A GENERAL STUDY ON LIFE CYCLE COST ANALYSIS FOR ROADS

A Thesis submitted in partial fulfillment of the requirements for the award of the Degree of

Master of Technology

in

Transportation Engineering

by

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DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA - 769008

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CERTIFICATE

This is to certify that the thesis entitled "**A GENERAL STUDY ON LIFE CYCLE COST ANALYSIS FOR ROADS**" submitted by **Mr. ARIJIT DUTTA** (Roll No. 212CE3056) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Transportation Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

Life cycle cost analysis of existing road is becoming more significant to determine the proper time of maintenance and the proper action, which should be taken for maintenance. An efficient maintenance policy is essential for a cost-effective, comfortable and safe transportation system. But, the decision to maintain the road facilities, consider a number of possible ways from routine maintenance action to reconstruction of the road network. Moreover, an economic analysis of a road network is dependent upon a number of factors, which are responsible for deciding road serviceability level. Optimization model is an analytical model, which helps to make a cost benefit analysis and compare that with various possible alternatives to give out the best possible activity within the allocated budget, before being carried out in field work.

In the present study, the aim was to develop a general optimization model to give the most cost-effective activity. The choice of maintenance action is divided in four groups from no action to rehabilitation. Various factors like traffic growth, environmental conditions are taken into account, along with the International Roughness Index (IRI). 'C' language program is used to formulate the model.

Keywords: Life cycle cost analysis, Optimization model, 'C' language program, Maintenance, Rehabilitation, IRI.

Contents

Contents	Page No
Abstract	1
List of tables List of Figures	3
Chapter 1	1
1.1 Introduction	2
1.2 Objective of Project	3
Chapter 2	4
2.1 Literature review	5
2.2 Summary	8
2.3 Problem Statement	9
Chapter 3	10
3.1. Empirical study & Analysis	11
3.2 Regression Analysis	13
Chapter 4	14
4.1 Proposed Model	15
4.3 Algorithm of C language programming	24
Chapter 5	27
Result & Discussion	28
Chapter 6	29
6.1 Conclusion	30
6.2 Scope of future work	31
Chapter 7	32
Reference	33

List of tables **Page No**

Table 3.1 Primary factor for cost analysis & their values 11

Table 4.1 Respective PSR values of IRI values 16

Table 4.2 Choice of maintenance 19

Table 4.3 Cost of maintenance actions 21

Table 4.4 Type of maintenance over year 24

List of figures **Page No**

2.1 Analytical representation of pavement maintenance 7

3.1 Relationship between traffic growth and time 13

3.2 Relationship between impact of climatic condition and year 13

3.3 Relationship between impact of external features and year 14

3.4 Relationship between impact of environmental condition and year 14

CHAPTER 1

1.1 INTRODUCTION

1.2. OBJECTIVES

1.1. Introduction

Road authorities of all around the world are finding and innovating ways to cope with the high cost of road network maintenance, the increasing demands of road users and the changing traffic type and volume. The road network plays a vital role in contributing to the economic, social, cultural and environmental development of the country. A well-maintained road is needed to make the network sustainable for future generations. Improving road maintenance management has become a key factor in developing nations like India.

As per a student paper submitted on 2006 at Atlantic International University, Life cycle cost analysis (LCCA) is a financial analysis instrument which is valuable in deciding the execution of a roadway. The instrument thinks about and examines the relative monetary alternatives of diverse constructional and recovery plans for a roadway. It decides the execution data by analysis of pavement administration information and verifiable experience to assess the pavement condition.

As per Bangasan (2006), Life-Cycle Cost Analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.

As the past studies like Bangasan (2006), Lamptey (2005), are more focused on case specific cost analysis it is much needed that a general form of such analysis will prove much more useful in future. In this study an effort to generalize the LCCA of roads is attempted.

1.2. Objectives

The main objective of this study is to review few literatures on life cycle coat analysis of roads and apply some of them to develop a model as a general form to analyze life cycle cost analysis of roads in general. Development of an optimization model can be more useful if along with reduction of maintenance cost, the road condition also improves and being serviceable for a longer duration during the design period.

