International Journal of Engineering &Technology, 8 (2) (2019) 95-101

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Critical review of flexible pavement maintenance management systems

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Abstract

Worldwide, the national road has a very important role to sustain and to increase the region's economy, while its maintenance plays an essential and integral part in the life of road pavement. The road pavement maintenance management system (PMMS) is a systematic method for inspection and rating the pavement condition which ensure a timely maintenance solving altogether all undetected pavement defects. Defects in pavement is an issue of multiple dimensions which is due to the unforeseen increase of axle loading of commercial vehicles, the ad-hoc rapid expansion of the road network, the non-availability of up to date technology and equipment, poor quality of construction material, unavailability of skilled labor and lack of adequate funding provision. Essential road pavement maintenance is a set of activities directed towards keeping it in a serviceable state during its design life involving a variety of operational procedures such as identification of deficiencies, programming and scheduling for actual implementation in the field. Thus, the essential objective should be to keep the road surface and appurtenances in good condition and to extend the life of the road assets to its design life. Broadly, the activities include identification of defects and the possible cause there off, determination of appropriate remedial measures; and implementation these in the field inclusive of monitoring of the results. It is hope that the conclusion from this study will allow relevant authorities to employ a state-of-the-arts road maintenance system that is compatible to Highway Development and Management (HDM-4) analysis.

Keywords: *Pavement Maintenance Management System (PMMS); Systematic Road Pavement Maintenance Approach; Highway Development and Management (HDM-4)*

1. Introduction

A road network system is perhaps one of the most important necessities for the economic development in Malaysia, invest huge amount on road construction, while many developing in Malaysia appreciate the necessity for huge investment in the capital development of roads. Only a few gives due importance to road maintenance. It is found more glamorous to embark on new construction than to maintain what is already in existence [1]. But unfortunately, pavement structure can be destroyed in a single season due to much different penetration. Maintenance activities may be required at intervals throughout the year, but their frequency varies with traffic, topography and climatic conditions, type of roads, grading and repairing potholes and ruts for paved roads Maintenance activities may or may not be federal-aid eligible. Preventive maintenance activities are potentially federal-aid eligible. Reactive maintenance is not. The Pavement Management System yearly pavement condition reports help identify whether a project is reactive or preventive. Maintenance activities are either preventive or reactive. Preventive maintenance is doing the right thing at the right time before deterioration of the road occurs. A reactive maintenance repair to the road after deterioration has occurred. Transportation contributes to the economic, industrial, social and cultural development of any country. Transportation is vital for the economic development of any region since every commodity produced whether it is food, clothing, industrial products or medicine needs transport at production and distribution stages. The inadequate transportation facilities retard the process of socio-economic development of the country. The adequacy of the transportation system of a country indicates its economic and social development. The most demanding fact is that this country needs to provide road links both for major proportions of villages and marked centres like significant important roads, important buildings, destinations of schools and hospitals, etc [2]. Malaysia has a largest Road Network System expanded from 61,420 km State & Municipality Roads, 18,904 km Federal Roads, 1,820 km Toll Highways, and TOTAL = 82,144 km, mostly paved with the flexible/rigid pavement. Road user safety, comfort, and cost are influenced to a large extent by its state of maintenance. The quality of roads is a critical indicator of a nation's economic vitality because a poor road transport system can constrain the location of economic activity, hamper the integration of economic markets, limit the gains from specialization and eventually become a major barrier to growth and competitiveness. Roads Construction involves substantial investment and therefore proper maintenance of these assets is of paramount importance [3]. Malaysia large road networks built at great expense have been inadequately maintained and used more heavily than the design values. The deficiencies affecting road system apart from inadequate capacity and insufficient pavement thickness include poor riding quality, week and distressed bridges/culverts, congested sections, excessive axle loading, and lack of wayside amenities and enforcement. Factors that contributed in this direction are flexibility, door to door service, reliability and speed.

2. Basics and concepts of pavement maintenance management system

The pavement maintenance management system is a set of tools that helps decision maker to determine optimal strategies for existing pavement condition by evaluation and maintenance of the pavement to reserve an acceptable serviceability for a desired period. For a small city or rural roadway networks, a simple system based on visual inspection may be enough [4]. On the other hand, for a bigger city or urban roadway network, an automated monitoring system is usually appropriate. The function of PMMS is to provide feedback data to improve the efficiency decision-making. The system of PMMS needs huge massive data to store in the database, then, through processing, the system will convert them into information [4]. The information after processing is used in supporting the decision and planning. Fig 1 illustrates the system framework.

