniya	2.5	Gravel	C/D class Rd	A/B Class Rd	Forest		yes	2	Dry	Sometimes	Flat	None						0	297	3
30	Rambaikulam-Palamoddai Rd	Vavuniya	3.5	Metal & Tar	A/B class Rd	C/D class Rd	Residenti/Agri	Low	yes	4	Dry	Never	Flat	Paddy/veg	1	1				2	371	15
31	Weligama-Imaduwa Rd	Matara	4.5	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	High	yes	12	Wet	Sometimes	Flat	Paddy	1	1		1		3	1321	79
32	Jaburagoda-Koledanda Rd	Matara	3	Concrete	A/B class Rd	C/D class Rd	Residenti/Agri	Low	No	0	Wet	Never	Flat	Paddy						0	1215	12
33	Panchaliya-Borala Rd	Matara	4	Asphalt	Other Rd	Other Rd	Resident/Forest	Low	yes	6	Wet	Never	Flat	None	1		1	1		3	824	21
34	Ibbawala-Panchaliya-Andugoda Rd	Matara	4	Asphalt	Other Rd	Other Rd	Residenti/Agri	Average	yes	0	Wet	Never	Flat	Paddy/Other	1	1				2	1210	14
35	Ibbawala-Ranamaduragama Rd	Matara	3	Asphalt	Other Rd	Other Rd	Residenti/Agri	Low	No	0	Wet	Never	Flat	Other				1		1	357	0
36	Wellawatta-Kammmalgoda Rd	Matara	4	Asphalt	A/B class Rd	A/B Class Rd	Residenti/Agri	Low	No	0	Wet	Sometimes	Flat	Paddy/Coconut	1	1				2	577	5
37	Jaburagoda-Koledanda Rd	Matara	4.5	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Low	yes	5	Wet	Never	Flat	Paddy		1	1	1		3	1013	54
38	Kananke P.S - Dewalagoda Rd	Matara	2.8	Metal & Tar	A/B class Rd	Other Rd	Residenti/Agri	Low	No	0	Wet	Never	Flat	Paddy/Tea	2	2				4	419	11
39	Welipitiya-Udukawa Rd	Matara	4	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Low	yes	8	Wet	Never	Rolling	Paddy/Tea	1		1	3		5	1215	67
40	Welipitiya-Moonamalpa Rd	Matara	3.5	Asphalt	A/B class Rd	A/B class Rd	Residenti/Agri	Low	No	0	Wet	Never	Flat	Paddy			1			1	856	31
41	Pallala Rd	Matara	3	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Low	No	0	Wet	Never	Flat	Paddy	1	1		1		3	279	0
42	Pangirihena-Mayakaduwa Rd	Galle	3.5	Metal & Tar	A/B class Rd	A/B class Rd	Residenti/Agri	Average	yes	4	Wet	Sometimes	Rolling	Paddy/Tea	2	2	1	1		6	995	68
43	Pitapola Rd	Badulla	2.5	Metal & Tar	A/B class Rd	Other Rd	Resident/Forest	Low	yes	8	Wet	Never	Mountain	None				1		1	277	12
44	Taldena-Hunuketapitiya-Egodawela Rd	Badulla	3	Metal & Tar	A/B class Rd	Other Rd	Res/Agri/Forest	Low	yes	6	Wet	Never	Rolling	Paddy/Milk				2		2	223	9
45	Soranathota Rd	Badulla	3.8	Asphalt	A/B class Rd	Dead End	Resident/Forest	Low	yes	10	Wet	Never	Mountain	Other	1	1				2	834	15
46	Madapathana Rd	Badulla	3	Concrete	A/B class Rd	Other Rd	Resident/Forest	Average	No	0	Wet	Never	Mountain	None	1	1				2	385	0
47	Hinnaragolla-Pitapola Rd	Badulla		Asphalt	A/B class Rd	Other Rd	Res/Agri/Forest	Low	yes	6	Wet	Never	Mountain	Tea/Vegetble	2	2		1		5	833	9

