A COST-BENEFIT OPTIMIZATION MODEL FOR MAINTENANCE AND REHABILITATION ACTIVITIES OF ROADS

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY

In

CIVIL ENGINEERING

[Specialization: Transportation Engineering]

By

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CERTIFICATE

This is to certify that the thesis entitled, **"A COST-BENEFIT OPTIMIZATION MODEL FOR MAINTENANCE AND REHABILITATION ACTIVITIES OF ROADS"** submitted by **Bhagyashree Panda** 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 her under my supervision and guidance. To the best of my knowledge, the matter embodied in this Project Report has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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DATE: **BHAGYASHREE PANDA**

ABSTRACT

The maintenance and rehabilitation of existing, mature road facilities are becoming gradually more significant and important components of highway activity. An efficient maintenance and rehabilitation policy is essential for a safe, comfortable and cost-effective transportation system. But, decisions to maintain existing road facilities involve a number of possible options in activities ranging from routine maintenance to rehabilitation or reconstruction, in choices for allocation of resources throughout a highway network, and to decide between investments versus non-investment option. Moreover, any economic analysis should not only consider the cost factor but also be designed to give maximum coverage of benefits like changes in road maintenance costs, changes in accident rates, increased travel or demand, environmental effects, change in value of goods moved, changes in agricultural output, changes in services, changes in industrial output, changes in land values, etc. As a result of these characteristics developing a maintenance and rehabilitation policy for roads is difficult and new concepts and analytic approaches needs to be introduced to address this problem. Optimization models is one such analytical approach which helps in making a cost-benefit analysis of maintenance and rehabilitation activities of roads and in comparing the various possible alternatives to give out the best activity within the budget allocated, before being actually carried out in practical.

In the present study it was aimed to formulate a multi-objective optimization model considering all necessary as well as sufficient factors responsible in ‘maintenance and rehabilitation activities’ of highway facilities so as to minimize the total cost and increase the total return in terms benefits from improved road condition subject to the practical limitations faced by concerned agency and user due to deterioration in road condition. A non-dominated sorting genetic algorithm II (NSGA-II) based C programming was studied and used to validate the developed model. Lastly, the proposed optimization model is compared with real-time field data collected from National Highway Division, Dhenkanal, Odisha so as to ensure its functionality and usability.

Keywords: Analytical Models, Multi-Objective Optimization Model, Road Maintenance and Rehabilitation, Pavement Management Systems (PMS), Model Validation, Genetic Algorithm.

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LIST OF SYMBOLS

M_{RH}	Binary Decision Variable for Rehabilitation "RH"
M_{RP}	Binary Decision Variable for Repair "RP"
p	Repair Interval
h	Rehabilitation Interval
TC	Total Cost
C_h^{RH}	Cost of Rehabilitation
C_p^{RP}	Cost of Repair
r_{RH}	Frequency of Rehabilitation within design period
r_{RP}	Frequency of Repair within design period
n_l	Total number of lanes
N	Design Period
w_l , w_y	Relative Weight age for each lane & each year respectively
TB	Total Benefits in terms of improved road condition "$RC_{y,l}$" depending upon the pavement strength and riding surface
S_T	Strength parameter
S_C	Cracks/Potholes/Patches parameter
l_L	Length of longitudinal cracks

l_T	Length of transverse cracks
A	Area of alligator or block cracks, potholes, patches etc.
R_1, R_2, R_3	Weights of different types of cracks which is user defined depending upon the severity of cracks
S_R	Road Roughness parameter
UI	Unevenness Index
C_1, C_2, C_3	Relative Weights of various parameters as road strength, cracks/ potholes and roughness as perceived by user
BD_{max}	Maximum budget allocated for maintenance work within design period
I	Integral multiplicative of repair interval "p"
CI_1	Road Condition Index just after repair or rehabilitation work
CI_2	Road Condition Index just before repair or rehabilitation work
CI_3	Road Condition Index for repair work
CI_4	Road Condition Index for rehabilitation work
RC_{post}	Road condition just after repair or rehabilitation work
RC_{pre}	Road condition just before repair or rehabilitation work
K_1, K_2	Very large positive numbers
j	particular year in which maintenance work is carried out

CHAPTER-1

INTRODUCTION

1.1. GENERAL

Road network is essential to facilitate trade and transport, economic development and social integration. It is used for the smooth conveyance of both people and goods. Moreover size of the road network, its quality and access has a direct link with transport costs. Transportation by road has the advantage over other means of transport because of its easy accessibility, flexibility of operations, door-to-door service and reliability due to which it is the preferred mode of transportation. Global competition has made the existence of efficient road transport and logistics systems in delivery chain an absolute imperative. Rehabilitation and construction of new roads are essential to provide sufficient, safe and efficient transportation for passenger and goods and are vital for making the economy competitive and for sustaining a high rate of growth. The road development in many ways exemplifies both the challenge and opportunity in infrastructure development.

