Development of a Methodology for Pavement Maintenance Optimization and Prioritization for Provincial Road Network in Sri Lanka

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DECLARATION

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ABSTRACT

Pavement management system is a decision support system that is used by highway agencies to maintain its road networks, extending their useful life within the available budget and resource constraints. Methodology of selecting maintenance strategies for authorities is an integral component of the pavement management system. Most current systems cannot be customized to reflect the local conditions with resources available and required extensive data collection and calibration, which are not sustainable for those authorities especially in developing countries. Thus, the identification of new approaches, which have been suited for the relevant factors in developing countries in pavement management, is a major requirement.

The study focused on the existing pavement management systems, first it aims to identify the main constraints that affect the pavement maintenance planning and for formulation of the maintenance strategy in road agencies at provincial level. The main constraints and priority factors were identified by the opinion survey from the Engineers of road agencies. Based on the opinion survey five main priority factors were finalized namely pavement condition, traffic volume, connectivity to local road network, land use pattern and importance to community.

An optimization model was developed to maximize the overall network condition whilst incorporating the priority factors identified in the study. Priority index of each pavement sections computed from the prioritization model is incorporated to optimization model. The proposed model is capable of determining the optimum maintenance activities for each road sections considering the budgetary, network condition and road section priority considerations. Applicability of the proposed model is illustrated using a case study consists with pavement sections with different attributes. Results from a case study using the proposed method show that the suggested maintenance and rehabilitation plans make sense from engineering and socio-economic considerations.

Keywords: Pavement management systems, Pavement Maintenance, Optimization, Prioritization

DEDICATION

To My Loving Parents for Their Guidance for Success in My Life

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1 INTRODUCTION

1.1 Background

Roads are an integral part of the transport system. Transport aims at meeting the present and future demand for the transportation of passengers and goods ensuring quality, safety and affordability. Road transportation is the main facilitator for passenger transport and freight activity representing more than 90 percent of both sectors. (Annual report, ministry of finance, 2016). Rate of pavement deterioration is increased drastically with the rapid increase of road network usage and low improvement of roads (Annual report, ministry of finance, 2016). Table 1.1 represents the percentage increase of total vehicles and total road length considering 2011 as the based year.

Table 1.1 : Percentage Increase of Total Vehicles and Road Length

	2011	2012	2013	2014	2015	2016
Total vehicles %	0	8.87	16.16	25.75	40.68	51.69
Total road length %	0	0.43	0.97	2.40	1.87	3.31

Source: Annual Report (Ministry of Finance, 2016)

With the expansion of the total vehicles and small increment of road network length, traffic load is expanded and caused a large deterioration in roads. Therefore, authorities need to allocate more resources to ensure the road network is maintained at the desired condition. This is critical to ensure the road user benefits such as high mobility, safety and low operating costs achieved from a new road is sustained throughout the pavement's asset life, which will ensure that the economic benefits from the investments are achieved. If, however, the road network is poorly maintained, social and economic benefits to the society decreased significantly and prompting higher vehicle operating costs and delays due low speeds on deteriorated roads and increase in road accidents.

Due to traffic and environmental influences, all road surfaces will deteriorate over time. The selection and timing of maintenance activities is an important aspect of maintaining the cost-effectiveness of the pavement life cycle. Using the right maintenance treatment at the right time will help you get the most benefit. This depends in part on the condition of the road surface and the life cycle of the road. if early processing is applied more frequently, the overall cost will be smaller if the pavement is repaired earlier than later. When the road surface is in good condition, the price is much lower than the treatment cost after the deterioration of the road surface is accelerated.

Considering the constraints faced by road authorities due limited capital allocation, technical and manpower limitation and socio-economic factors, maintaining the road network has become a very complex task. Lack of funding and other resources leads to poor maintenance level of the roads and lack of consideration of the socio-economic factors will result in improper prioritization of the maintenance activities. This is especially valid in the provincial and local road networks. Therefore, a systematic approach is needed to plan the maintenance program of the road network, taking into consideration the budget and other resource constraints and socio-economic factors in the area. Moreover, the pavement maintenance management system should be implementable at the provincial highway agency level, taking into account the resource constraints prevailing in those institutions.

Over the years, pavement management systems have been utilized in road agencies to enhance maintenance management activities, provide the information needed to support the decision-making process and compare long-term impacts on alternative strategies. Pavement management is a fundamental part of the asset management of the road agencies and an important tool for large-scale investment in the economic and effective management. Each pavement maintenance system aims to increase the efficiency of repairing and treatment of pavements through utilizing the existing funds in their maximum benefits. Pavement maintenance management framework is regarded as “a basic methodology to reduce the road deterioration rate, protect the safety of road users improve the service life of the road surface, and the road quality” (Shafik and Mehar, 2005).

PMSs have been utilized by several road agencies to exhibit the cost-viability of pavement maintenance strategies that incorporate both prioritization and optimization of pavement maintenance. However, since most PMS do not fully incorporate maintenance prioritization process to the analysis, there is limited success for institutions expanding the use of PMS to support maintenance programs. Therefore, in pavement maintenance management, it is important to consider both optimization and prioritization techniques simultaneously to determine the best maintenance strategy.

The priority setting or sorting procedure is utilized as a part of PMS aims to sort the road sections in an urgent order of maintenance and repair. The significance of the prioritization procedure in PMS comes from the fact that it is one of the main steps before the final decision to implement the program. The quality of priority settings can specifically impact the viability of available resources. (Sharaf, 1993).

Prioritization is a methodical procedure that determines the best ranking list of candidate pavement segments for maintenance in view of particular criteria such as road conditions, traffic levels, land use patterns, connection to existing roads and the overall importance of the road section to the community etc. Different strategies and approaches are utilized for prioritization of pavement segments for maintenance from a simple list based on engineering judgment to advanced mathematical formulas. Once the pavement segments are listed in their urgency of maintenance by prioritization then it is needed to find the relevant maintenance operation by optimization approaches according to the available budget and other relevant constraints.

Pavement maintenance optimization approaches incorporate mathematical models that focus on finding the ideal maintenance strategy which optimize the benefits for expenditures. Cost of corrective and preventative maintenance per year, and overall condition of the pavement sections are the frequently considered parameters in pavement maintenance optimization. Any basis for maintaining an optimization model depends on the underlying degradation process and failure behavior of the pavement segments

Optimization involves maximizing or minimizing an objective function of several binary, integer or real valued decision variables while satisfying equality or inequality constraints. (Farhan et. al., 2011). The optimization is capable of estimating total mileage of the pavements to be repaired by the relevant treatments to maintain the overall pavement network above an acceptable level of conditions, taking into account the availability of the budget (Bako et. al., 1995).

Although there are numerous strategies for Pavement Maintenance Optimization and Prioritization tools in the world, there is no proper strategy for Sri Lankan road agencies to follow. Thus, it is needed to develop a mechanism that provides optimizing resource allocations and prioritizing road sections for maintenance. In this research it is aimed to bridge this gap by developing a methodology for Pavement Maintenance Optimization and Prioritization for Provincial Road Network in Sri Lanka

1.2 Pavement Maintenance Management

A pavement management system is defined by AASHTO (American Association of State Highway and Transportation Officials) as “a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time” (Huang, 2004). Pavement optimization tool that can produce the best maintenance and rehabilitation strategy for the pavement network is a key component of the pavement management system.

As the pavement network covers many kilometers of roads, it cannot be managed through simple methods or individual experience, consequently a more extensive framework approach is required. Pavement maintenance management is a procedure which used to enhance the performance of the road network by maintaining the pavement sections in a preplanned manner. The method of selecting the maintenance strategy is the major component of the pavement maintenance management. The quality of pavement management process, which in most cases depends primarily on the judgment of the decision maker, can directly influence the effectiveness of the handling of available resources (Sharaf, 1993).

In order to develop the optimal maintenance strategy, different prioritization and optimization approaches are used by road agencies’ engineers. Prioritization involves ranking the pavement sections with respect to the identified set of factors by using subjective judgment or adopting quantitative techniques. Optimization approaches involve evaluation of all possible repair strategies to enhance the road condition while considering the budget constraints.

Pavement management decisions incorporated with three major levels, Strategic level, Network level and Project level. At the strategic level, decision makers settle on choices that impact long-term strategic efforts inside the organization. These decisions may incorporate setting performance goals, fund allocation and preservation strategies.

Decisions at the network level involve planning and policy issues for the entire network. These decisions incorporate with formulating pavement preservation policies, prioritizing, estimating funding needs, and allocating budgets for maintenance, repairs, and reconstruction (MR&R).

Project-level decisions involve the engineering and technical aspects of pavement management, which is the selection of site-specific MR&R actions for individual projects and task groups.

Comprehensive PMS includes components that help network and project-level decision making (Pavement management system overview). Main 3 modules of a pavement management system is represented as follows. This will be discussed in further in chapter 2. The decisions of the road authorities must be made within the scope of the current planned work. Moreover, it is vital to evaluate the cost of future treatment for the development of preservation and rehabilitation programs.

- Data base: - The database is the first building block of any management system, since the analysis used, and recommendations made by a management system should be based on reliable, objective, and timely (current) information.
- Analysis: - A variety of methods are available to analyze pavement performance and cost data to identify cost-effective MR&R treatments and strategies. “Treatment” refers to a single action selected to correct specific pavement deficiencies
- Feedback: - Pavement management systems, similar to any other engineering tool, must be reliable in order to be credible. The feedback process is crucial to verify and improve the reliability of a PMS.

1.3 Significance of the Study

Methodology of selecting maintenance strategies for road authorities is an integral component of the pavement management system. Most of the current systems cannot be customized to reflect the local conditions with resources availability. It is required extensive data collection and calibration, which are not sustainable for those authorities especially in developing countries. Since Sri Lanka is also a developing country, the identification of new approaches is essential and identification of relevant factors which have been suited for the in developing countries in pavement management is a major requirement.

1.4 Objectives of the Study

1. Review the current state of the practice at the provincial road agencies with respect to pavement management systems

   Identify the main constraints that affect the pavement maintenance planning in the provincial level road development authorities
2. Propose a methodology adopting optimization and prioritization models that can be used to assist the decision making for selecting roads for pavement maintenance, in the local context

1.5 Scope of the Study

Many factors are considered in any modeling process in pavement management, and a large number of sections of the pavement network are considered for evaluation. In the process of prioritization of road sections for maintenance, main priority factors were considered namely pavement condition, traffic volume, connectivity to local road network, land use pattern and importance to community. The form or structure of the priority weights used varies from road agency to agency. The study aims to develop a prioritization method considering identified five priority factors. Then priority factors are incorporated into an optimization model.

The proposed procedure presents an integrated prioritization and optimization approach using Analytical Hierarchy Process (AHP) and Integer Programming. This integrated prioritization and optimization approach is developed in the study to enable road agencies to select optimal maintenance strategy considering budgetary, network condition constraints as well as considering socio-economic factors which are reflected through priority factors of the roads.

2 LITERATURE REVIEW

2.1 Road Network in Sri Lanka

Sri Lanka has an extensive road network and it plays an important role in the economic development of the country. The country's production sector has a direct relationship with the road sector. Research shows that the present interest for passenger travel is around 80 billion traveler kilometers for each year. Out of this demand, 93 percent of the traveler kilometers are covered by the road transportation. Additionally, road transportation is the real facilitator for freight activity representing 97 percent of freight transport (Public investment program, ministry of national policies, 2017).