48	Etampitiya-Dehiwinna Rd	Badulla		Metal & Tar	A/B class Rd	A/B Class Rd	Res/Agri/Forest	Low	yes	6	Wet	Never	Mountain	Tea/veg	1	1		1		3	223	9
49	Etampitiya-Ketawala-Keenakale Rd	Badulla	3.2	Asphalt	A/B class Rd	Other Rd	Agri/Forest		yes	4	Wet	Never	Mountain	Tea				3		3	817	8
50	Etampitiya-Abewela-Maligathenna Rd	Badulla	3	Metal & Tar	A/B class Rd	A/B Class Rd	Agricultural		yes	4	Wet	Never	Mountain	Tea						0	891	21
51	Ketawala-Haliela Rd	Badulla	4	Asphalt	A/B class Rd	Other Rd	Res/Forest	Average	yes	10	Wet	Never	Flat	Paddy/Other	2	2		2		6	932	16
52	Pitaweliya Rd	Badulla	2.25	Concrete	A/B class Rd	Dead End	Residential	High	No	0	Wet	Never	Mountain	None	1					1	125	0
53	Keppetipola Rd	Badulla	3.5	Metal & Tar	A/B class Rd	A/B Class Rd	Residential	High	No	0	Wet	Never	Flat	None	2			3		5	406	0
54	Kalupahana-Ohiya Rd	Badulla	2.2	Metal & Tar	A/B class Rd	A/B Class Rd	Agri/Forest		No	0	Wet	Never	Mountain	Other						0	851	17
55	Haldummulla-sorunge-Nikapotha Rd	Badulla	3.2	Asphalt	A/B class Rd	Other Rd	Res/Agri/Forest	Low	yes	12	Wet	Never	Mountain	Other	2	2	1	4		9	875	23
56	Tambapillai Ave	Badulla	2	Metal & Tar	A/B class Rd	Dead End	Agricultural		No		Wet	Never	Mountain	Tea						0	59	0
57	Diyathalawe-Yahalabedda Rd	Badulla	3	Asphalt	A/B class Rd	A/B class Rd	Agricultural		yes	16	Wet	Sometimes	Flat	Tea	1	1		1		3	818	22
58	Moragolla Rd	Badulla	2.25	Asphalt	A/B class Rd	A/B class Rd	Residenti/Agri	Average	yes	16	Wet	Never	Mountain	Tea	2	2				4	1263	29
59	Galedanda Rd	Badulla	3	Asphalt	A/B class Rd	A/B class Rd	Res/Agri/Forest	Low	yes	12	Wet	Never	Mountain	Tea	2	1				3	594	18
60	Mapanawatura Rd	Kandy	3.2	Asphalt	A/B class Rd	Other Rd	Residential	Average	yes	6	Wet	Never	Mountain	None				2		2	1032	43
61	Rangala Rd	Kandy	3.8	Asphalt	A/B class Rd	Other Rd	Res/Agri/Forest	Low	yes	16	Wet	Never	Mountain	Paddy/Coconut	1	2				3	1265	83
62	Karaliyadda-puthuhapuwa-werapitiya Rd	Kandy	3.8	Asphalt	A/B class Rd	Other Rd	Resident/Forest	Average	yes	14	Wet	Never	Mountain	Spices	2	1		2		5	1040	65
63	Victoria Golf club Rd	Kandy	3.8	Asphalt	A/B class Rd	Dead End	Resident/Forest	Average	yes	10	Wet	Never	Mountain	Other	1	2		2		5	1678	95
64	Milco Rd	Kandy	4.5	Asphalt	A/B class Rd	Other Rd	Resident/Industrial	High	No	0	Wet	Never	Flat	Milk	2	2	1	3	1	9	1345	78
65	Menikhinna-Kengalla Rd	Kandy	3.5	Asphalt	A/B class Rd	A/B Class Rd	Residential	High	yes	10	Wet	Sometimes	Rolling	Fruits	1	1		2		4	989	39
66	Aswalapitiya Rd	Kandy	2	Concrete	A/B class Rd	Dead End	Residenti/Agri	Average	No	0	Wet	Sometimes	Mountain	Vegetables						0	438	0
67	Moragahapitiyawatte Rd	Kandy	3	Metal & Tar	A/B class Rd	A/B Class Rd	Resident	High	No	0	Wet	Never	Rolling	None	1					1	594	3
68	Uratiyagahawatte Rd	Kandy	2.2	Concrete	A/B class Rd	Dead End	Resident	High	No	0	Wet	Never	Rolling	None						0	191	0
69	Nittawela Rd	Kandy	3.8	Asphalt	A/B class Rd	A/B Class Rd	Resident	Average	No	0	Wet	Never	Mountain	None	2	2		1		5	1982	29
70	Thurunusavigama Rd	Kandy	3.2	Asphalt	A/B class Rd	Other Rd	Resident	High	No	0	Wet	Never	Flat	None	2			3		5	1567	45