The thesis is divided into five chapters of which this is the first. The second chapter presents a review of the past work done on LCCA in accordance with roads as well as the literature model development and expresses the motivation for this thesis.

In Chapter 3, the data calibrated for this thesis work are described. The governing factors such as the distress values and cost of maintenance works and their limitations are prescribed.

Chapter 4 describes in detail the proposed model for Cost analysis of roads. The chapter defines the model and presents the results obtained from the proposed model. These results are used to validate the model.

Chapter 5 concludes the thesis by summarizing the work done here.

CHAPTER 2

2.1. LITERATURE REVIEW

2.1.1. SUMMARY

2.2. PROBLEM STATEMENT

2.1. Literature review and motivation of work:

Jain et al. (2004) presented that the flexible maintenance strategies after an analysis period of twenty years can save more than thirty three percent highway agency cost than that of scheduled maintenance strategies. They compared their adopted model with predefined models on selected pavement sections. As the fund granted for maintenance management is only 60percent of the fund required, they prepared an optimized and prioritized work process for 60 percent budget availability. They showed us that the average roughness value of the highway network increases with reduction in budget levels, which in turn can lead to a very high road user cost values.

Zhang (2009) developed a new life cycle optimization model for pavement asset management system. He evaluated three potential overlay systems. One of these is a concrete overlay system. He observed the application of dynamic programming as an optimization tool in life cycle optimization of pavement overlay systems, which obtain outputs considerably faster and more accurately compared to conventional methods. His results demonstrate the importance of including user costs and roughness effects in pavement management accounting.

Whiteley-Lagace et al. (2011) attempted to show us the challenges and successes of implementing a pavement management system for roads. Their project team developed a 5 and a 10 year budget plans for road network and developed a number of recommendations to improve the level of detailed data to be added to the system to refine the models. They collected data for four years. They collected performance based data, which included the distress data for asphalt and concrete, gravel and native roads. They calibrated decision trees and cost models for all pavement types. They translated distress rating scores into individual distress index scores and then combined both to create a single surface condition rating.

Jhonson (2008) discussed about current issues facing roads managers. They discussed new methods to stabilize dirt and gravel roads, reclamation process for full depth of the roads. They provided information to support decision making of when to upgrade gravel roads. They also discussed cost safety improvements, farm to market road issues, best practices and resources in pavement design methods for roads.

Zhang et al. (2013) described about the development of a new pavement network management system that helps analysis and optimization. This LCCA optimization was implemented to regulate the optimum conservation scheme for a pavement network and to reduce supportability metrics within a given analysis period. They discussed about pavement deterioration, which is a main aspect to focus future pavement conservation procedures and is extremely difficult to focus faultlessly.

Pradhan Mantri Gram Sadak Yojona (2006) presented the choice of the appropriate economical and advantageous pavement type, was made by carrying out life cycle cost analysis, which takes into account the initial cost and the maintenance cost. They also presented the cost of construction for both rigid and flexible pavements. They also estimated an economical cost analysis, which showed us that the life cycle cost of concrete pavement is about twenty to twenty five percent lower than bituminous pavement.

Omkar et al. (2001) developed relationship between international roughness index (IRI) and present serviceability rating (PSR) for rigid, flexible and composite pavement types. PSR is defined as mean user panel rating for ride ability on the conventional 0 to 5 scale.

Virginia transportation research council report (2002) presented economic analysis components and cost factors for life cycle cost analysis. The report also showed us the different types of pavement maintenance option for rigid, flexible and composite pavements like asphalt concrete reconstruction, rehabilitation of rigid pavement with overlay, continuously reinforced concrete pavement construction, reconstruction with wide lane and ac shoulder.

A picture demonstration is given below to show how maintenance strategy and rehabilitation action taken into action for a pavement.