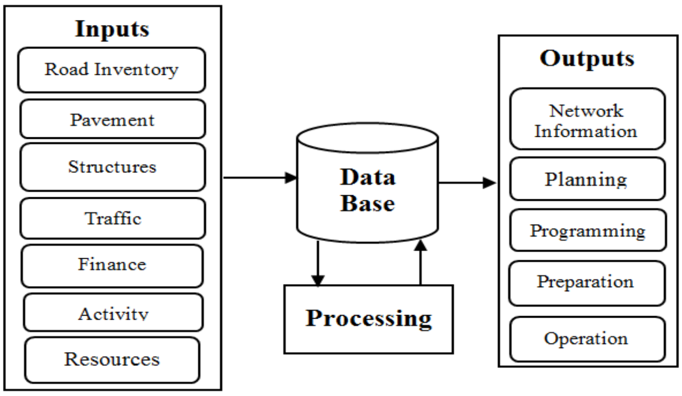

Fig. 1: Modular System Framework, by Sarsam [4].

3. Systematic review on pavement maintenance management system

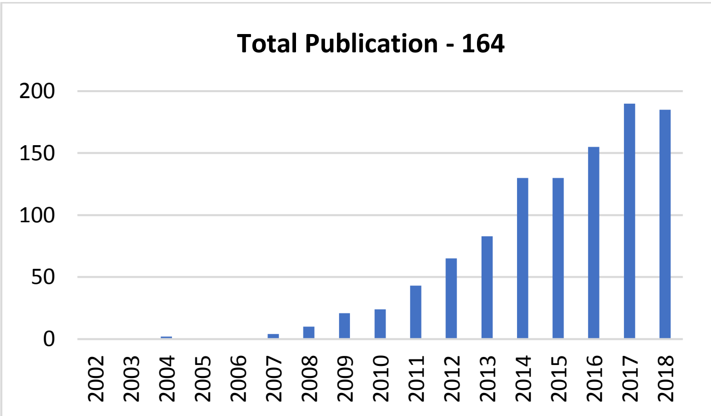

Fig. 2: The Number of Journal Publication on Pavement Maintenance Management System (Keyword Used for Search Pavement Maintenance; ISI Web of Knowledge, Thomson Reuters http:// http://apps.webofknowledge.com.ezproxy.utm.my/ august 15. 2018.

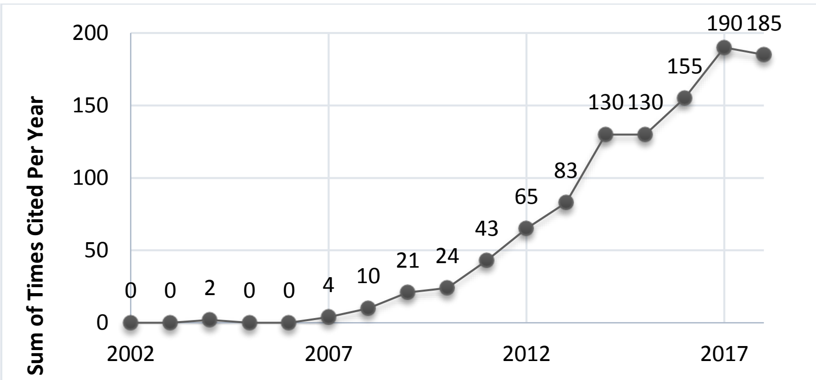

Fig. 3: The Sum of Times Cited Per Years on Pavement Management System (Keyword Used for Search Pavement Maintenance; ISI Web of Knowledge, Thomson Reuters http:// http://apps.webofknowledge.com.ezproxy.utm.my/ august 15. 2018.

4. Types of maintenance management system

There are two types of maintenance management system, the first one is the information system, which collects, organizes and stores data as network information. The second type is the decision-support system, which comprises applications modules to process the data and to provide the information on which decisions can be based, and ultimately implemented [5]. The system has four stages, planning; programming; preparation; and operation. The planning stage of the decision-support system is undertaken to develop long-term and strategic plans for the roadway network as a whole; planning time is typical of five years or more undertaken to determine future budget needs, consequential pavement conditions, and user costs [6, 7].
The tactical programming stage of the decision-support system is concerned with determining need in the budget year; planning time is typical of one to three years; including identification of sections from the network, which require treatment, and the suitable timing of treatments, it is also concerned with cost estimating, prioritization, budgeting, monitoring. The third stage of the decision-support system is for project preparation, including project formation and design, costing, works order or contract preparation and issue. The fourth stage of the decision-support system is for the management of operations on a daily or weekly basis. It includes defining work to be carried out, developing appropriate costs and requirements of labour, equipment, and materials, and making arrangements for carrying out the work by self-force or by contract [8].