71	Mosque Rd	Kandy	3.2	Metal & Tar	A/B class Rd	Dead End	Residenti/Agri	Average	No	0	Wet	Never	Rolling	Vegetables	1	1		2		4	1129	41
72	Udamaluwa Rd	Kandy	3	Metal & Tar	A/B class Rd	Dead End	Forest		No	0	Wet	Never	Flat	None				3		3	434	13
73	Ampitiya-Gurudeniya Rd	Kandy	3.6	Asphalt	A/B class Rd	A/B Class Rd	Resident/Forest	Average	yes	8	Wet	Never	Mountain	None	1	1		1		3	711	19
74	Ampitiya-Ratemulla Rd	Kandy	3.2	Metal & Tar	A/B class Rd	Other Rd	Resident/Forest	Low	No	0	Wet	Never	Mountain	None		2		2		4	698	5
75	Polwatta Rd	Kandy	2	Concrete	A/B class Rd	Dead End	Residential	High	No	0	Wet	Never	Flat	None		1				1	172	0
76	Meekanuwa Rd	Kandy	4	Asphalt	A/B class Rd	Dead End	Resident/Forest	Low	yes	10	Wet	Never	Mountain	Tea	1	1	1	1		4	638	20
77	Dangolla Rd	Kandy	3.2	Asphalt	A/B class Rd	Other Rd	Resident/Forest	Low	yes	6	Wet	Never	Mountain	Coconut		1		1		2	1598	37
78	Edanduwava Rd	Kandy	2	Concrete	A/B class Rd	A/B Class Rd	Residential	Average	No	0	Wet	Never	Mountain	None						0	178	0
79	Edanduwava Rd	Kandy	2.5	Metal & Tar	A/B class Rd	A/B Class Rd	Residential	Average	No	0	Wet	Never	Mountain	None	1	1	1	2		5	178	0
80	Galwala Rd	Kandy	2.5	Asphalt	A/B class Rd	Other Rd	Residential	High	yes	6	Wet	Never	Rolling	None				2		2	1217	40
81	Kiribathkubura-Diyapalagoda Rd	Kandy	5	Asphalt	A/B class Rd	Other Rd	Residenti/Agri	Average	yes	16	Wet	Never	Rolling	Paddy	1	2		4		7	1945	57
82	Owala-Pinnagolla Rd	Kandy	2.2	Metal & Tar	A/B class Rd	Other Rd	Residential	High	No	0	Wet	Never	Mountain	None		1				1	637	15
83	Gonnoruwa-Muruthalawa Rd	Kandy	4	Asphalt	A/B class Rd	Dead End	Residential	Average	yes	14	Wet	Never	Rolling	Paddy/Fruits	1	1		1		3	2024	94
84	Estate Rd	Galle	3.5	Asphalt	A/B class Rd	Other Rd	esident/Indust/Ag	Average	No	0	Wet	Never	Flat	Other	1	1	1	2	2	7	1301	71
85	Kettarama Rd	Galle	3	Asphalt	A/B class Rd	A/B Class Rd	Residential	Average	No	0	Wet	Never	Flat	Paddy/Spices	1	2		1	1	5	562	8
86	Sri Saranapala Mw	Galle	3	Metal & Tar	A/B class Rd	Other Rd	Residential	Average	No	0	Wet	Sometimes	Flat	None		1		1		2	487	4
87	Cemetry Rd	Galle	2.3	CBP	A/B class Rd	Dead End	Residential	Low	No	0	Wet	Sometimes	Flat	Tea				1		1	183	0
88	Ambagahawatta Rd	Colombo	2.2	CBP	A/B class Rd	Dead End	Residential	High	No	0	Wet	Frequently	Flat	None						0	351	3
89	Herman Meigner Rd	Colombo	3.5	Metal & Tar	A/B class Rd	Other Rd	Residential	High	No	0	Wet	Never	Flat	None	1	1		1		3	891	11
90	Madanwila Rd	Colombo	3.5	Asphalt	A/B class Rd	Other Rd	Residential	High	No	0	Wet	Never	Flat	None	1		1			2	1767	60
91	Attygalle Housing lane	Colombo	3.2	Metal & Tar	A/B class Rd	Dead End	Residential	High	No	0	Wet	Sometimes	Mountain	None						0	832	0
92	Sarvodaya Rd	Colombo	3	Metal & Tar	A/B class Rd	Dead End	Residential	Average	No	0	Wet	Sometimes	Flat	None		1				1	573	0
93	Dewala Rd	Colombo	3.8	Asphalt	A/B class Rd	A/B Class Rd	esident/commercia	High	No	0	Wet	Sometimes	Flat	None	2	1		1		4	1844	76
94	Gangabada Rd	Colombo	3.8	Asphalt	A/B class Rd	Other Rd	Residential	High	No	0	Wet	Sometimes	Flat	None	1	1				2	1932	81
95	Church Rd	Colombo	3	Asphalt	A/B class Rd	Other Rd	Residential	Average	yes	10	Wet	Never	Flat	None	1	3				4	2735	46