Therefore an effective transport system is a necessary prerequisite for a country's overall economic development. According to the National Road Master Plan (RDA 2007), the road network's density is among the highest in Asia. The international indicators are shown in Table 2.1 to compare the effectiveness of Sri Lankan Road network with Pakistan and Bangladesh in the year 2004.

Table 2.1 : Transport Network

Indicator	Sri Lanka	Bangladesh	Pakistan
Population Density	301	985	198
Road Density:			
*km/1000 people	5.91	2	1.69
*km/km^2 land	1.66	1.79	0.32

Source: Transport in South Asia (World Bank Report, 2016)

In Sri Lanka, Road classification is based on principle functions, geometrical standards, pavement conditions and traffic loads. Table 2.2 shows the variation in road length across the different provinces. Most roads in rural area are unpaved. North western province has the highest provincial road network when compared to the remaining provinces. Public Transportation is mainly based on the road network and Sri Lankan rural enterprises listed transportation as a major obstacle in beginning or operating a business. Provincial roads provide the necessary connectivity, linking national roads connecting consumer areas; and local roads linking rural agricultural production areas. Provincial roads also promoted Basic bus services ensure economic opportunities and inclusive growth "(Sri Lanka eastern and north central provincial road project).

Development of new roads according to the demand could not be achieved due to the financial constraints. Allocation of adequate financial resources to maintenance also becomes a problem with increasing demand for road usage.

Table 2.2 : Road Length According to Province

Province	National Roads	Provincial Roads	Rural Roads	
	Express way / Class A and B	Class C and D	Tarred	Concrete or Gravel
Western	1,699	1,952	6,696	13,336
Central	1,766	2,246	1,344	8202
Southern	1,575	1,630	2,820	9,323
Northern	1,258	2,120	1,067	7,139
Eastern	1,160	1,098	1,207	9,236
North Western	1,336	2,875	1,004	18,623
North Central	1,158	1,947	747	14,659
Uva	1,168	1,739	3,603	8,306
Sabaragamuwa	1,214	2,791	1,724	4,497
Total	12,340	18,397	20,215	93,326

Source :Public Investment Program report 2017-2020 (Department of National Planning, 2017)

Table 2.3 shows the corresponding length of lane type. Most cities and major connecting roads are still two-way single-lane highways.

Table 2.3 : Classification of National Roads According to Lane Type

Lane Type	Length
Multi lanes	335
Dual lanes	5,966
Intermediate lane	2,714
Single lane	3,325
Total	12,340

Source: Public Investment Program report 2017-2020

People’s travel demand is expanding gradually and hence the number of operating vehicles is increased. As well as the expanding industrial activities put an extra pressure to the road system and may prompt an expansion in yearly travel demand. As a result, the amount of maintenance required enhancing the road in acceptable condition and the pavement will require reconstruction or rehabilitation to strengthen it to carry the additional loading earlier in the useful life of the pavement. Table 2.4 shows the classification of motor vehicles and it is clear that number of vehicles in all categories expanding significantly.

Table 2.4 : Classification of Motor Vehicles

	2011	2012	2013	2014	2015	2016
Motor cars	4,479,732	4,877,027	5,203,678	5,633,234	6,302,141	6,795,469
Three Wheelers	468,168	499,714	528,094	566,874	672,502	717,674
Buses	88,528	91,623	93,428	97,279	101,419	104,104
Goods vehicles	311,510	323,776	329,648	334,769	341,911	349,474

Source : Annual Report (Ministry of Finance,2016)

Table 2.5 shows the variation of road condition as a percentage. 55% of the roads are in better condition in 2015 and when compare to the previous year it is a 1% increment. 36% of the roads are in bad condition.

Table 2.5 : Road Condition as per IRI as a Percentage

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Excellent %	7	7	11	16	23	24	29	27	27
Good %	28	23	24	27	23	29	36	27	28
Fair %	19	18	17	13	10	10	8	9	9
Poor %	36	41	37	33	26	17	13	16	16
Bad %	10	11	11	11	18	20	14	22	20

Source : Annual Report (Ministry of Finance, 2016)

2.2 Road Network Management Structure

In Sri Lanka, Pavement maintenance administration is divided into three levels. National highways which incorporate expressways and A & B class highways are managed by the road development authority (RDA). Provincial road development authorities have the responsibility in managing C and D class roads. Moreover, some organizations such as Local authorities, Department of Irrigation, Department of Wild Life Conservation manage some of unclassified roads. Road network management structure with the relevant functions are shown in Table 2.6

Table 2.6 : Road Network Management Structure

Type	Class	Designated Function	Administration
Express ways	E	Connecting major cities, Ports	Ministry of Highways and Road Development Authority
National Roads	A	Inter-provincial trunk roads connecting major cities	Ministry of Highways and Road Development Authority
	B	Intra-provincial arterial roads connecting major urban areas	
Provincial Roads	C	Major feeder roads and roads connecting settlements with markets	Provincial Road Development Authority of relevant Provincial Council
	D	Minor feeder roads & roads connecting settlements with markets, etc	
Local Authority Roads		Local roads providing access to specific locations	Municipal/Urban Council or Local Authority

Source :National Road Master Plan (RDA, 2007)

2.2.1 Provincial Road Authorities

Provincial Road Development Authorities are responsible for developing provincial road network to meet ongoing development plan. The functions performed by provincial road authorities are mainly to maintain and advancement of the Provincial Road Network, including C and D Class roads and the arranging, planning and development of new roads, bridges and other road structures to improve the current provincial road network. On the other hand, provincial road development agencies have the responsibility to provide road networks to meet people’s social desires in terms of mobility and safety. Since most people rely on public transportation to meet their travel needs, it is PRDA's responsibility to keep the provincial road network at a reasonable standard so that public transport can be used without interruption. The necessary funds for PRAD are provided by local authorities and the central government allocates funds. Since the restoration and development of the provincial road network is carried out at high cost using public funds, PRDA has the responsibility to ensure that sufficient investments are made to achieve sufficient economic benefits through provincial roads.

Functional divisions of PRDA

- Roads & Bridges Division
- Planning, Designing & Special Projects Division
- Administration Division
- Finance Division
- Mechanical Division
- Material Testing Division
- Internal Audit Division

2.3 Funding for Pavement Maintenance

Improvement and maintenance of the provincial road network has been severely influenced because of absence of sufficient funds. A large portion of the "C" and "D" roads should be renovated as quickly as funds available. Additionally, a considerable number of gravel roads have not been properly maintained and are in a bad condition

The central government allocates a higher percentage of all provincial budget requirements of the provincial council for regular and capital expenditures. The Central Government annually negotiates with the Finance Committee to allocate domestic and foreign funds for provincial development in the form of grants. Provincial councils prepare their regular and capital expenditures through consultation with the National Finance Committee then apply for grants through the state budget.

2.3.1 Types of Treasury Funding for Road Development

The following funding options are typically available.

- Domestic Funds
- Foreign aid loans
- Foreign aid related grants
- Reimbursable Foreign aid loans
- Foreign aid related domestic funds

The Provincial Road Development Authorities allocation of funds came from the Ministry of Finance, through the funds approved directly by the Finance Committee and the Provincial Council. In the urban areas, local taxes are insufficient to cover highway and capital maintenance costs, while regular maintenance is subsidized by the Ministry of Finance, but unfortunately this fund is insufficient

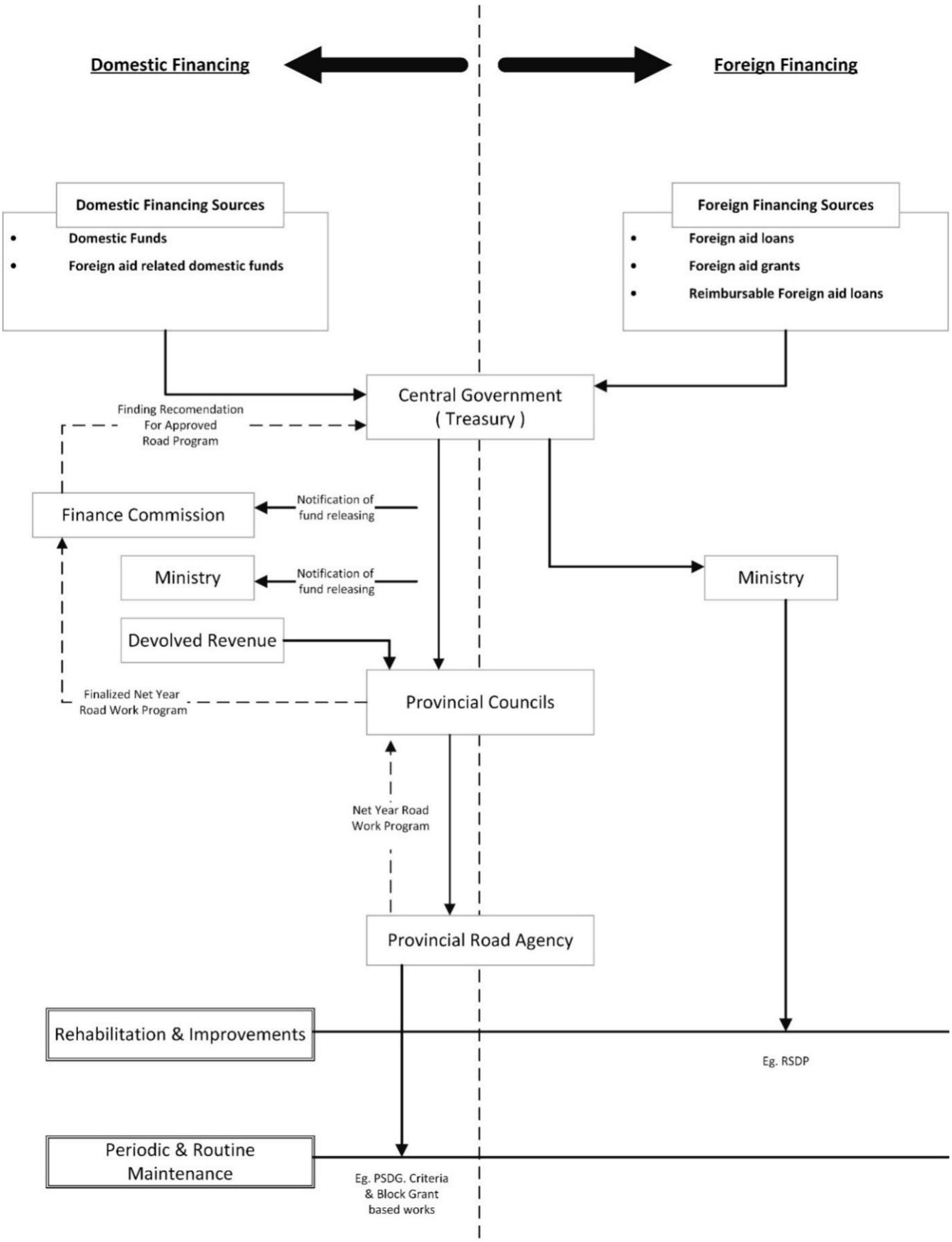

Figure 2.1 : Hierarchy Structure of Pavement Maintenance Prioritization

Source: Foreign Financing (Department of External Resources, 2016)

In the past few years, the funds being allocated to the PRDA for road construction, making improvements to the "C" and "D" roads, and attending to regular road maintenance have been diminishing. Regular negligence of road maintenance would intensify road conditions and increase maintenance costs

At present, there is a gap between investment and savings, and the country is relying more on foreign resources to implement development strategies for major infrastructure projects and other small and medium-sized projects. Road sector has the highest percentage of commitment by foreign financing. These projects are funded by multilateral and bilateral donor funds.