5. Levels of pavement maintenance management system

Pavement management may be implemented at the project level and the network level. Network level management is concerned with the evaluation of all pavements under an agency's responsibility. The main goal of network level management is to prepare an agency-wide prioritized pavement repair program that will yield the greatest benefit or least total cost under overall budget constraints. Also, network level management depends on more approximate data than project level management [9]. At the network level, questions concerning short and long-range budget needs and the overall condition of the network (both current and future) are answered. In addition, network level management assists in prioritizing which pavement section should be rehabilitated, reconstructed or has maintenance performed on them [4]. The level of inspection utilized in this type of evaluation is generally basic, consisting mainly of visual inspection of a portion of the surface of each of the pavement sections contained within the network.
On the other hand, Project level management is concerned with a location and it usually comes after the analysis of network level in local agencies. Once a section has been identified for repair at the network level, then an engineering analysis is performed at the project level. A more detailed evaluation is required through this analysis since the information collected at the network level does not normally contain the type of data required to make detailed decisions for an individual project design. During a project level analysis, additional testing such as visual inspection, nondestructive and coring testing are often conducted to give additional information about pavement condition and the cause of deterioration [5].
At the project level, management decision is made regarding to the most efficient maintenance and rehabilitation alternative for a given pavement section. The evaluation of the project level is more weighted in analysis manner than in the network level. The pavements that were assigned as candidates for maintenance and rehabilitation actions during the network - level analysis is further assessed. A higher sampling rate for pavement inspection is often used. In addition, a supplementary testing methods such as texture and roughness test may be conducted based on specific needs [10].

6. Optimization of maintenance requirements

To optimize the processes of treatment selection, the selection process always incorporates more than one pavement condition indicator such as; distress types and roughness index, structural capacity index, skid resistance number, and the expected increment in pavement service life if such alternative is implemented. Cost analysis shows that some required maintenance tasks can be accomplished by several alternatives that differ in both costs incurred and degree of performance obtained [4, 10]. The effectiveness of each alternative is, therefore, expressed in its cost than compared. The basic criteria for selecting the optimum alternative using cost-effectiveness analysis is to maximize net benefits, minimize the number of resources required to achieve a given level of service and meet other requirements demanded of the situation, and maximize the level of service or from a given level of investments and operating costs. As long as cost constraints can be pre-established, while significant variations in the level of service and other objectives can occur among alternatives, this criterion can provide a basis for evaluation [10].

7. Problems incorporating the implementation of PPMS

The need to process data and provide meaningful information through management reports for the maintenance process can be greatly facilitated by using computer. The installation of operational management system can, therefore, make an essential contribution to the effective operation of highway organizations [4, 10]. The system needs to be structured to support the primary management functions of planning (including budgeting), organizing (including staffing), directing, and controlling. Unfortunately, experience with the implementation of system in many countries has been disappointing. Reasons for this include:

a) User attitudes which include a lack of genuine commitment to the implementation; expectation of high-tech solutions when, in fact, simple common-sense solutions are appropriate; and resistance to change.
b) Cultural issues including problems of introducing modern management practices, and including incentives, into cultures with no management tradition.
c) Economic and financial problems, which is concerned with weak local economies and foreign exchange shortages preventing the purchase of even basic commodities needed to support the system; and local budgets dominated by the payment of staff salaries, with residual funds being insufficient to pay for maintenance works to be carried out.
d) Key staff positions not filled or filled with a staff of insufficient experience.
e) Training which includes operational requirements preventing local staff being released for training, over-ambitious training programs with instructors being inadequately prepared, and insufficient follow-up training and revision.
f) Deficient computer facilities and inadequate availability of hardware, and poor availability of data.
g) Systems being too complicated and demanding to be sustainable with local resources.

8. Life cycle analysis and research framework

Designing the framework of pavement maintenance practice involves different stages Fig 4, below shows each stage involves in preparation to produce a final output map of pavement maintenance practice on basis of various types of criteria.