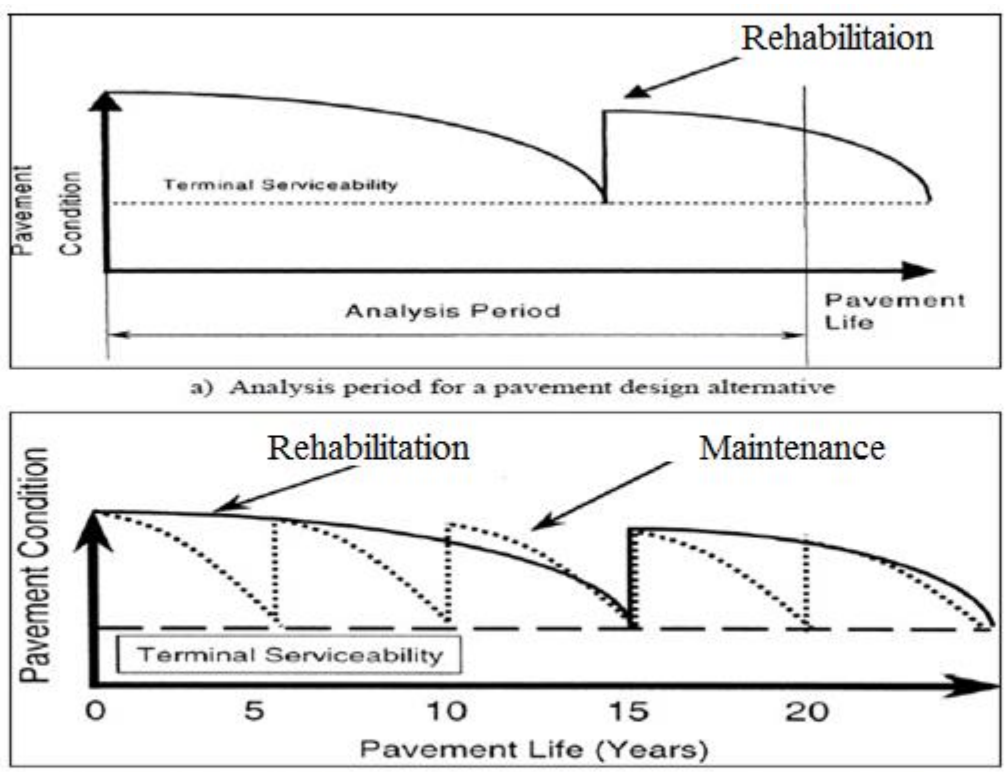


Figure 2.1 Analytical representation of maintenance (Adopted from Markov et al. 1987)

2.2. Summary

It is clear from the above study that there is no specific schematic for life cycle cost analysis process. Any general form for any roads can be taken into action. It is obvious from all the literature reviewed in this study that in spite of adapting different types of optimization models, there were some common factors of same centrality. Another thing is that life cycle cost analysis is more economically effective process for rigid pavements than flexible pavements.

2.3. Problem statement

In this study the motive was to develop a model for the following cases

- Low traffic growth
- Moderate weather in term of rainfall
- Stable area development

In this study an optimization model was developed, with respect to the above conditions. The pavement can be considered as a general pavement. For the chosen pavement a low traffic growth had been considered. The weather condition was taken as moderate condition. That means the impact of rainfall on that area is average. Urbanization and development of the area were also considered as average.

CHAPTER 3

3.1. EMPERICAL STUDY AND ANALYSIS

3.2. REGRESSION ANALYSIS

3.1. Empirical study and analysis

As the study is not case specific, from the past studies, assumptions were made to develop the optimization model. The elements considered are

- Traffic growth
- Climate
- External features
- Environment

Table 3.1 Primary factors for cost analysis & their values (adopted from report of annual conference of transportation association of Canada, 2001)

Year	Traffic growth	Impact Climatic condition	Impact of External features	Impact of Environmental condition
5	9.693%	20	8.0	20
10	9.932%	25	8.5	20
15	5.806%	30	9.0	20
20	2.118%	35	9.5	20
25	1.128%	40	10.0	20
30	0.925%	45	10.5	20

- **Traffic growth:** Traffic growth denotes the increment or growth of traffic volume in the given road section over past years. In this study traffic is represented as the axle load of vehicles. It showed the growth of traffic in percentage with a gap of five years.
- **Climate:** Climate is a measure of the average pattern of variation in temperature, wind, precipitation and other factors. Rainfall or precipitation is the main factor for pavement deterioration. And assumptions were also made to present the climatic condition as a factor.
- **Other factors:** In this study urbanization and development of the area were considered as the other factors in percentage. These factors have huge impact on pavement life.
- **Environment:** Environment is the surroundings of a physical system that may interact with the system by exchanging mass, energy, or other properties. This environmental factor which is presented in percentage is more or less same throughout the life period of a pavement.