The Asian Development Bank is the major multilateral donor of the foreign aid commitment. Bilateral donors played a key role in large and small project financing. The Government of China and the Government of Japan are the two leading bilateral donors provided grants, loans and export credits to finance various development projects.

Table 2.7 : Foreign Financing Commitment

Bilateral	Multilateral	Export credits
China	Asian Development Bank	China
France	World Bank	Sweden
Germany	UN Agencies	Austria
Japan		United Kingdom
Korea		Norway
Sweden		
Sprain		
USA		

Source: Annual Report (Department of External Resources, 2016)

Although road density and the proportion of roads that are paved are higher in Sri Lanka than in many developing countries, many roads are highly congested and road conditions are inadequate to handle rapidly growing freight and passenger traffic effectively. In order to solve the serious backlog of maintenance work, it is necessary to establish a mechanism to provide predictable and reliable resource allocation for road maintenance and to ensure that the funds were paid for and properly used for maintenance in accordance with the maintenance plan.

Due to the scarcity of resources, need for an effective and efficient management system for pavement maintenance have become a real challenge for the local road authorities. This research aims to identify the factors affecting to pavement maintenance prioritization decision. This chapter describes the literature based on pavement maintenance management, optimization tools which are in current practice, Prioritization techniques and prioritization decision factors.

2.4 Pavement Maintenance Management

In pavement management, the motive of maintenance is to carry out protective and remedial measures to decelerate the pavement deterioration process, thereby extending the service life of the road. If the action is taken at the proper time in a pre-planned manner, the effectiveness of pavement maintenance is considerably accelerated (AASHTO, 2004; NCHRP, 2004).

Inside the beyond 30 years, the use of pavement management systems (PMS) in road improvement agencies has multiplied substantially and it have become a powerful and effective tool for managing the large investments related with the transportation infrastructure. The benefits of pavement management are encompassing,

- Improve the planning capability of maintenance at strategic, network and operational levels
- The ability to evaluate different treatment strategies based on different budget estimates or administration approaches.
- Provide maintenance and rehabilitation recommendations (Zimmerman et. al., 2011).

The main goal of the network-level pavement management system is to establish short-term and long-term budget requirements and to compile potential project lists based on a limited budget (Butt et. al., 1994). This research aims to fulfill the network level requirement of pavement maintenance which optimize the value of maintenance funds and provide the highest possible road quality for the allocated resources for provincial road agencies.

Primary components of pavement management system are categorized into three main sections; Database, Analysis and Feedback. Components under each category is represented as follows

Data	• Inventory: Physical pavement features including the number of lanes, length, width, surface type, functional classification, and shoulder information • History: Project dates and types of construction, reconstruction, rehabilitation, and preventive maintenance • Condition survey: Roughness or ride, pavement distress, rutting, and surface friction • Traffic: Volume, vehicle type, and load data • Data base: Compilation of all data files used in the PMS
Analysis	• Condition analysis: Ride, distress, rutting, and surface friction • Performance analysis: Pavement performance analysis and an estimate of remaining service life • Investment analysis: An estimate of network and project level investment strategies. These include single- and multi-year period analyses and should consider life-cycle cost evaluation • Engineering analysis: Evaluation of design, construction, rehabilitation, materials, mix designs, and maintenance
Feed back (Update)	Evaluation and updating of procedures and calibration of relationships using PMS performance data and current engineering criteria

2.4.1 Best Practices in Introducing Pavement Management System.

Compendium of best practices in road asset management which is introduced by Asian Development Bank in the year of 2018 is represented in Table 2.8.

Table 2.8 : Best Practices in PMS

Limit the Data to be collected	Collection of data costs time and money the data collection should be limited to what is actually needed. Collection of data not required or not suitable for use in pavement management systems can make data collection too costly, putting the PMS sustainability at risk.
Make the Database Easy to Use	The database needs to be properly structured, using appropriate software and local language interfaces to make it easily accessible by different levels so it may be used not only for the RAMS, but also for monitoring of road sector performance.
Start with Simple Software	Pavement Management Systems vary from simple spreadsheets with decision matrices, to complicated software requiring many types of data. In introducing a RAMS, it is important to start simple and gradually evolve to a more comprehensive system that fits the needs of the country and its road network

2.4.2 Pavement Management Systems in Different Countries

Road agencies use a variety of different road management methods to select projects and recommend preservation processes for their road network. In some cases, agencies have highly sophisticated computerized processes. In other cases, agencies are more traditional Network management methods to make decisions, including visual rating and group decision on preservation behavior. Following are the few pavement management systems used in different countries.

2.4.2.1 Arizona Pavement Management System

The framework is built as a single objective cost minimization linear programming model that is relied upon to limit the agency discounting cost for pavement maintenance and repair (M&R) tasks inside a given arranging time while keeping up the system's commitment to the pavement aspect ratio.

The Markov chain model is utilized to foresee the execution of framework since it can catch the vulnerability of the street deterioration process. The verifiable information of the road surface can scarcely be incorporated becausethe future status of the road surface is construct just with respect to the present status.

This model is connected to every road category characterized by traffic load and climate conditions, separately. The disintegration of the road surface is portrayed by an arrangement of Markov chains. Four variables were considered at first, to be specific, roughness, cracking, cracking change, and initial crack index to decide a restrictive state. Each factor is assigned a seriousness, such as low, medium, and high (Farhan et. al., 2011).

2.4.2.2 Singapore (PAVENET) Pavement Management System.

Pavenet is a road based model which was developed as a single objective optimization model. It is the first optimization model in PMS that utilized genetic algorithms to determine the PMS programming issues. This model effectively built up a multi-year road maintenance program in view of the GA working guideline, and clarified the qualities of the PAVENET demonstrate. Fwa et. al., 2011 combined the capacity to illuminate multi-purposeroad surface administration issues to additionally enhance the PAVENET (Farhan et. al., 2011)

2.4.2.3 Caltrans Pavement Management System.

The California Transportation Department (CALTRANS) has been utilizing a road distress-based resource allocation framework to perform road M&R requirements investigation. The objective of the caltrans resource allocation framework is to build up important repair and repair methodologies. Maintenance plan based only on the road conditions of the year.

The Caltrans resource allocation framework comprises of a pavement condition assessment and assessment framework. The road condition rating framework is utilized to gather road condition information for a 2-year cycle. The rating framework decides the seriousness and degree of every one of the six road surfaces on an adaptable road surface and the eight street surfaces on a rigid road surface. The central office utilizes a road condition appraisal framework to associate road distress for conceivable repair systems in light of a progression of decision trees.

The principle confinements of the framework incorporate the absence of road execution models and predictive capabilities, absence of of prioritized or optimized programming and more frameworks that can't perform multi-year maintenance requests.(Farhan et. al., 2011)

2.4.2.4 Washington state (WSPMS) Pavement Management System

The current WSPMS is a Microsoft Windows-based program that contains yearly road surface information, roughness data, and itemized development and traffic history data. The WSPMS utilizes an observational model x called basic condition PSC as a trigger to distinguish competitor pavement items. The score of the PSC 100 relates to a non-perilous circumstance, while the lower limit of 0 represents the most pessimistic scenario with broad enduring. The objective of WSPMS is to accomplish the PSC 50 pavement repair design. In addition to the PSC, the WSPMS also considers prioritizing the candidate portion of traffic. In addition to using a prioritized approach based on empirical indicator values and traffic parameters, WSPMS also uses subjective judgments when it comes to the trade-off between PSC and traffic volume.(Farhan et. al., 2011)

2.4.2.5 ALDOT Pavement Management System.

The ALDOT model was developed by using Microsoft Visual Basic and C++. It was designed to make “obtaining road information quick, easy, and inexpensive, which is what county engineers wanted” (Anderson and Wilson, 2005). The ALDOT model utilizes regression statistical analysis to build up pavement deterioration model. Deterioration models are utilized to how quickly the road surface will deteriorate and become unusable.

Once employing regression statistical model 3 assumptions should be created. It is assumed that the statistical errors are normally distributed. The second is the fluctuation of the error is consistent. The last assumption is the errors areindependent (Anderson and Wilson, 2005).

The information gathering within the ALDOT mainly focused on pavement condition index (PCI), the average daily traffic (ADT), and tractor trailer traffic. Authorities utilize this framework need to get the significant data that incorporates the length, start and end point (geographical), and also the date collected. The PCI data is gathered utilizing a visual assessment rating or VSR at 20 mph and takean image of the road phase. Scores range from 1 to 10, with 9 and 10 being excellent conditions. The ADT and measure of tractor-trailer data are then gathered by taking traffic counts or got from city or province records.

2.4.2.6 TAMS Pavement Management System

The Transportation Asset Management System (TAMS) is a road management system designed to help local agencies in Utah which is used to maintain, preserve and improve their road and street facilities and deal with the distribution of funds in accordance with the current road network. Inventory details incorporate road names, begin and end point of segment, useful characterization, road width and length, useful life, surface area in square yards, and network area percentage of each segment.

TAMS assigns the remaining service life (RSL) value to each registered road segment from 0 to 20 years. TAMS then calculated that if no action was taken, the annual RSL loss per road would be 1 year. This is a very simple way to predict a single road RSL, but it works well with agencies that have used TAMS in the past decade. This kind of road surface prediction model also helps to estimate when the entire road network will deteriorate to a certain level on average, or when a certain part of the road network will completely fail, these characteristics are very important and are often used by city officials.

In pavement management, the role of optimization and prioritization is not restricted to solving a mathematical programming model, but to address engineering, socio-economic, political and environmental concerns (Farhan et. al., 2011) The goals that want to be achieved are usually more than one and conflicting which want to maximize or minimize several objective functions simultaneously.

2.5 Prioritization Techniques for Pavement Maintenance

Prioritization is a procedure for helping with deciding or choosing favored elements from numerous feasible options. Harwell et. al., (1993) expresses the need as an element of a necessity that can be utilized for an assortment of purposes as per the requirements of the program and the organization. The requirement for priority isn't just to neglect the minimum imperative prerequisites, yet additionally to determine clashes and execute the arrangement (Wiegers, 1999). In pavement management, Prioritization process can be utilized for choosing the pavement segments as for the distinguished arrangement of elements to decide the best maintenance strategy. Even with the challenge of the problem, numerous prioritization methods have been introduced in the literature. According to the budget level, location and specific conditions of the road authorities, several methods alternating from the simple subjective ranking of the project to the broad mathematical index.

Pavement maintenance priorities are generally expressed in the form of priority index using empirical mathematical expressions. Although it is easy to use an empirical mathematical index, most of the times physical meaning of the index is not clear and cannot accurately and effectively express the priority assessment. In addition, some of the factors concerned in prioritization process cannot be expressed and measured quantitatively.