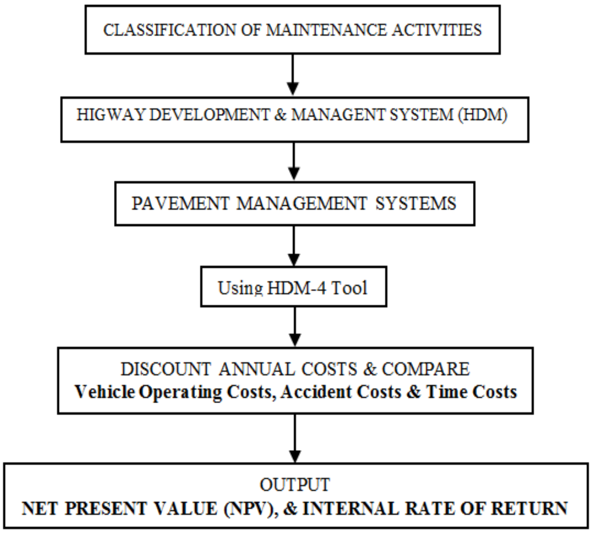

Fig. 4: Life Cycle Analysis and Research Framework.

9. Classification of maintenance activities

Engineering maintenance as far as the road is concerned should be taken as comprising several small-scale engineering activities that are carried out at varying intervals, depending upon climate, terrain, traffic and design standards of the roads. All the operations described here are aimed at keeping or restoring the road to a state of preservation and acceptable standards for its current and intended uses [11, 12]. These operations can be classified as routine, recurrent, periodic and urgent. The routine activities are likely to be required, irrespective of the engineering characteristics of the road or the density of traffic it carries. Cost activities include grass cutting, cleaning of ditches, culverts and bridges and road sign maintenance, however the maintenance of highway is classified under the following categories:

- **Routine Maintenance**

Activities involved in routine maintenance are irrespective of the engineering characteristic of road and density of traffic carried by it. These are required to be carried out throughout the year.

- **Periodic Maintenance**

It is nothing but periodic renewals of the existing surface. In this type of maintenance, a surfacing layer over the pavement at regular intervals of time to preserve the characteristics of the pavement and offset the wear and tear caused by traffic, weathering, etc. and thereby prolongs the life of the pavement.

- **Special Maintenance**

The type, frequency, and degree of maintenance of pavements can influence performance and time at which major rehabilitation such as overlay is required. Pavement rehabilitation is performed due to the existing distress and improves riding quality, and to increase the structural capacity of the pavement.
The overlay is generally laid when Characteristic Deflection (CD), Rut Depth Index (RDI), Crack Index (CI) and Roughness Index (RI) reach acceptable limits.

10. Highway development and management system (HDM)

In the last twenty years, the maintenance management system has improved significantly due to the advances in computer technologies. However, the highway administrators have a series of tools or mechanisms that allow them to make a better use of the available resources for the maintenance and rehabilitation. but are not acceptable globally. Hence, these tools are lacking in universal acceptance and implementation. The World Bank has developed Highway Development and Management System (HDM) which is an internationally recognized tool available for making timely and cost-effective maintenance management decisions for urban road network. HDM system could be implemented to assist the highway agencies for establishing realistic levels of funding, and to set levels and priorities to maximize the effectiveness of expenditure on pavement maintenance activities

11. Pavement management systems

Pavement management systems are recognized as important tools to help transportation agencies optimize the use of available funding, better communicate funding needs, and more objectively manage their pavement network. The American Association of State Highway and Transportation Officials (AASHTO) defines pavement management as “the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life-cycle cost (AASHTO, 1985).” This concept of providing pavements and maintaining them in acceptable condition is as old as the first pavement. The following sections list and discuss contemporary research papers that focus on the maintenance of pavements. [13], [14].

One important aspect is to consider the possibilities of performing future maintenance activities. Often the need for a specific maintenance measure is caused by problems only at a specific location on the road [14]. The cost of carrying out these measures can be very high. Some of these problems could probably be considerably reduced by a more suitable design. The designers should take maintainability into consideration to a higher extent than today, insufficient consideration of maintainability during the road planning and design process is a well-known problem for actors involved in this process and in maintenance activities [15].
Study carried out by Nurul Hidayah Muslim [16], to compare the two different practices on road maintenance; traditional method and automated method, the comparative study was conducted interviews among five expert panels in road maintenance sector and the interview was divided into three sections, which consist of panels' information, preliminary questions, and detailed response on the adopted method. Based on interviews conducted, it is concluded that the automated method has long-term benefits compared to the traditional method. It is obvious that several comments made by expert panels likely reflect the dissatisfaction level of users, issues of discrepancies in information, insufficient funds to adopt high technology tools, cost saving and time efficiency, work prioritizing, and to overcome workmanship issue, the below Fig 5: rating analysis on Summary of Interviews on Adopted Road Maintenance Practices