1.2. REPAIR AND REHABILITATION OF ROADS

The maintenance and rehabilitation of existing, mature road facilities are becoming increasingly important components of highway activity. An efficient maintenance management policy is critical for a safe and cost-effective transportation system.

Decisions to maintain existing road facilities involves a number of possible options in activities ranging from routine maintenance to rehabilitation or reconstruction, in the spatial and temporal allocation and distribution of resources throughout a highway network, and in choices between investments versus non-investments in a particular road network. Moreover the planning of maintenance programs implies the ability to evaluate life-cycle performance and costs, with tradeoffs measured in economic as well as technical terms. Postponing road maintenance results in high direct and indirect costs. If road defects are repaired promptly, the cost is usually modest. If defects are neglected, an entire road section may fail completely, requiring full reconstruction at three times or more the cost, on average, of maintenance costs. Still then many countries tend to favour new construction, rehabilitation, or reconstruction of roads over maintenance. As a result of these characteristics, the development of repair and rehabilitation policy is complicated, and new concepts and analytic approaches need to be introduced to address this problem.

However, comparatively little work has been devoted to the development of analytic models as optimization models intended specifically for maintenance programs. These models project the future conditions and performance of roads by identifying deficiencies and use a cost-benefit analysis to select economically-justified improvements on roads from among various alternatives available.

Any economic analysis should take into account the maximum coverage of benefits like changes in road maintenance costs, changes in accident rates, increased travel and decrease in vehicle operating cost and travel time; and social benefits as environmental effects, change in value of goods moved, increase in agricultural and industrial output, changes in services, changes in land values etc. Evaluating the benefit component of a transportation system is difficult, and sometimes is not possible to quantify benefits for some components like social benefits, future traffic situation etc.

Rehabilitation activities (such as overlays, major slab replacements, etc.) produce a substantial, immediately identifiable correction of deficiencies, represented by immediate improvements in the condition or deterioration curve and is carried out at definite intervals or frequencies, as suggested by Markow et al., 1987. The analytical representation of the effect of rehabilitation activities on pavement condition with time is shown in Figure 1.

The periodical repair or routine maintenance activity includes minor repairs and improvements to eliminate the cause of defects and to avoid excessive repetition of maintenance efforts. It is performed between occurrences of construction, rehabilitation, or reconstruction may not correct any existing damage, but rather may prevent future damage, or may slow down the current rate of deterioration. The effects of routine maintenance are harder to detect. Figure 2 shows the analytical representation of the effect of repair or routine maintenance activities on pavement condition with time as given by Markow et al., 1987.