The prioritization is applied in a particular order by using first looking for pavement maintenance operations that want to be done. When the factors are recognized the next step is based on their preference for the pavement sections relative to the identified factors, Pavement sections with the highest precedence are ranked

2.5.1 Evaluate Factors Using Goals

This method is used to assess the factors by determining a set of numbers that relate to the relative importance of the project to sustain the goals. This technique is simplified through getting ready an appraisal chart that lists every undertaking with applicable goals. This table includes scoring system, definitions of goals and project. The method used to create this appraisal table should be easy and user friendly. Once the goals are determined and the scoring system is selected, the assessment of the project is continued in a straightforward manner. Each item uses the selected scoring system to rate each goal. Multiply the item score for each goal by the appropriate weighting factor and determine the sum of the scores for each item. Highest project score ranked first (Bernard ,1998).

2.5.2 Worst First Approach

A typical approach is to classify tasks and manage the worst conditional sections, regardless of their impact on the overall road network conditions and maintenance costs. This technique is called the "worst first" ranking method. The "worst first" approach seems logical, and in a sense, the worst road will lead to the highest user costs and road users' biggest complaints. Despite this, it ignores the level of change that represents the advantage of spending. The "worst first" method does not consider the speed of deterioration of the road section and the cumulative efficiency of the maintenance process. It is basic practice to order the venture with the most exceedingly terrible road conditions to begin with, paying little respect to the effect of road conditions and maintenance costs

2.5.3 Reverse Prioritization

It usually does not produce cost-effective solutions (Bemanian, 2007). Some highway agencies have adopted a "reverse-first" strategy to overcome the problems encountered by the "worst-first" strategy (Broten et. al., 1996). In the state where the maintenance cost is effective, the highest level is assigned to the road surface portion, so that the effect of performing the road surface repair is produced while reducing the maintenance cost. However, since road management involves multiple objectives that are in conflict with each other, this method of maximizing effects may not necessarily optimize other objectives, such as safety and conditions.

2.5.4 Direct Assessment Method

The Direct Assessment Method is naturally the strategy a typical individual would use in making need evaluation In theory, to rank and rate n number of items, the Direct Assessment Method would involve n(n-1)/2number of comparisons. The major demerit of this methodology comes out to be the large number of comparisons required to be made even for a small problem and its inability to quantify the exact difference between the alternatives which dominates the outcome in certain situations.

2.5.5 Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a powerful priority tool and is a mathematical method for multi-criteria decision-making. It helps decision makers choose the best alternative.

The Analytic Hierarchy Process (AHP) was developed by Saaty (1980) to facilitate decision makers in choosing the best option. It has been found that the application of analytic hierarchy process (AHP) is valuable in general transportation related decision problems. Saaty (1995) introduced the application of analytic hierarchy process in transportation analysis and explained it with five examples. Tsamboulas and Yiotis (1999) conducted a comparative analysis of five multi-criteria methods for assessing transport infrastructure projects, including AHP. El-Assaly and Hammad (2001) proposed a decision support system that uses the analytic hierarchy process (AHP) to prioritize road maintenance activities in the transportation infrastructure in Alberta, Canada

Ramadan uses the analytic hierarchy process to determine the priority of road maintenance factors such as road type, road condition, traffic volume, road riding quality, safety, maintenance costs, and the overall importance of the road to the community. AHP is used in 131 sections in Tehran to determine priority for road maintenance, taking into account road condition indicators, traffic volume and road type, etc.

Farhan and Fwa used the analytic hierarchy process to prioritize road activities on a single road segment in distress. The main purpose of this study is to determine a method that can better reflect the engineering judgments of highway agencies and engineers. They studied three forms of AHP, namely, distribution, ideal mode, and absolute AHP. The study concluded that the absolute analytic hierarchy process is most suitable for the pavement maintenance process.

Kinoshita (2005) described AHP in his paper as the most effective method for selecting the best alternative method based on pair wise comparison. In addition, by making pair-wise comparisons between standards and alternatives, the common problems of the most advantageous alternatives are eliminated. He emphasized that the idea of pair wise comparison is fully consistent with human behavior and reduces the dependence of decision makers on their intuition. In addition, he claims that AHP reduces the burden on the brain in the presence of a large number of alternatives.

Based on the advantages of AHP over other prioritization techniques described in the previous section, AHP is included in this study as the prioritization technique for pavement maintenance

2.6 Optimization Techniques for Pavement Maintenance

Optimization involves maximizing or minimizing an objective function of several binary, integer or real valued decision variables while satisfying equality or inequality constraints (Farhan et. al., 2011). In pavement management, there are problems involving single or multiple objectives functions with several constraints in the real world problems. The commonly considered objective functions are maintenance costs, overall network condition and effectiveness, and so on. The most usually utilized mathematical programming strategies for pavement management are linear programming, nonlinear programming, integer programming, dynamic programming and genetic algorithms (Cristina et. al., 2014).

Optimization of pavement maintenance expenditures can be conducted at either the network- or the project-level. Network-level optimization focuses on the overall pavement network condition and budget allocation, which is handled with the global view of the entire pavement network (Huang, 2004). The optimization is capable of estimating total mileage of the pavements to be repaired by the relevant treatments to maintain the overall pavement network above an acceptable level of conditions, taking into account the availability of the budget (Bako et. al., 1995). In contrast project-level optimization focuses on the identified subsection of the entire pavement network and produces maintenance and rehabilitation strategy for each pavement section (Huang, 2004).

Since the early 1980s, many optimization techniques have been adopted for maintenance programming in PMS, such as integer goal programming (Cook, 1984), linear goal programming (Benjamin, 1985), linear programming (Karan and Haas, 1976 and Lytton (1985)), linear integer programming (Fwa and Sinha, 1988) and Li et. al., (1998), dynamic programming (Feighan et. al., 1987). Most of the approaches either maximized pavement performance subject to maintenance and rehabilitation budget constraints, or minimize maintenance and rehabilitation cost subject to performance constraints (Abaza and Murad, 2007).

The network-level optimization is usually employed by a “macroscopic” approach, in which “the repair variables are introduced for each pavement condition category and they represent the proportions of pavement that should be treated by the applicable treatments” (Abaza, 2007). The project-level optimization is generally implemented by a “microscopic” approach, in which each pavement section is assigned a repair variable for each repair treatment and the value of this variable is 1, if the repair treatment is recommended for this pavement section, otherwise it is 0 (Abaza, 2007, Bako et. al., 1995).

2.6.1 Linear and Integer Programming

Linear and integer programming are the two optimization algorithms used by most of the developed pavement optimization models. In pavement management, Most of the pavement optimization models were developed using linear and integer programming optimization algorithms. Choosing a suitable algorithm is essential for building an effective optimization tool. Linear programming is a dominant mathematical approach used to deal with the best way to allocate limited resources in competing activities (Hillier and Lieberman, 2010).

It is essential to be linear functions which are considered as the objective functions and constraints of a linear programming model (Abaza, 2007). Due to the rapid progress of efficient solution algorithms and computational power, the linear programming model can be solved within an adequate time period, even if the problem size is relatively large (Hillier and Lieberman 2010). Therefore, many researchers, such as (Golabi et. al., 1982; Bako et. al.,1995; Chen et. al., 1998 and Abaza, 2007) have developed network-level optimization models using linear Programming.

The more complete name for integer programming is “integer linear programming”, which indicates that the integer programming model is derived from the linear programming model by adding a restriction that all variables must be integers (Hillier and Lieberman, 2010).

(Li et. al., 1998 and Ferreira et. al., 2002) use integer programming models, in which each pavement section is assigned a set of repair variables and a specific maintenance and rehabilitation plan can be generated for all pavement section. However, this approach results in a very large number of variables and makes the optimization model extremely difficult to solve, especially when it is used for a large pavement network (Abaza, 2007). Therefore, it is often used in the project-level optimization, where the number of pavement sections is much less than that of the entire network (Ferreira et. al., 2002; Li et. al., 1998).

2.6.2 Non-Linear Programming

Objective functions and constraints are expressed as nonlinear equations. It fits the best solution at the project level. Same as linear programming, but it is difficult to ensure that a global optimum is found instead of a local optimum.

2.6.3 Dynamic Programming

Dynamic programming is utilized as a part of circumstances where an expansive number of successive decisions are required. This optimization method begins with the desired final solution and finds the ideal estimation of the variable later. Dynamic programming has applied holistic and sequential ways to deal with treatment strategy optimization and pavement section determination (Cristina et. al., 2007). There is no existing standard formula. The problem is divided into several stages, and each stage needs to make a decision. Each stage has various states related with it. The solution process is to find an overall optimal strategy. This can be used to optimize pavement management issues for many years to provide the best solution and utilized when various choices must be made in sequence. Every time a problem changes, formulation is needed each time. There are too many stages in the big problem (Farhan et. al., 2011).

2.6.4 Artificial Neural Networks

Neural networks can be learned from the examples so that these systems can summarize and simulate decisions. Fwa and Chan developed a neural in view of the need appraisals granted by the engineers. After the training phase, it provides scores for the sections based on their condition. Neural systems help to recreate designs and sum up. In any case, they don't ensure the relevance of the choices made, and they go about as “black boxes " and it isn't conceivable to effectively extract the path followed by the interpretation of the solution. (Cristina et. al., 2007).

The model consists of a large number of nodes. Each node is associated with a state variable and an activation threshold. Each link between nodes is associated with a weight, and the state of the node is determined by the activation function. Being able to solve a combination problem which can handle a large number of decision variables. Artificial neural network reduce computational complexity but slow in the training phase. It is difficult to explain the what network learns (Farhan et. al., 2011).

2.7 HDM4 – Identification of Limitations

Highway Development and Management Tool (HDM-4) has been used for preparing road investment plans and network strategies in the analysis of road management investment alternatives. The different versions of these model are broadly used in many countries demonstrate the increased rationality of road maintenance and maintenance budget. HDM4 models have been used to examine the economic feasibility of road projects and enhance the economic benefits to road users under various expenditure levels.

Since the HDM-4 is designed for a variety of environments, it is needed to configure and calibrate for local practice before using the system. The default data and calibration coefficients are not applicable to many countries and differ according to the road classification system used in local road agencies.

The pavement deterioration model introduced in HDM-4 is derived from the large experimental results conducted in different countries. Thus, if the default equation in HDM-4 is used without calibration, the prediction may not precisely match the pavement performance observed on a particular road segment. The basic assumption made before using HDM is that the pavement performance model will be calibrated to replicate the pavement deterioration rate observed on the road to the application model.

As for any analysis based on a computer simulation model the reliability of the results is depend on two primary conditions. How well the data provided represent the real conditions been analyzed as understood by the model. How well the predictions of the model fit the real behavior and the intersections between the various factors for the variety of conditions to which it is applied.

2.7.1 Challenges in Using HDM- 4

It is a complex technique and the working expense is high. In this way utilization of HDM-4 for local agencies is difficult. Facilitate gathering of information is monotonous and on the off chance that one classification of info information is erroneous the whole framework will give the incorrect output.

Road development authority has started to utilize the model for different applications. But there are challenges in application with the calibration issues and various difficulties in provincial level; in collecting data because of absence of trained individuals and due to the lack of equipment used in data collection.

Though some countries like South Africa using this model there are issues with running the model with rural and urban roads together, due to lower benefits from the rural roads compared to the urban roads rural roads are not selecting for improvements and they are using separate allocation for the improvement of rural roads.