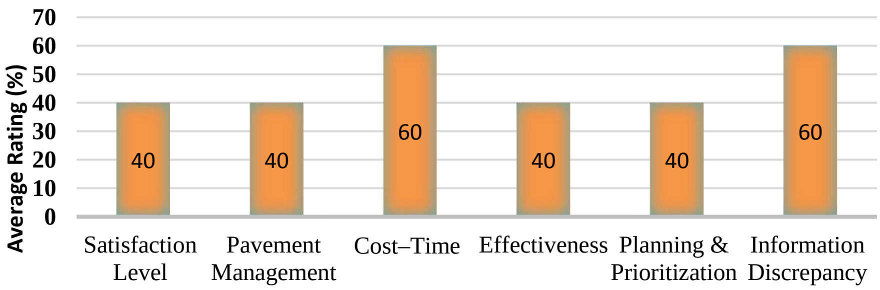

Fig. 5: Rating Analysis on Summary of Interviews on Adopted Road Maintenance.

12. Using highway development and management system-4 (HDM-4) tool

The Highway Development and Management System is a decision tool to help you investigate your road investment choices. HDM-4 is a computer software for Highway Development and Maintenance Management System. It is a decision-making tool for checking the Engineering and Economic viability of the investments in road projects [17].
Čutura, et al. [18], Using the HDM-4 model it is necessary to collect a large number of input data such as inventory and current condition of the Road data, vehicle characteristics and traffic loading, climatic conditions, etc. [19], the Highway Development and Management System (HDM-4) the system has been developed after a series of studies carried out in different countries of the world. Though initiated by World Bank in the late sixties, many leading research institutions of the world have contributed immensely in its development during the last three decades. Following are the three main areas of analysis in HDM-4 which can be undertaken using the following applications Project analysis, Programmed analysis, and Strategy analysis [17].

Project Analysis: Project analysis is concerned with the evaluation of one or more road projects or investment options. It includes the appraisal of M&R options for existing roads, widening or geometric improvement schemes, pavement upgrading, new road construction, etc.
Programme Analysis: Programme analysis is concerned with the preparation of work programmes in which candidate investment options are identified and selected, subject to resource constraints. Road networks are analyzed section by section and estimates are produced of road works and expenditure requirements for each section over a funding period. Programme analysis may be used to prepare multiyear rolling work programmes.
Strategy Analysis: Strategic planning is concerned with the analysis of a chosen network as a whole. A typical application is the preparation of long-range planning estimates of expenditure needs for road network development and maintenance under different budget scenarios. Estimates are produced for expenditure requirements for medium to long-term periods of between 5 to 40 years.

13. Vehicle operating costs, accident costs & time costs

Fuel consumption cost is frequently the most significant component of Vehicle Operating Costs (20% to 40%) and the one with the most research work. Recently fuel consumption has been modelled using mechanistic principles that relate consumption to the motion opposing forces [20]. On the other hand, the engine oil consumption cost represents a very small contribution to the total Vehicle Operating Costs, therefore. However the tyres are concerned, and although the tyre consumption costs can represent a significant contribution in the total Vehicle Operating Costs, especially in heavy trucks [21].
The Accident Costs assessment is complex (especially accident predictions) but the increasing cost of road accidents justifies the consideration of possible accident savings, especially in low-medium design standard roads, as well as Vehicle Operating Costs reductions and time saving in economic appraisals [21].
Due to the inability to predict accidents based on road design characteristics, as acknowledged by several published data, methodologies like the ones adopted by COBA and HDM-4 developed flexible and simple look-up tables to obtain accident predictions [20]. In these tables, accident rates are obtained according to road category and urban/rural location [21].
Most of the models allow separate estimation of a number of accidents taking place in intersections, sections and total (intersection and section), and consider three types of accidents: fatality, injury and damage only [21].
The value of time, related to time savings, is an important variable for economic analysis varying according to road improvement scenarios which result in significant changes in operating vehicle speed [20]. Value of time evaluation is normally made by attributing a mone-

tary value to user time in travel, usually as a function of an average wage. Most of the existing models distinguish between two main purposes of travel: travel in the course of work activities and travel for non-work purposes [21].