By considering the factors traffic growth, climate, external features and environment a graph was developed as shown below.

By slope analysis and regression model criteria an equation was developed.

3.2. Regression analysis

As per Wikipedia, regression analysis is a measurable methodology for evaluating the connections among variables. It fuses numerous methods for displaying and examining a few variables, when the center is on the relationship between a ward variable and one or more autonomous variables. The focus of estimation is a capacity of the autonomous variables called the regression capacity.

$$Y = 0.412*Xa + 5*Xb + 0.5*Xc + Xd \quad \text{...equation (1)}$$

Where,

Xa = cost parameter for traffic growth = (percentage of traffic growth * cost for that growth)

Xb = cost parameter for climate = (climate condition percentage * respective cost)

Xc = cost parameter for external features = (effective external features percentage * respective cost)

Xd = cost parameter for environment = (environmental factor percentage * respective cost)

Y = optimized total cost.

These respective costs are summation of material cost, labor cost and transportation cost.

CHAPTER 4

4.1. PROPOSED MODEL

4.1.1 FLOW CHART OF ‘C’ LANGUAGE PROGRAMMING

4.2. ALGORITHM OF ‘C’ LANGUAGE PROGRAMING

4.1 Proposed model

Life cycle cost analysis

According to Virginia research council report (2002), 'LCCA' is an economic method to compare among alternatives that satisfy a need in order to determine the lowest cost option. According to Chapter 3 of the AASHTO Guide for Design of Pavement Structures2, life cycle costs "refer to all costs which are involved in the provision of a pavement during its complete life cycle." These costs borne by the agency include the costs associated with initial construction and future maintenance and rehabilitation. In addition, costs are borne by the traveling public and overall economy in terms of user delay. The life cycle starts when the project is initiated and opened to traffic and ends when the initial pavement structure is no longer serviceable and reconstruction is necessary.

In this study no case study was taken into account. Hence, values were assumed from past studies. From that studies International roughness index (IRI) values were taken. And the IRI values vary between 80 inches per mile to 170 inches per mile.

In this study from IRI values helped to calculate present serviceability rating (PSR). Where, PSR is a parameter to indicate the road condition. It is used to estimate long term pavement rehabilitation needs. Generally PSR value ranges from 0 to 5 (very poor to very good).

From a past study of Al-Omari et al. (2005), following relationship was adopted for PSR values and IRI values. It was also observed that the IRI values for general roads varied from 80 to 200 inches per mile. Hence values within that range have been considered to determine the corresponding PSR values, as given in Table 4.1

$$\mathbf{PSR = 5*e^{-0.0041(IRI)}} \quad \text{...equation (2)}$$

Calculated PSR values with respect to IRI values are given in tabular form.

Table 4.1 Respective PSR values of IRI values (source:)

IRI (inches/mile)	PSR=5e^(-0.0041*IRI)
80	3.601
85	3.529
90	3.457
95	3.387
100	3.318
105	3.251
110	3.185
115	3.120

120	3.057
125	2.994
130	2.934
135	2.875
140	2.816
145	2.759
150	2.703
155	2.648
160	2.595
165	2.542
170	2.490

By the motivation from the methodology of Al-Omari and Dartetr (2005), the values are analyzed and the PSR values were divided into four groups:

1. A – PSR value greater than 3.200
2. B – PSR value between 3.200 and 2.800
3. C – PSR value between 2.800 and 2.400

4. D – PSR value less than 2.400

Depending upon the PSR values, the decision for pavement maintenance was chosen, as given below :

For,

A – no action, so choice is o

B – minor maintenance, so choice is 1

a) Milling, overlays, reclamation, interlayer
b) Filling, sealing, coating
c) Pre-overlay layer, rubblizing

C – major maintenance, so choice is 2

a) Thick overlays
b) Patching
c) Micro surfacing

D – rehabilitation, so choice is 4

This model is developed by using C language programming.