One of the advantage in using HDM 4 model is the ability of predicting the condition of the road network with different level of budgetary allocations this is very useful in convincing the necessity of the budget to keep the road network in good condition. But again the challenge in using HDM4 is using the accurate or realistic data for the running the program.

There are various limitations in using this kind of a model in provincial level organizations due to lack of data and lack of experienced staff, equipment and the budget.

3 METHODOLOGY

In order to carry out the work it was necessary to identify the major factors relevant to the prioritization of road sections maintenance. The main objective of this study is to develop the maintenance strategy for rural road network. It is proposed to select maintenance activities to be carried out on different rural road sections in two stages.

Stage one determines rural road sections priority based on the basis of the strategy proposed in this study. Stage two determines priority factor activities on different sections. Thus the strategy proposes that first section which are more critical for maintenance needs to be selected. The strategy identified to select maintenance activities using minimal data. Further, strategy proposes that the sections identified in stage one needs to be evaluated in more details so that the various maintenance activities to be carried out on these sections can be prioritized.

Thus, the proposed strategy will be more economical as detailed studies needs not to be carried out on all the sections. The strategy to determine priority for stage one and stage two are briefly explained in the following section:

3.1 Identification of Priority Factors

Priority factors were identified by the opinion survey from the Engineers of provincial road agencies and through a literature survey. Based on the opinion survey five main priority factors were finalized namely pavement condition, traffic volume, connectivity to local road network, land use pattern and importance to community. In order to quantify the Importance to community factor it was spitted into 4 sub factors namely, civic centers, cultural events, produces in area and alternative roads during maintenance.

Table 3.1 : Factor Description

No.	Criteria	Description
1.	Pavement Condition	Considering a present state of the road by using an index (E.g.: PCI -Pavement Condition Index and IRI - International Roughness Index)
2.	Traffic Volume	Consider about the Number of vehicles per day (E.g. : Average daily traffic)
3	Connectivity to Local Roads	A or B Class C or D Class Pradeshiya Sabha Road Minor Road Dead End
4.	Land Use Pattern	Following factors are considered under this criterion Residential, Commercial, Industrial, Agricultural, Forest
5.	Importance to Community	a) Civic centers served by the road (E.g.: Schools, Hospitals, Post office, Banks and Temples) b) Cultural events served by the road (E.g.: Perahara and Priest) c) Produces in the area served by the road (E.g.: Paddy, Vegetable, Tea and Fruits) d) Alternative roads during maintenance

3.2 Basic Principle of Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a mathematical technique used in multi-criteria decision making to help decision makers choose the best choice. In this approach, the complexity of the problem can be reduced by dealing with this complexity at different levels. Each level consists of a set of parameters with similar characteristics. In this approach, the overall goal is to be at the top level, followed by a set of criteria in the middle level, followed by a set of alternatives to achieve the overall goal. In general, criterias are further divided into sub-criteria based on the complexity of the problem. AHP recommends using a nine-point scale to calculate the relative importance of all elements, comparing them in pairs.

3.2.1 The Relative Importance of Alternatives

Table 3.2 : Relative Importance

Numeric Value	Preferred level
1	Equally Preferred
3	Moderately Preferred
5	Strongly Preferred
7	Very Strongly Preferred
9	Extremely Preferred
2,4,6,8	Intermediate values between the two adjacent judgments

The judgmental value for pairs of attributes *Ci* and *Cj* are presented by an n-by-n matrix as shown in equation (1).

$$A = (a_{ij})_{n\times n} i, j = 1,2,3, \dots \dots \dots n \qquad (1)$$

aij denotes the importance of alternative i over alternative j

If *aij* = α, then *aji* = 1/α, α ≠ 0 and If *Ci* is judged to be of equal relative importance as *Cj*, then *aij* = *aji* = 1. Obviously *aii* = 1 for all *i*.

The value of each element in matrix A is evaluated and the priority vector w is determined. Saaty's eigenvector method (EM) is usually used to derive the alternative's priority and calculate the value of w', the principal eigenvector, the vector corresponding to the largest eigenvalue, and the λmax of the matrix A, as in the formula

$$Aw' = \lambda_{max} w' \qquad (2)$$

where, λmax ⩾ *n*, *w*′ = [*w*1, *w*2, *w3*, …, *wn*]*T*, and the superscript *T* denotes transpose of a matrix.

The priority vector *w* is obtained by normalizing the principal Eigen vector *w*′ and is called the normalized principal Eigen vector of the pairwise comparison matrix. It is established for each criterion, sub-criterion as well as the alternatives under each sub-criterion. The overall priority weight of alternatives is computed using following equation

$$V_i = \sum_j w_j x_{ij} \qquad (3)$$

where *Vi* = overall priority weight of alternative *i*, *Wj* = weight assigned to criterion *j*, and *Xij* = weight of alternative *i* given criterion *j*.

The literature shows that AHP allows 10% inconsistency in human judgment. To check the consistency of decision makers' judgment, the consistency ratio (CR) defined as the ratio of the consistency index (CI) and the random index (RI) is used to use the equation

$$CR = \frac{CI}{RI} \qquad (4)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (5)$$

where *n* is the size of the matrix.

The values of the random index for quantities of attribute to the different size of the matrix were adopted. Also, a matrix is considered consistent only if CR 0.1

3.3 Hierarchy Structure of Goal, Criteria and Sub Criteria

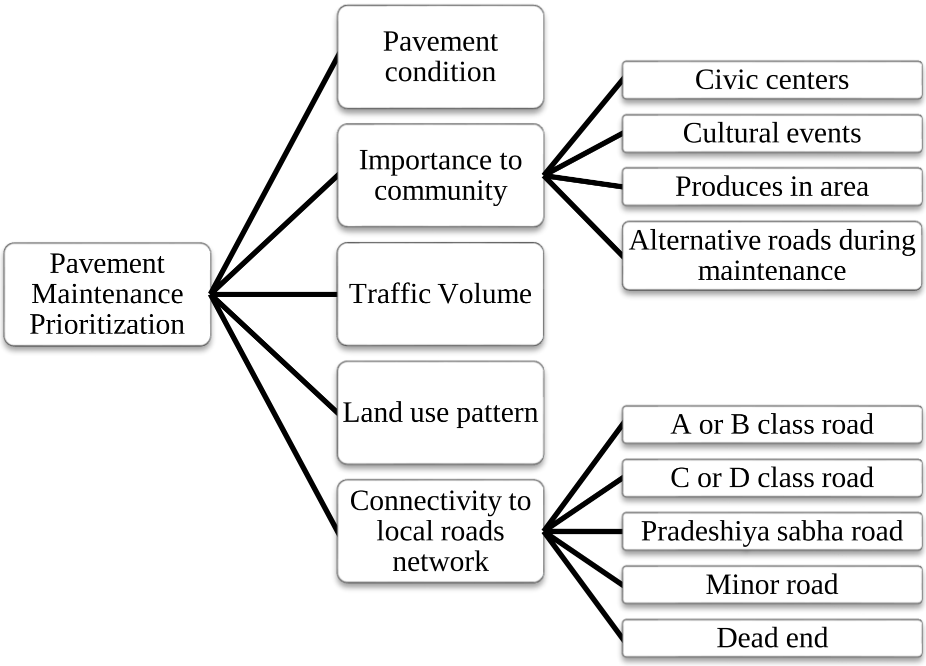

Figure 3.1 : Hierarchy Structure of Pavement Maintenance Prioritization

3.3.1 Rank the Importance of Selected Factors

Five Engineers of the road maintenance agencies were asked to rank the importance of selected priority factors. Each Engineer was approached individually 3 times within a month. Ranking was done by using AHP method which is used the ratio scale. Pairwise comparison matrices were checked for consistency using consistency ratio.

3.4 Formulation of Prioritization Model

$$PI_S = \sum_{i=1}^{5} W_i F_{is} \qquad (6)$$

PI_s = Priority index of road section s

W_i = Priority Weight of factor F_i

F_{is} = Value of priority factor i for road section s

Priority weight of each factor was determined by the AHP method as described in previous section. Value of priority factor (F_{is}) can be calculated as demonstrated in section 4.1.3. PI_s were defined by the summation of the product of W_i and F_{is}.

3.5 Pavement Maintenance Optimization Model

Prioritization of maintenance activities depends on several factors such as present condition of road i.e. quantity and quality of deterioration, increasing rate of deterioration, importance of the different sections, etc. Hence it is difficult to select various activities in order of their maintenance priority in a road network. Thus there is an urgent need to develop a rational strategy for priority of maintenance activities to be carried out in a low volume road network.

3.5.1 Formulation of Optimization Model

Formulation of optimization model is carried out in such a way that the performance level of the road network is maximized with a cost effective maintenance strategy. Objective functions and constraints are described as follows.

3.5.1.1 Definition of Sets

R: a Set of Operations (1-Do minimum, 2-Non-structural maintenance, 3-Minor rehabilitation, 4-Medium rehabilitation, 5-Major rehabilitation)

S: a Set of Pavement Sections (1, 2, 3, 4 …8)

3.5.1.2 Definition of Parameters

L_s: Length of road section s

T_r : Cost of operation r (per km)

C_{rs}: Cost of applying operation r to road section s

Q_{bs}: Present condition of road section s

Q_{rs}: Condition of road section s after applying the operation r

PI_S: Priority index of road sections

B : Total budget available for the year

Q_{min}: Warning level for pavement condition

Q_{max}: Maximum value of pavement condition

3.5.1.3 Definition of Decision Variables

Xrs: 1 when operation r is applied to road section s

: 0 when no action applied

3.6 Pavement Performance Optimization Model

Maximize the Pavement Condition,

$$Maximize : Z = \sum_{r=1}^{R} \mathrm{Q_{rs}} \, . \, \mathrm{PI_S} . \, \mathrm{L_S} . \, \mathrm{X_{rs}} \qquad (7)$$

Annual Budget Constraint,

$$\sum_{S=1}^{S} \sum_{r=1}^{R} \mathrm{T_r} . \, \mathrm{L_S} . \, \mathrm{X_{rs}} \leq \mathrm{B} \qquad (8)$$

Annual Operations Constraint,

$$\sum_{r=1}^{R} \mathrm{X_{rs}} = 1 \qquad (9)$$

Warning Level Constraint,

$$\mathrm{Qmax} \geq Qrs \geq Qmin \qquad (10)$$

Decision variable constraint,

$$\mathrm{X_{rs}} \quad \in \{0,1\} \qquad (11)$$

Objective function of maximization of performance of the road network as shown in Equation (7) was defined by summation of the pavement condition after the maintenance operations applied. The computed Priority index PI in equation (6) is incorporated in to the optimization model. Each maintenance action is accounted in the performance of the pavement by the objective function. Condition after applying each operation is defined as the following equation.

$$Q_{rs} = Q_{bs} + \Delta Q_{rs} \qquad (12)$$

Condition after applying operation r is equal to the sum of present condition and condition increment after applying operation r

First Constraint of the optimization model which is given in equation (8) ensures that maintenance expenditure does not exceed the available budget allocation. Only one operation could be applied for a particular road section during a particular optimization period as given in Equation (9). The maintenance actions should be carried out in such a way that road condition of each section after rehabilitation is above a minimum acceptable level as explained in equation (10).Equation (11) defines the decision variable X_{rs} to be an integer of value either 0 or 1 .