APPENDIX C

SAMPLE COMPLETED FIELD DATA SURVEY FORMS

Questionnaire- Pavement Type selection Framework for Low Volume Roads

This survey is designed to collect primary information on Traffic volume, Traffic composition, Land use, Terrain and climate characteristics of the low volume road network. This information will be used to develop a framework to select pavement types for low volume roads.The information obtained from this survey will not be used in anyway that will disclose the identity of any individual.Thankyou in advance for your time and cooperation.

Road Name	Cemetry road		
District	Galle	DS Division(s)	Yakkalamulla
Date	DD MM YY: 17 03 16	Enumerator	Deshan

Part A: General Information about the Road

A1. Length (km)	1.5 km	A2. Width (m)	2.3 m

A3. Road Surfacing material(Mark x)

1	Gravel		2	Metal & Tar		3	Concrete Blocks	✓	4	Concrete		5	Asphalt Concrete	

A4. From	Nakiadeniya Junction	A5. To	Nakiadeniya Cemethy

A6. Connection to Existing Roads (Mark x)

	Connection	Start	End
1	National Road (A or B Class)	✓	
2	National Road (C or D Class)		
3	Pradeshiya Saba Road		
4	Other Minor Road		
5	Dead End		✓

A7. Land Use pattern (Mark x where appropriate)

	Land Use	Along the road	Start	End
1	Residental	✓	✓	
2	Commercial			
3	Industrial			
4	Agricultural			
5	Forest			✓

A8. If answer to A7 is 1 or 2, density of landuse?

1	High		2	Average		3	Low ✓

A9. Is this a bus route? If answer is yes go to A10. Otherwise Go to Section B

1	Yes	
2	No	✓

A10. Number of buses operate during one day	—

Part B: Detail Information of the Road

B1. Climatic zone

1	Wet	✓	2	Dry		3	Intermeadiate	

B2. Are there any flooding in rainy periods?