In computing, C is an universally useful programming dialect at first created by Dennis Ritchie between 1969 and 1973 at AT&T Bell Labs. Like most basic dialects in the ALGOL convention, C has offices for organized programming and permits lexical variable degree and recursion, while a static sort framework counteracts numerous unintended operations. Its outline gives builds that guide effectively to commonplace machine guidelines, and consequently it has discovered enduring use in provisions that had previously been coded in low level computing construction.

Table 4.2 Choice of maintenance

PSR	J (choice)							
	A	B			C			D
		a	b	c	a	b	c	
3.555	#	-	-	-	-	-	-	-
3.o12	-	#	-	-	-	-	-	-
2.929	-	-	#	-	-	-	-	-
2.807	-	-	-	#	-	-	-	-
2.705	-	-	-	-	#	-	-	-
2.546	-	-	-	-	-	#	-	-
2.452	-	-	-	-	-	-	#	-

2.103	-	-	-	-	-	-	-	#

By the model it is evident that the PSR value is solely responsible for choosing the maintenance method for the pavement, but the other factors which have major impact on the PSR value are traffic growth and weather condition. Hence, the study has combined the analysis part for more precise solution.

$$\mathbf{Z = 0.412Xa + 0.5Xb + 5Xc + Xd + PSR}$$

And for no action,

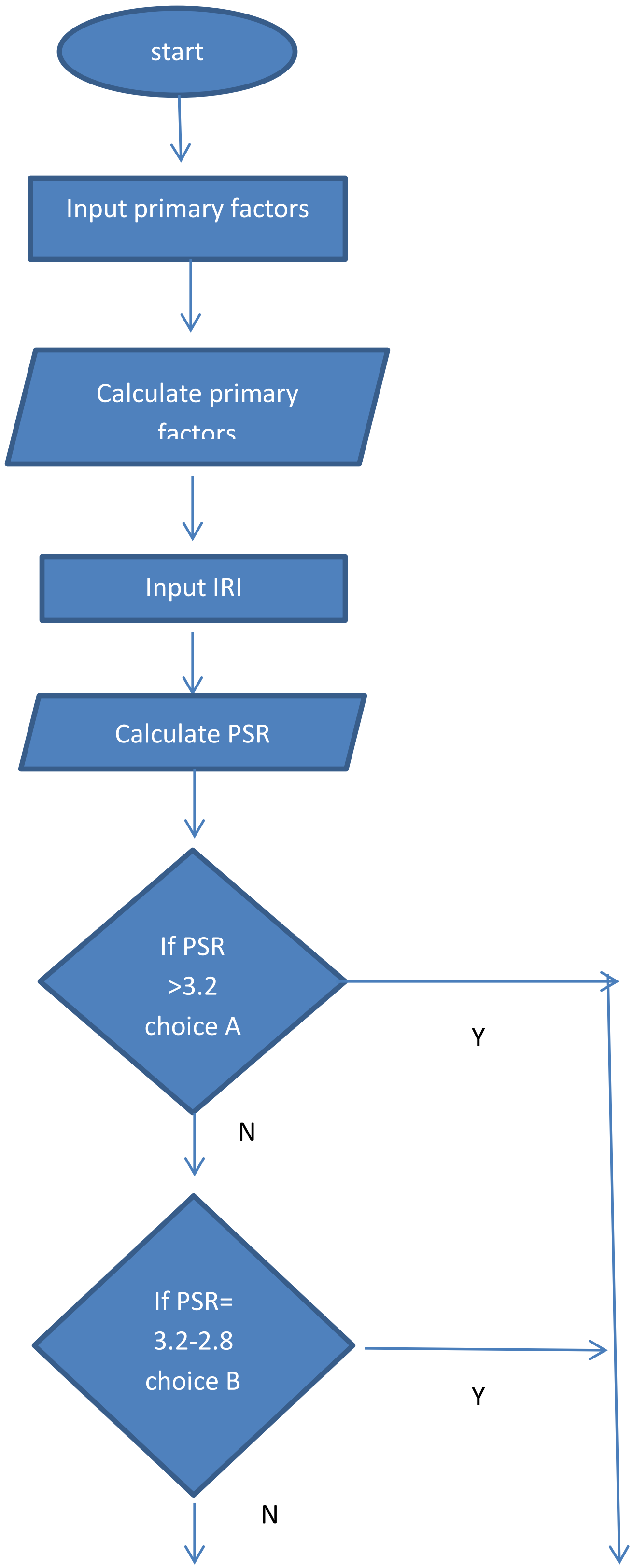
$$\mathbf{Z = Y = 0.412Xa + 0.5Xb + 5Xc + Xd}$$