Condition of the road section is measured by International Roughness Index (IRI), Pavement Condition Index (PCI) or any Index which can be measured by available data about road sections.

4 ANALYSIS AND RESULTS

The proposed strategy consists with two stages. Evaluation of priority index of each road section was done as the first stage of the analysis. Stage II includes the determination of maintenance operations for each road section by using developed optimization model. Two illustrative examples were presented in this chapter to demonstrate the proposed method.

4.1 Analysis and Results for Stage One- Evaluation of Priority Index

This section presents an illustrative example where PI were computed for 10 sample road sections taken from a road network in western province. Priority weight for Pavement condition, Traffic volume, Connectivity to local road network, Land use pattern and Importance to community were determined by the AHP method as explained below.

4.1.1 Pair Wise Comparison of Criterion

In this step, pair wise comparison of criterion of the decision hierarchy model was done by the road agency Engineers' rankings. Example of pair wise comparison of criterion is given below.

Table 4.1 Illustration of Pair wise comparison of factors.

Criteria	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria
Pavement Condition									1									Traffic Volume
Traffic Volume							3											Connectivity to Local Roads
Connectivity to Local Roads													5					Land Use Pattern
Connectivity to Local Roads																	9	Importance to community

Pair wise comparisons were done by using nine point scales and detailed description of numeric values from 1 to 9 was given in Table 3.2 in section 3.2.1. According to the above comparisons, pavement condition and traffic volume was equally preferred. Traffic volume is moderately preferred when compare to the connectivity to local roads factor. Importance to community is extremely preferred over the connectivity to local roads factor. Land use pattern is strongly preferred when compare to the connectivity to local roads factor.

4.1.2 Computation of Weightages for the Priority Factors

After the initial comparison, reciprocal matrix was developed using average values of scores and it was given in Table 4.2. Sum of the columns in reciprocal matrix is computed and then each value of reciprocal matrix is divided by the respective column sum to find normalized relative weights. Priority weight of each factor was given by the average of the normalized relative weight. Results were shown in Table 4.3, 4.4 and 4.5.

Priority weights of each factor obtained by the AHP method were shown in Table 4.3. It is clear that Importance to community factor has the highest weight when compare to the other factors. Land use pattern is the least important factor. Consistency ratio determines how consistent obtained results are. Consistency ration of this comparison is 0.089 which is lesser than 0.1 hence the results were accepted.

Importance to community and Connections to existing roads factors were divided into sub criterion and evaluated the priority weight of each sub criterion as shown in Table 4.4 and Table 4.5. Civic center has the highest priority weight under the importance to community criterion. Cultural events also have a significant priority weight when compare to the remaining factors.

4.1.3 Calculation of Priority Index for Each Pavement Section.

This section describes how priority index (F_i) can be computed for a given set of attributes based on priority factors and their weightages. Priority index for pavement sections were computed by using the above calculated priority weights of each criterion. Priority index calculation was done to demonstrate how PIs can be computed for the given attributes of a road. As an illustrative example ten road sections were selected with varying attributes to demonstrate PI calculation method.

Step 1 - Identification of attributes:

Table 4.6 represents the all attributes of 10 road sections with respect to the priority factors and sub factors considered in prioritization model. Land use pattern was divided into 3 sub factors residential, agricultural/industrial and commercial. Both residential and commercial sub factors were again divided into high, medium and low. Under residential and commercial sub factor number 1 represents their category. As an example, in Table 4.6 road section 4 is highly residential and highly commercial. Under importance to the community factor number1 represents the availability of sub factor a, b, c and d which were described in Table 3.1

Step 2 – Assignment of values for attributes:

Scores were assigned for the attributes based on the criteria described below.

Pavement Condition – IRI value was adopted to represent the pavement condition.

Traffic Volume- Average daily traffic was used to represent the traffic level on the road.

Connectivity to Local Roads- The scores for connectivity to local road network was assessed based on the class of the road at the start and end nodes. Detailed score assignment was given in Table 4.7

Land Use Pattern- Under residential and commercial factors, scores for high, medium and low were considered as 10, 5 and 2 respectively. 5 marks was given for industrial or agricultural areas. Then these sub categories were combined to represent one value by assigning weightage for each sub factor. Weighted priority factor score was calculated by summing up the product of this weight and sub criterion score.

Importance to community -5 marks was given for each sub factor of importance to community.

Priority factor scores for road sections were presented in Table 4.8.

Step 3 – Scaling the weighted scores of road sections.

After deriving scores, the original scores were divided by their own standard deviation to make the variables with unit variance. Standard deviation of each factor was given in Table 4.9

Eg. Weighted score of Pavement condition of road section 1 is 2.3 and standard deviation for the pavement condition factor is 1.75. Scaled value is calculated by 2.3/1.75

The Cronbach's alpha value (Keith,2017) is used to check the reliability of the result. The Cronbach's alpha value of the original score of the priority factors was 0.762 which was greater than 0.7 which means that the consistency of the indicator variables was at a satisfactory level. The Cronbach's alpha value for the scaled scores of the priority factors was 0.864 which means that the internal consistency of the original indicator variable is enhanced by scaling.

Step 4 – Calculation of PI.

Multiplying the scaled value of each attribute by the corresponding weightage to get the priority index for the respective road section.

Eg. For road section 1

PI = $24.39 \times 1.31 + 16.95 \times 4.67 + 16.85 \times 8.53 + 4.4 \times 2.92 + 37.41 \times 2.35 = 356$

Step 5- Final Priority Indices.

The calculated priority index values were also scaled using the method given in step 3. The final scaled values were shown in column (viii) of Table 4.10 represents the priority index of each road sections.

4.2 Analysis and Results for Stage Two: Optimization.

A hypothetical network of 12 different road sections was considered. Each pavement section was defined using section ID and the relevant attributes for each priority factors that was discussed in preceding section. Prioritized pavement sections were included into the optimization model and maintenance operations were generated by optimization model. Arbitrary priority indexes were assigned for the 12 roads for optimization model to analyze the variations and impacts. Table 4.11 shows the details of road sections selected for analysis

Main input parameters of the optimization model include priority index values of road sections obtained from the previous analysis, length and PCI of each road section, Minimum expected PCI value, Annual budget and cost of each operation applied.

The maintenance operations program obtained for the road network keeping minimum expected level of each road section at a PCI value of 45 and assigning Priority index for all road sections is shown in Table 4.12 Different maintenance strategies were obtained by changing the available annual budget. Maintenance operations were presented with respect to the different percentages of total budget.100% of the budget is enough to maintain all road sections to achieve the maximum of overall network condition. Table values clearly show how the operations were changed when the available budget decreases. 50% of the road sections were not selected to apply any maintenance operation when the budget decreased to 10% of the total budget. In order to achieve the objective of maximization of total pavement condition while considering the budget constraints condition of each road section vary with budget. Selected operations were oscillating without decreasing according to the budget

Maintenance operations program obtained for the road network without assigning Priority index for all road sections (non prioritized scheme) and keeping minimum expected level of each road section at a PCI value of 45 is shown in Table 4.13. It shows the similar variation but different operations due to non-prioritized scheme.

4.3 Analysis of Improvement of Pavement Sections for Different Budget Level with Priority Index

This analysis is performed to illustrate the differences in improvements of the road sections caused by changing the magnitudes of the available budget. Maintenance operations depend on the priority index of each road section.

Table 4.14 clearly shows that for all budget levels, all road sections condition after applying operations is greater than or equal to 45 which satisfied the minimum expected level of road condition constraint. When the budget decreased, condition of the all road sections after applying operations were decreased drastically.

Table 4.15 represents the comparison of operation selection for each road with respect to different budget levels. It is clearly shows that when the budget level is increased number of roads sections for maintenance also increased.

4.4 Variation of Network PCI

Figure 4.1 represents the comparison of network PCI for different budget levels corresponding to priority and non priority scheme of road sections. Network PCI is calculated by summing up the product of road length and respective PCI value. Network PCI decreases drastically when budget level decreases for both prioritized and non prioritized schemes. Network PCI for both schemes is similar for 100%, 40% and 10% of the budget levels. Network PCI is always higher or equal for non prioritization scheme when compare to the prioritization scheme.

4.5 Analysis of Pavement Section Conditions with Lower Present Condition

This analysis is performed to illustrate the variation of pavement condition improvement with respect to present pavement condition and priority index. Present condition of all selected road sections is below the minimum expected level of condition.

Table 4.16 clearly shows that the condition of each road section after applying operations is greater than the expected minimum level of condition. Compare to the improvement of road section 11 all other road sections improvement tends to maximum when the budget level decreasing. Priority index mainly affect to this variation.

4.6 Effects of Priority Index for Maintenance Operations

Figure 4.2 shows the new condition of road section 11 which has the minimum priority index among 12 road sections. Present condition of the road section 11 is 40. It is clear that improvement is considerably high under the non priority scheme (all sections have equal priority) for higher budget levels when compare to the priority scheme improvement. This implies that the incorporation of priority index to the optimization model gives the practical solutions.

The new condition of road section 10 which has higher priority index among 12 road sections was represented by Figure 4.3. Present condition of the road section 10 is 35. It is clear that improvement between two schemes priority and the non priority scheme have similar improvement values for higher budget levels.

Figure 4.4 shows the new condition of road section 7 which has the higher priority index and higher present condition among 12 road sections. It is clear that improvement between two schemes priority and the non priority scheme have similar improvement values for all budget levels.

The new condition of road section 3 which has the minimum priority index and higher present condition among 12 road sections was represented by Figure 4.5. Present condition of the road section 11 is 95. It is clear that improvements are comparatively similar when the present condition is high and the priority index is low.