1	Frequently		2	Sometimes	✓	3	Rarely		4	Never	

B3. Road Condition

1	Good		2	Average	✓	3	Bad		4	Impassable	

B4. Year of last rehabilitation/ Major repair	2009

B5. Terrain of the area served by the road

1	Flat	✓	2	Rolling		3	Mountain	

B6. History of Exposure to other Natural Disasters

1	Droughts		2	Cyclones		3	Tsunami	
4	Wild Fire		5	Land Slides		6	Other	

Part C: Social & Natural Environment

C1. Produces in the area served by the road

1	Paddy		2	Tea	✓	3	Fish		4	Coconut	
5	Vegetable		6	Fruits		7	Spices		8	Other	

C2. Other products / Services (specify)	–

C3. Does this road provide access to the following?

1	Tourism		2	Raw Material		3	Markets		4	Construction	

C4. Number of civic centres/Factories served by the road

1	Schools/Technical colleges/Universities	–	2	Hospitals/ Dispensary	–
3	Temples/Kovils/Mosques/Churches	–	4	Banks/Post Offices/Police Stations	–
5	Government Offices (Cemetry)	01	6	Factories	–

Part D: Traffic and Roughness Charactristics

D1. 12 hour Traffic Volume(Vpd)	183	**D2. No. of Heavy vehicles per day**	–
D3. Average Speed of the Vehicle(Km/h)	25	**D4. Average Resultant acceleration(m/s^2)**	

Other Comments:

Questionnaire- Pavement Type selection Framework for Low Volume Roads
This survey is designed to collect primary information on Traffic volume, Traffic composition, Land use, Terrain and climate characteristics of the low volume road network. This information will be used to develop a framework to select pavement types for low volume roads.The information obtained from this survey will not be used in anyway that will disclose the identity of any individual.Thankyou in advance for your time and cooperation.

Road Name	Kiribathkubura - Diyapalagoda road			
District	Kandy	DS Division(s)	Yatinuwara	
Date	D D M M Y Y 0 2 0 1 1 6	Enumerator	Deshan	

Part A: General Information about the Road

A1. Length (km)	3.20 km	A2. Width (m)	5.0 m

A3. Road Surfacing material(Mark x)

1	Gravel		2	Metal & Tar		3	Concrete Blocks		4	Concrete		5	Asphalt Concrete	✓

A4. From	Kiribathkubura	A5. To	Diyapalagoda

A6. Connection to Existing Roads (Mark x)

	Connection	Start	End
1	National Road (A or B Class)	✓	
2	National Road (C or D Class)		
3	Pradeshiya Saba Road		
4	Other Minor Road		✓
5	Dead End		

A7. Land Use pattern (Mark x where appropriate)

	Land Use	Along the road	Start	End
1	Residental		✓	✓
2	Commercial			
3	Industrial			
4	Agricultural	✓		✓
5	Forest			

A8. If answer to A7 is 1 or 2, density of landuse?	1	High		2	Average	✓	3	Low	

A9. Is this a bus route? If answer is yes go to A10. Otherwise Go to Section B	1	Yes	✓
	2	No	

A10. Number of buses operate during one day	(Dekianga - Kandy Bus) 16

Part B: Detail Information of the Road

(Once in ½ hour in morning & evening)

B1. Climatic zone

1	Wet	✓	2	Dry		3	Intermeadiate	

B2. Are there any flooding in rainy periods?

1	Frequently		2	Sometimes		3	Rarely		4	Never	✓

B3. Road Condition

1	Good	✓	2	Average		3	Bad		4	Impassable	

B4. Year of last rehabilitation/ Major repair	2014

B5. Terrain of the area served by the road

1	Flat		2	Rolling	✓	3	Mountain	

B6. History of Exposure to other Natural Disasters

1	Droughts		2	Cyclones		3	Tsunami	
4	Wild Fire		5	Land Slides		6	Other	

Part C: Social & Natural Environment											
C1. Produces in the area served by the road											
1	Paddy	✓	2	Tea		3	Fish		4	Coconut	
5	Vegetable		6	Fruits		7	Spices		8	Other	
C2. Other products / Services (specify)			—								
C3. Does this road provide access to the following?											
1	Tourism		2	Raw Material		3	Markets	✓	4	Construction	✓ (Sierra Yard)