In the above equation this PSR gave the choice of action. And depending upon the action the cost was calculated. There are different values for different type of maintenance. The calibrated values are given below in tabular form.

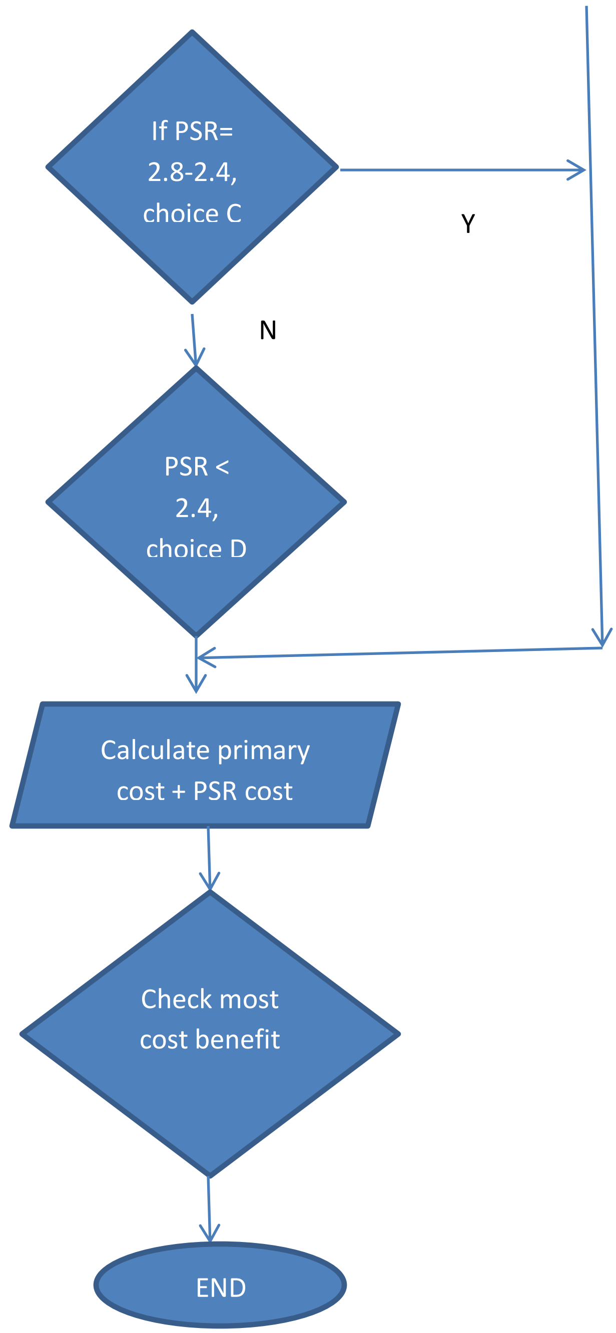
Table 4.3 Cost of maintenance actions

Primary choice	Secondary choice	Choice of action	Assumed Cost per unit area (material cost + labor cost)
B	A	Milling	565
		Overlays	1595
		Reclamation	3595
		Interlayer	2078
	B	Filling	447
		Sealing	520
		Coating	685
	C	Pre overlay	2254
		Rubbilizing	1257
C	A	Thick overlays	695
	B	Micro surfacing	3500
	C	Patching	898

4.2. Flow Chart



Continue..