Table 4.2: Comparison (Reciprocal) Matrix

Criteria		Pavement Condition	Traffic Volume	Connectivity to Local Roads	Land Use Pattern	Importance to community
		1	2	3	4	5
Pavement Condition	1	1	5	3	3	1/5
Traffic Volume	2	1/5	1	3	5	¼
Connectivity to Local Roads	3	1/3	1/3	1	5	1
Land Use Pattern	4	1/3	1/5	1/5	1	1/5
Importance to Community	5	5	4	1	5	1
Column Sum		6.867	10.533	8.2	19	2.65

Table 4.3: Normalized Matrix with Weights of Criterion

Criteria		Pavement Condition	Traffic Volume	Connectivity to local road network	Land Use Pattern	Importance to community	Total	Priority Weights	Priority Weights %
		1	2	3	4	5			
Pavement Condition	1	0.146	0.475	0.366	0.158	0.075	1.220	0.244	24.39
Traffic Volume	2	0.029	0.095	0.366	0.263	0.094	0.847	0.169	16.95
Connectivity to local road network	3	0.049	0.032	0.122	0.263	0.377	0.843	0.169	16.85
Land Use Pattern	4	0.049	0.019	0.024	0.053	0.075	0.220	0.044	4.40
Importance to community	5	0.728	0.380	0.122	0.263	0.377	1.870	0.374	37.41

Consistency ratio = 0.089

Table 4.4: Normalized Matrix with Weights of Sub Criterion Importance to Community

Sub Criteria		Civic Centers	Cultural events	Produces in area	Alternative road during maintenance	Total	Priority Weights	Priority Weights %
		1	2	3	4			
Civic Centers	1	0.571	0.749	0.286	0.381	1.987	0.497	49.67
Cultural events	2	0.143	0.187	0.500	0.476	1.306	0.327	32.66
Produces in area	3	0.143	0.027	0.071	0.048	0.289	0.072	7.22
Alternative road during maintenance	4	0.143	0.037	0.143	0.095	0.418	0.105	10.46

Consistency ratio = 0.043

Table 4.5: Normalized Matrix with Weights of Sub Criterion Connections to Existing Roads

Sub Criteria		A or B class road	C or D class road	Pradeshiyasabha road	Minor road	Dead end	Total	Priority Weights	Priority Weights %
		1	2	3	4	5			
A or B class road	1	0.402	0.366	0.517	0.424	0.389	2.099	0.420	41.97
C or D class road	2	0.402	0.366	0.310	0.303	0.278	1.659	0.332	33.19
Pradeshiyasabha road	3	0.080	0.122	0.103	0.182	0.167	0.654	0.131	13.09
Minor road	4	0.057	0.073	0.034	0.061	0.111	0.337	0.067	6.74
Dead end	5	0.057	0.073	0.034	0.030	0.056	0.251	0.050	5.20

Consistency ratio = 0.072

Table 4.6 : Priority Factor Details for Road Sections

Section No	IRI	ADT	Connectivity		Land use pattern							Importance to community			
			From	To	Residential			Agri/Industrial	Commercial			A	b	c	d
					High	Medium	Low		High	Medium	Low				
1	2.3	9850	A	A	1	0	0	0	0	1	0	1	0	0	1
2	1.5	8350	A	B	0	1	0	0	0	1	0	0	0	0	1
3	6.5	6250	A	B	1	0	0	1	1	0	0	1	1	1	0
4	2.7	7850	B	B	0	1	0	0	0	1	0	0	0	0	1
5	2.3	4600	B	B	0	0	1	1	0	0	1	1	1	1	0
6	1.7	6000	A	B	0	1	0	0	0	1	0	0	1	1	0
7	2	5100	A	C	0	1	0	0	1	0	0	0	1	0	0
8	3.8	6150	A	A	0	1	0	1	0	1	0	1	1	1	0
9	4.5	6300	A	B	1	0	0	0	0	1	0	0	1	0	1
10	5.8	1350	A	D	0	0	1	0	1	0	0	0	0	0	1

Table 4.7 : Scores for Connectivity

Node(Start-End)	A	B	C	D
A	40	35	30	25
B	35	30	25	20
C	30	25	20	15
D	25	20	15	10

Table 4.8 : Weighted Priority Factor Scores for Road Sections

	IRI	ADT	Connectivity	Land Use pattern				Importance to community
				Residential	Agri/Industry	Commercial	Total	
1	2.3	9850	40	5	0	1.25	6.25	10
2	1.5	8350	35	5	0	1.25	6.25	5
3	6.5	6250	35	2.5	2.5	2.5	7.5	15
4	2.7	7850	30	1	0	1.25	2.25	5
5	2.3	4600	30	2.5	2.5	0.5	5.5	15
6	1.7	6000	35	2.5	0	1.25	3.75	10
7	2	5100	30	2.5	0	2.5	5	5
8	3.8	6150	40	1	2.5	1.25	4.75	15
9	4.5	6300	35	1	0	1.25	2.25	10
10	5.8	1350	25	0	0	2.5	2.5	5

Table 4.9 : Standard Deviation of Priority Factors

Factor	Standard deviation
Pavement condition	1.751
Traffic volume	2111.059
Connectivity	4.687
Land use pattern	3.965
Importance to community	4.264

Table 4.10 : Scaled Values of Priority Factors and Priority Index for Road Sections

I	ii	iii	Iv	v	Vi	vii	viii
Section No	Pavement condition	Traffic volume	Connectivity	Land use pattern	Importance to community	Priority index	Final PI
*Weightage	24.39	16.95	16.85	4.4	37.41		
1	1.31	4.67	8.53	2.92	2.35	356	55
2	0.86	3.96	7.47	2.92	1.17	270	42
3	3.71	2.96	7.47	3.51	3.52	414	64
4	1.54	3.72	6.40	1.05	1.17	257	40
5	1.31	2.18	6.40	2.57	3.52	320	49
6	0.97	2.84	7.47	1.75	2.35	293	45
7	1.14	2.42	6.40	2.34	1.17	231	35
8	2.17	2.91	8.53	2.22	3.52	387	60
9	2.57	2.98	7.47	1.05	2.35	331	51
10	3.31	0.64	5.33	1.17	1.17	231	35

*Weightage calculation was given in section 4.1.2

Table 4.11 : Details of Road Sections Selected for Analysis

Road Section	Length	PCI before applying operations	Priority index
S	Ls	Qbs	PIs
1	0.7	65	60
2	0.4	45	70
3	0.6	95	10
4	0.8	25	50
5	1	55	70
6	0.9	65	45
7	1.5	85	90
8	0.8	75	35
9	0.7	45	55
10	1.5	35	90
11	0.6	40	10
12	0.4	35	85

Table 4.12 : Optimized Maintenance Operations with Priority Factor

	Optimized maintenance operations for road sections											
Budget %	1	2	3	4	5	6	7	8	9	10	11	12
100	5	5	4	5	5	5	5	5	5	5	5	5
90	5	5	1	5	5	5	5	3	5	5	4	5
80	5	5	1	5	5	5	4	3	5	5	3	5
75	5	5	3	5	5	5	3	3	5	5	3	5
70	5	5	1	5	5	2	4	1	5	5	3	5
60	5	5	2	5	4	3	3	3	5	5	3	5
50	1	5	1	5	4	1	3	1	5	5	3	5
40	3	5	2	5	3	3	3	1	3	5	3	5
30	3	3	2	4	3	1	3	1	3	5	3	4
20	1	3	1	4	3	1	1	1	3	4	3	4
10	1	3	1	4	3	1	1	1	1	3	3	3

Table 4.13 : Optimized Maintenance Operations without Priority Factor

	Optimized maintenance operations for road sections											
Budget %	1	2	3	4	5	6	7	8	9	10	11	12
100	5	5	3	5	5	5	4	4	5	5	5	5
90	5	5	2	5	5	5	4	4	5	5	5	5
80	5	5	3	5	5	5	3	3	5	5	5	5
75	5	5	3	5	4	5	3	3	5	5	5	5
70	5	5	3	5	5	3	3	2	5	5	5	5
60	3	5	3	5	4	3	3	3	5	5	5	5
50	3	5	2	5	4	3	3	3	5	4	5	4
40	1	3	1	5	3	3	3	3	5	4	5	4
30	3	3	3	5	3	1	3	3	3	4	3	5
20	1	3	3	5	3	1	3	3	3	3	3	4
10	1	3	1	4	3	1	1	1	1	3	3	3

Note : 1- Do minimum, 2-Non-structural maintenance, 3- Minor rehabilitation,
4-Medium rehabilitation, 5-Major rehabilitation

Table 4.14 : Road Sections Condition after Improvement with Priority Index

S	1	2	3	4	5	6	7	8	9	10	11	12
100%	90	90	100	85	90	90	100	90	90	85	85	85
90%	90	90	95	85	90	90	100	80	90	85	65	85
80%	90	90	95	85	90	90	95	80	90	85	50	85
75%	90	90	100	85	90	90	90	80	90	85	50	85
70%	90	90	95	85	90	67	95	75	90	85	50	85
60%	90	90	97	85	80	70	90	80	90	85	50	85
50%	65	90	95	85	80	65	90	75	90	85	50	85
40%	70	90	97	85	65	67	90	75	55	85	50	85
30%	70	55	97	60	65	65	90	75	55	85	50	70
20%	65	55	95	60	65	65	85	75	55	70	50	70
10%	65	55	95	60	65	65	85	75	45	50	50	50

Table 4.15 : Selection of Road Sections for Operations

Road section	1	2	3	4	5	6	7	8	9	10	11	12
Present condition	65	45	95	25	55	65	85	75	45	35	40	35
Priority index	60	70	10	50	70	45	90	35	55	90	10	85
20% Budget level without PI	0	1	1	1	1	0	1	1	1	1	1	1
20% Budget level with PI	0	1	0	1	1	0	0	0	1	1	1	1
50% Budget level without PI	1	1	1	1	1	1	1	1	1	1	1	1
50% Budget level with PI	0	1	0	1	1	0	1	0	1	1	1	1
90% Budget level without PI	1	1	1	1	1	1	1	1	1	1	1	1
90% Budget level with PI	1	1	0	1	1	1	1	1	1	1	1	1

0-Do minimum   1- Select for maintenance

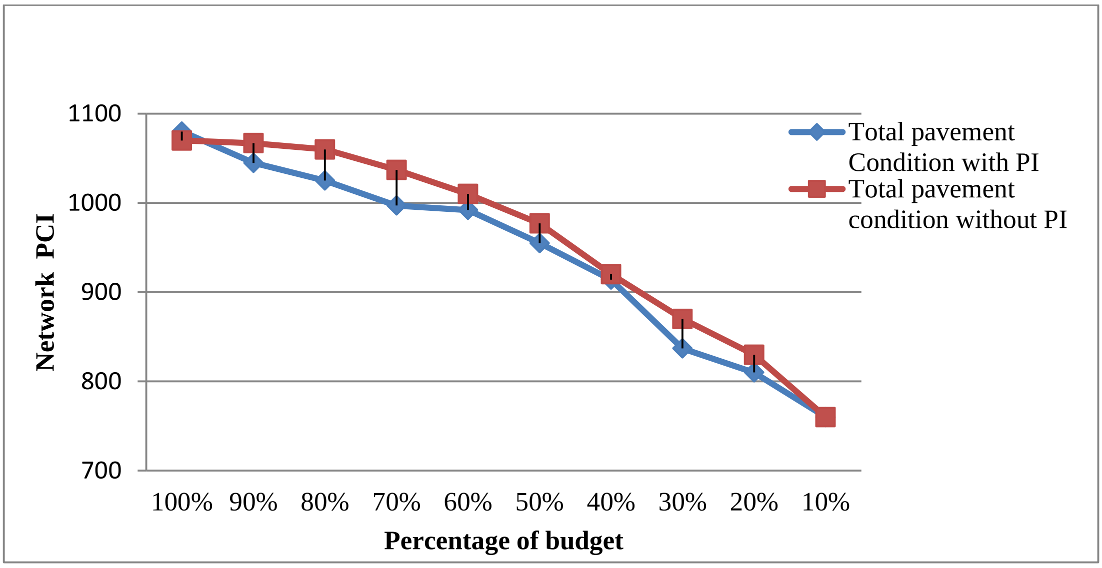

Figure 4.1: Comparison of Network PCI with Priority Scheme and non Priority Scheme.