C4. Number of civic centres/Factories served by the road					
1	Schools/Technical colleges/Universities	01	2	Hospitals/ Dispensary	
3	Temples/Kovils/Mosques/Churches	02	4	Banks/Post Offices/Police Stations	02
5	Government Offices	02	6	Factories	

Part D: Traffic and Roughness Charactristics			
D1. 12 hour Traffic Volume(Vpd)	1945	D2. No. of Heavy vehicles per day	57
D3. Average Speed of the Vehicle(Km/h)	32	D4. Average Resultant acceleration(m/s^2)	
Other Comments:			

Questionnaire- Pavement Type selection Framework for Low Volume Roads

This survey is designed to collect primary information on Traffic volume, Traffic composition, Land use, Terrain and climate characteristics of the low volume road network. This information will be used to develop a framework to select pavement types for low volume roads.The information obtained from this survey will not be used in anyway that will disclose the identity of any individual.Thankyou in advance for your time and cooperation.

Road Name	Attygalle Housing lane			
District	Colombo	DS Division(s)	Kesbawa	
Date	D D M M Y Y: 0 4 1 2 1 5	Enumerator	Deshan	

Part A: General Information about the Road

A1. Length (km)	-	A2. Width (m)	3.2m

A3. Road Surfacing material(Mark x)

1	Gravel		2	Metal & Tar	✓	3	Concrete Blocks		4	Concrete		5	Asphalt Concrete	

A4. From		A5. To	

A6. Connection to Existing Roads (Mark x)

	Connection	Start	End
1	National Road (A or B Class)	✓	
2	National Road (C or D Class)		
3	Pradeshiya Saba Road		
4	Other Minor Road		
5	Dead End		✓

A7. Land Use pattern (Mark x where appropriate)

	Land Use	Along the road	Start	End
1	Residental	✓	✓	✓
2	Commercial			
3	Industrial			
4	Agricultural			
5	Forest			

A8. If answer to A7 is 1 or 2, density of landuse?	1	High	✓	2	Average		3	Low	

A9. Is this a bus route? If answer is yes go to A10. Otherwise Go to Section B

1	Yes	
2	No	✓

A10. Number of buses operate during one day

Part B: Detail Information of the Road

B1. Climatic zone

1	Wet	✓	2	Dry		3	Intermeadiate	

B2. Are there any flooding in rainy periods?

1	Frequently		2	Sometimes	✓	3	Rarely		4	Never	

B3. Road Condition

1	Good		2	Average		3	Bad	✓	4	Impassable	

B4. Year of last rehabilitation/ Major repair	2009

B5. Terrain of the area served by the road

1	Flat		2	Rolling		3	Mountain	✓

B6. History of Exposure to other Natural Disasters

1	Droughts		2	Cyclones		3	Tsunami	
4	Wild Fire		5	Land Slides		6	Other	

Part C: Social & Natural Environment											
C1. Produces in the area served by the road											
1	Paddy		2	Tea		3	Fish		4	Coconut	
5	Vegetable		6	Fruits		7	Spices		8	Other	
C2. Other products / Services (specify)		—									
C3. Does this road provide access to the following?											
1	Tourism		2	Raw Material		3	Markets		4	Construction	

C4. Number of civic centres/Factories served by the road					
1	Schools/Technical colleges/Universities		2	Hospitals/ Dispensary	
3	Temples/Kovils/Mosques/Churches		4	Banks/Post Offices/Police Stations	
5	Government Offices		6	Factories	

Part D: Traffic and Roughness Charactristics			
D1. 12 hour Traffic Volume(Vpd)	832	D2. No. of Heavy vehicles per day	—
D3. Average Speed of the Vehicle(Km/h)	23	D4. Average Resultant acceleration(m/s^2)	

Other Comments:

Potholes ✓