If PSR=
2.8-2.4,
choice C
Y
N
PSR <
2.4,
choice D
Calculate primary
cost + PSR cost
Check most
cost benefit
END

4.3. Algorithm of C language programing

- Input primary factor and calculate the cost.
- Input IRI values and calculate corresponding PSR values.
- Divide the PSR values in four categories.
- Choose the action of maintenance.
- Calculate the total cost.

This study can provide a tabular form of cost analysis for a life period of 30 years. A generalized form is given below.

TABLE 4.4 Type of maintenance over year

Year	PSR	Cost			
		No action	Minor action	Major action	Rehabilitation
1	P1	A1	-	-	-
2	P2	-	B_b2	-	-
3	P3	A3	-	-	-
4	P4	A4	-	-	-
5	P5	-	B_{a5}	-	-

6	P6	A6	-	-	-
7	P7	A7	-	-	-
8	P8	-	-	C_a8	-
9	P9	A9	-	-	-
10	P10	A10	-	-	-
11	P11	A11	-	-	-
12	P12	A12	-	-	-
13	P13	A13	-	-	-
14	P14	-	B_C14	-	-
15	P15	A15	-	-	-
16	P16	A16	-	-	-
17	P17	-	B_a17	-	-
18	P18	A18	-	-	-
19	P19	A19	-	-	-
20	P20	-	B_a20	-	-
21	P21	A21	-	-	-

22	P22	A22	-	-	-
23	P23	-	-	C_c23	-
24	P24	A24	-	-	-
25	P25	A25	-	-	-
26	P26	A26	-	-	-
27	P27	A27	-	-	-
28	P28	A28	-	-	-
29	P29	-	-	-	D29
30	P30	A30	-	-	-

From the above table it is evident that, the choice of action is dependent on PSR value of the respective year. And it was assumed in the study that, if there is any need of minor maintenance on any given pavement, for the next two years no action will be the automatic choice. And for major maintenance the period of no action will be five years.

CHAPTER 5

RESULTS AND DISCUSSION

Results and discussion

It is evident from the table and the C programming output results that, $(B)_b$ is having the least value, whenever any kind of maintenance is needed. For major maintenance $(C)_a$ is having the least value among all major maintenances. So it can be said that, when the PSR values are between, 3.125 to 2.900 the cost incurred for maintenance seems to be least.

$Z_1(min) = 0.412Xa + 0.5Xb + 5Xc + Xd + PSR\ (B)_b$

$Z_2(min) = 0.412Xa + 0.5Xb + 5Xc + Xd + PSR\ (C)_a$

The equation contains Z_1 is the most generalized form of life cycle cost analysis for general roads which needs minor maintenance.

The equation contains Z_2 is the most generalized form of LCCA for general roads which needs major maintenance.

CHAPTER 6

6.1. CONCLUSION

6.2. SCOPE OF FUTURE WORK

6.1. Conclusions

In this study an attempt was made to determine the most general equation for any general road at moderate weather.

- By probabilistic analysis it was concluded that if the roads have roughness of 120 inches per mile to 130 inches per mile, then the road can serve twice its life time with minor maintenance at the end of its initial life period.
- In past studies the analysis which were done, were mainly dependent on time factor, in comparison of that this study is analyze with respect to road roughness parameter.
- This study tried to show that minor and major maintenance of any general road is more economical and give more benefit in term of serviceability than complete rehabilitation.

6.2. Scope of Future Work

Further studies may determine the most generalized life cycle cost equation for any type of roads at any given condition.

In future this study and the past studies can be combined to get the most generalized and economical LCCA equation. Time, traffic load, road roughness parameters, weather condition, user comfort these factors can be combined to get a relationship, which can be used to develop the most generalized equation, among them.

CHAPTER 7

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