Table 4.16 : New Pavement Condition

S	4	10	11	12
Qbs	25	35	40	35
PIs	50	90	10	85
100%	85	85	85	85
90%	85	85	65	85
80%	85	85	50	85
75%	85	85	50	85
70%	85	85	50	85
60%	85	85	50	85
50%	85	85	50	85
40%	85	85	50	85
30%	60	85	50	70
20%	60	70	50	70
10%	60	50	50	50

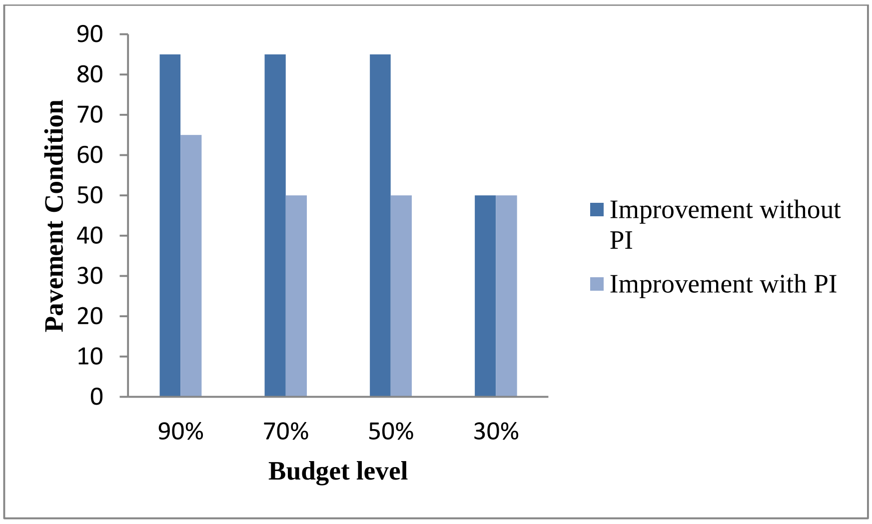

Figure 4.2: New Condition of Section 11 - Qbs- 40 , PIs-10

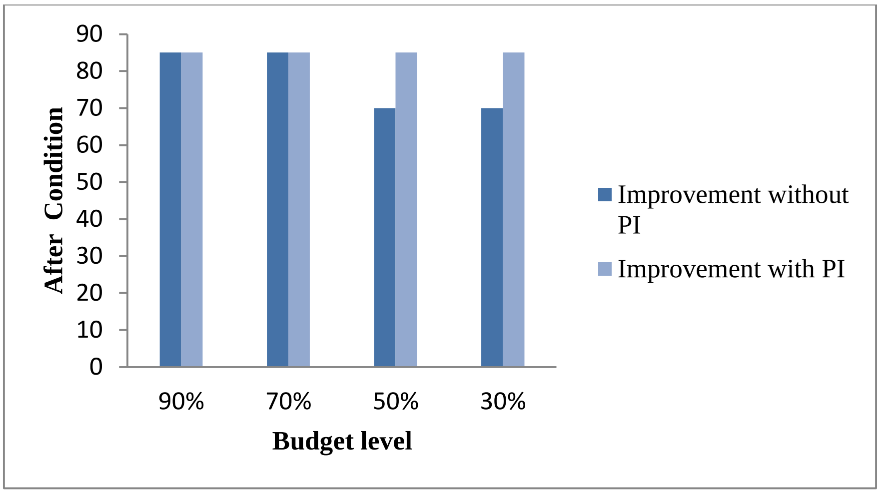

Figure 4.3: New Condition of Section 10 Qbs- 35 , PIs-90

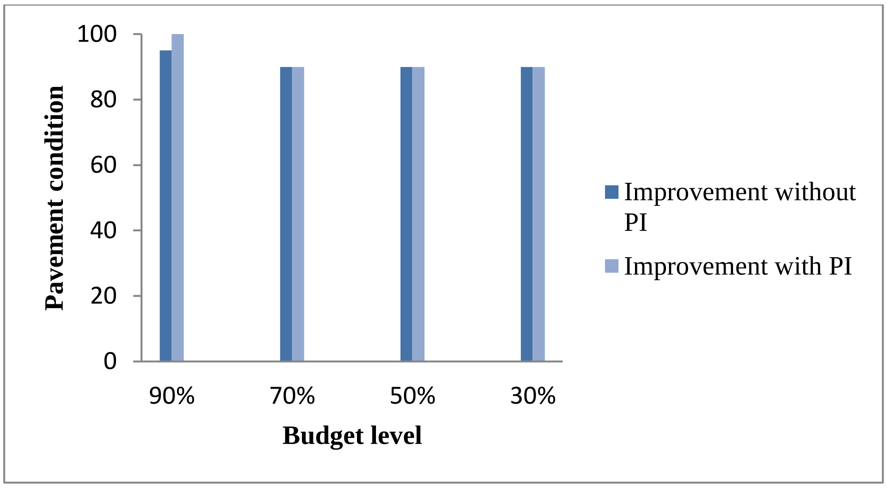

Figure 4.4: New Condition of Section 7 - Qbs- 85 , PIs-90

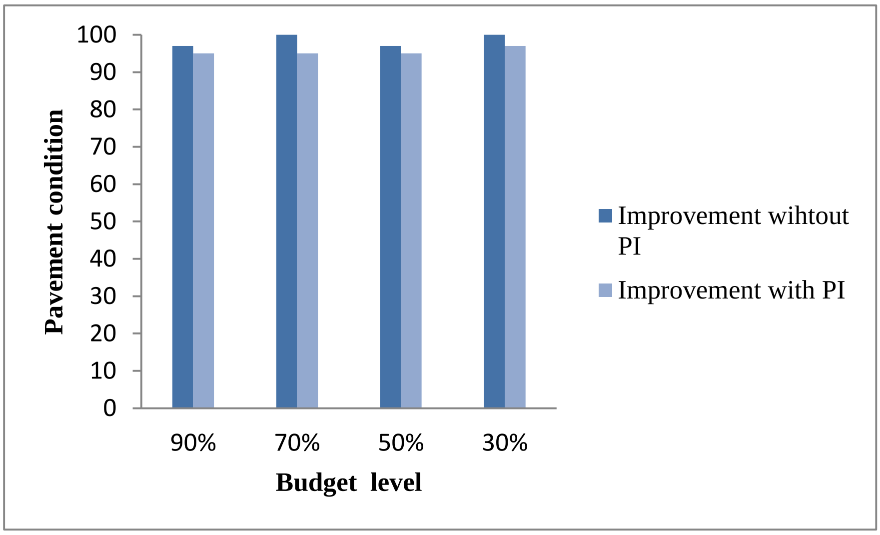

Figure 4.5 : New Condition of Section 3 - Qbs- 95 , PIs-10

5 CONCLUSION AND RECOMMENDATION

In this study, a combined approach of prioritization and optimization for road maintenance planning has been introduced. The proposed method generates an optimal maintenance plan for a road network while considering the priority weight of each road section.

The proposed approach intends to address the some of the issues prevailing in provincial road agencies. Major issues and constraints faced by the agencies were lack of resources for extensive data collection, complex analytical methods for pavement management, external influences and lack of methods for including socio-economic factors in the pavement maintenance decision making.

Inconsistency in judgments is one of major limitations of prioritization methods used in pavement maintenance planning. In order to overcome the limitations associated with ordinary subjective prioritization, it is necessary to determine a reasonable procedure for assessing maintenance priorities. For the purpose of prioritization of road sections five main prioritization factors were found. A higher weight was given to importance to community factor followed by pavement condition, traffic volume, connectivity to road network and land use pattern. Consistency ratio for all criterions is less than 0.1 and it's accepted the results of AHP.

The Priority index that is computed for different roads is incorporated in to the optimization model. The importance of incorporating priority index which is based on several non-technical factors is that it allows the road agencies to consider the needs of the communities without totally neglecting them. This will increase the acceptance of such a system for maintenance planning in provincial road agencies, where often maintenance decision making is often highly ad-hoc and politicized.

Maintenance strategies obtained by reducing the available annual budget were oscillating without decreasing according to the budget change. Improvement is considerably high for lower priority sections under the non priority scheme when compare to the priority scheme improvement. This implies that the incorporation of priority index to the optimization model gives the practical solutions. Maintenance operations program obtained for the road network without assigning Priority index for all road sections (non prioritized scheme) shows the similar variation but different operations due to non prioritized scheme.

The developed model does not require extensive data collection as the type of pavement condition of road sections can be defined by the user; hence it can vary from a PCI derived from detailed distress surveys, IRI or simple qualitative rating of the pavement condition. Therefore the proposed model can introduced as effective system to be used to select road sections for maintenance planning in a provincial road network in an optimal manner.

Other factors such as road safety, road upgrading priority can also be incorporated into the prioritization model. Road user cost function can be added for the optimization model and road maintenance cost can be included as a function of road condition. They can be considered as recommendations to the developed model.

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APPENDIX A- PRIORITIZATION MODEL DETAILS

Table A1: Priority Factor Scores for Road Sections

Section No	Length	IRI	ADT	Connectivity		Land use pattern							Importance to community			
				From	To	Residential			Agri/Industrial	Commercial			a	b	c	d
						High	Medium	Low		High	Medium	Low				
1	1.9	2.3	9850	20	20	10	0	0	0	0	5	0	5	0	0	5
2	11.54	3.8	7100	20	20	0	5	0	0	0	0	2	5	0	5	0
3	5.74	1.5	8350	20	15	10	0	0	0	0	5	0	0	0	0	5
4	15.28	6.5	6250	20	15	0	5	0	10	10	0	0	5	5	5	0
5	3.7	2.7	7850	15	15	0	0	2	0	0	5	0	0	0	0	5
6	10.8	2.3	4600	15	15	0	5	0	10	0	0	2	5	5	5	0
7	16.4	1.7	6000	20	15	0	5	0	0	0	5	0	0	5	5	0
8	1.08	2	5100	20	10	0	5	0	0	10	0	0	0	5	0	0
9	12.16	3.8	6150	20	20	0	0	2	10	0	5	0	5	5	5	0
10	7.564	5.8	5750	15	20	10	0	0	10	0	5	0	5	5	5	0
11	5.28	4.5	6300	20	15	0	0	2	0	0	5	0	0	5	0	5
12	2.86	5.8	1350	20	5	0	0	0	0	10	0	0	0	0	0	5

Table A2 : Land Use Pattern Weights

A	Agricultural/ Industrial	0.25
R	Residential	0.5
Co	Commercial	0.25

APPENDIX B – OPTIMIZATION MODEL DETAILS

Table B1 : Variable Set of Optimization Model

X11	X21	X31	X41	X51
X12	X22	X32	X42	X52
X13	X23	X33	X43	X53
X14	X24	X34	X44	X54
X15	X25	X35	X45	X55
X16	X26	X36	X46	X56
X17	X27	X37	X47	X57
X18	X28	X38	X48	X58
X19	X29	X39	X49	X59
X110	X210	X310	X410	X510
X111	X211	X311	X411	X511
X112	X212	X312	X412	X512

Table B2 : Treatment Cost

Treatment Type	Operation	Cost(m) /km
T1	Do minimum	0
T2	Non-structural maintenance	0.25
T3	Minor rehabilitation	0.5
T4	Medium rehabilitation	2.438
T5	Major rehabilitation	4.31

Table B3: Improvement of Index after Applying Operations

Present Index	T1	T2	T3	T4	T5
>90	0	2	5	10	15
80-90	0	2	5	10	15
70-80	0	2	5	10	15
60-70	0	2	5	10	25
50-60	0	2	10	25	35
40-50	0	2	10	25	45
30-40	0	2	15	35	50
20-30	0	2	15	35	60
10-20	0	2	20	45	70
0-10	0	2	20	45	80