14. Discount annual costs and compare

14.1. Net present value (NPV)

Net Present Value and Internal Rate of Return were indicators used in the cost analysis of commercial poplar plantations worldwide [22], Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. NPV compares the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. NPV analysis is sensitive to the reliability of future cash inflows that an investment or project will yield and is used in capital budgeting to assess the profitability of an investment or project [23]. Net present value (NPV) is calculated using the following formula

$$\text{Net Present Value} = \sum \frac{\text{Year n Total Cash Flow}}{(1+\text{Discount Rate})_n} \quad (1)$$

Where "n" is the year whose cash flow is being discounted

$$\frac{FV_1}{(1+\text{Discount Rate})_n} \quad (2)$$

Where "FV" is the projected cash flow for each year and "n" is the number of periods out the cash flow is from the present.

$$\frac{FV}{(1+\text{Discount Rate})_5} \quad (3)$$

Where "FV" is the projected cash flow for each year.

14.2. Internal rate of return (IRR)

Internal rate of return (IRR) is the discount rate often used in capital budget that makes the net present value of all cash flows from a project equal to zero. The higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first [24]. Internal rate of return (IRR) is calculated using the following formula

$$\text{Net Present Value} = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{(1+IRR)^3} + \frac{CF_4}{(1+IRR)^n} \quad (4)$$

$$\text{Net Present Value} = \sum_{n=0}^{N} \frac{CF_n}{(1+IRR)_n} \quad (5)$$

Where:
CF_0 = initial investment/ outlay
CF_1, CF_2, CF_3, CF_4 = Cash Flows
n = Each Period
N = Holding Period
NVP = Net present value
IRR = Internal rate of return

15. Challenges and future scope of work

A lot of work has been done to identify construction and maintenance challenges, in cold and hilly areas. The data were arranged about how to prevent the roads from frosting and securing road constructions [25], On the basis of various previous researches, a strategy was developed to prevent the formation of frost [26], The area surrounding river Jhelum has a soil that remains mostly saturated and thus retains more water. Since the area has mainly the flexible pavements, a lot of settlements occur there even at lesser loads [27], There is not much impact on the rigid and semi-rigid pavements, although there may be refection cracking due to differential settlements in the subgrade. Thus flood, Ground frost, and Drainage problems mainly affect the pavement and hinder the construction work [27, 28].

The factors that affect the deterioration of highway pavement can be categorized as follows: **1**. Pavement characteristics: pavement strength, layer thicknesses, base type, surface type. **2**. Pavement history: time since last rehabilitation, total pavement age. **3**. Traffic characteristics: average daily traffic, cumulative traffic, traffic mix (percentage of trucks). **4**. Environmental variables: average monthly precipitation, number of freeze-thaw cycles, average annual minimum temperature, and so on [29].

Insufficient consideration of maintainability during the road planning and design process is a well-known problem for actors involved in this process and in maintenance activities. The problems of performing maintenance activities and their related costs are often subject for discussion. This is not reflected in the literature as the published research within the subject is very limited. Efforts have been made to compile the various factors in the road design that generate unnecessary maintenance needs [15],

Based on the cost-benefit analysis, maintenance costs have been considered in simplified graphs to determine the need for road barrier installation [30]. Another study has compared different guardrail end terminals from a maintenance point of view [31]. Yet another study has concluded that a 100-year design life gives the lowest lifecycle cost for urban residential roads [15].

16. Conclusion

Most of the local government departments, responsible for the maintenance of rural roads, do not have a systematic process for taking maintenance and rehabilitation decisions logically. The instruments used for getting the relevant data do not always provide consistent data due to variation in field conditions. This review paper summarized the diffuse literature on the flexible pavement and its maintenance is a problem for a long time and there is a need for identification of problems and rectifying them. Thus, it is concluded that a research needs to be done to see the various alternatives which can be adopted. The methods of detecting, classifying and repairing pavement system failures require using proper techniques, materials, and implementation of an economic feasibility study. The key to solving pavement system failures is the establishment and use of an on-going method of repetitive repair processes integrated into a long-term maintenance and management strategy. Though the desired condition is to prevent being placed in the position of needing failure analysis by extensive front-end planning and design, following good construction practices and controls, and developing and utilizing an active pavement management program, some failure is inevitable.

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