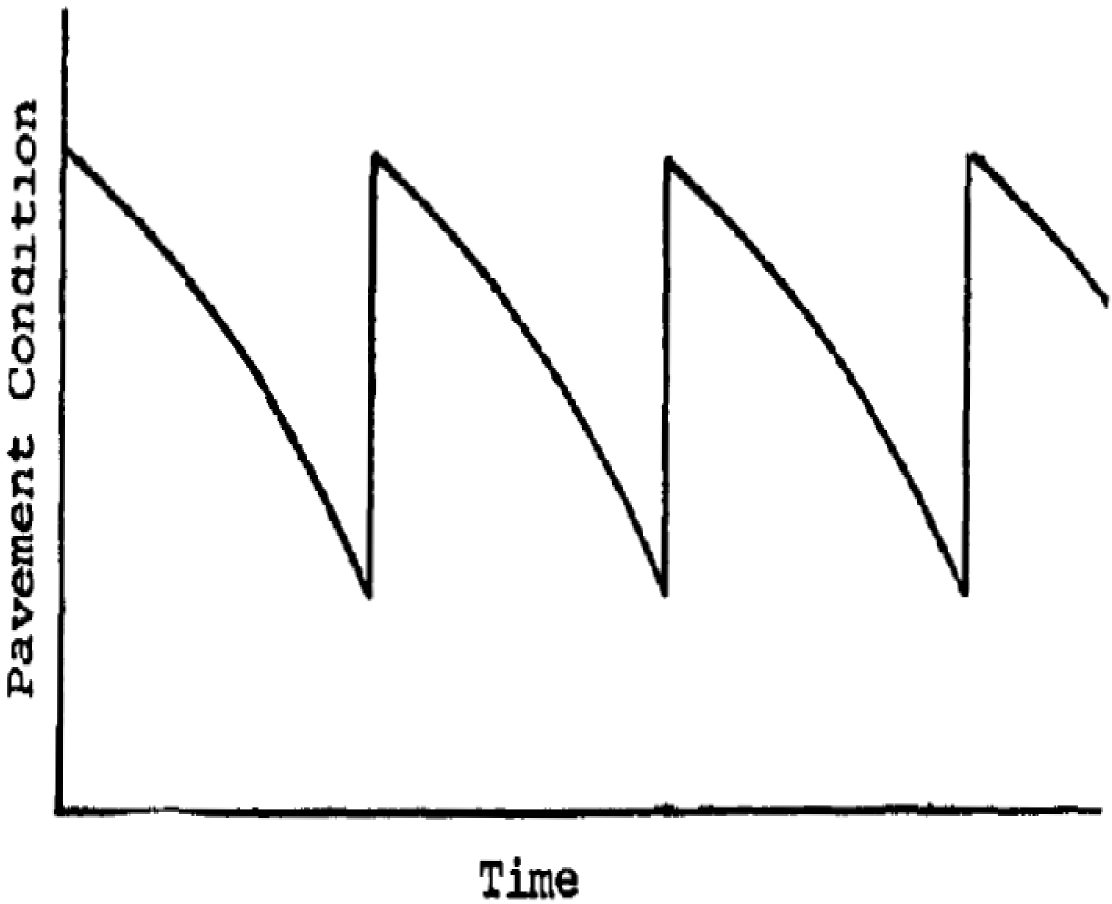

Figure 1. Analytic Representation Of Rehabilitation ***(adapted from Markow et al., 1987)***

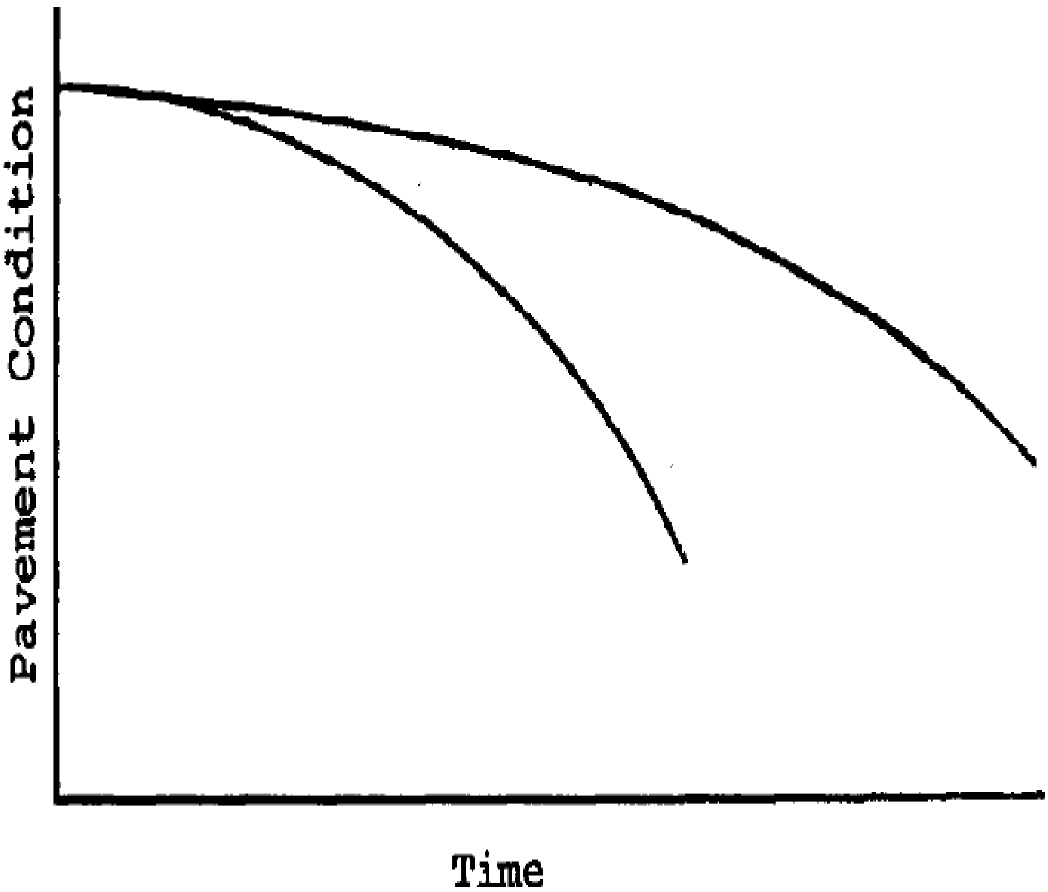

Figure 2. Analytic Representation Of Maintenance ***(adapted from Markow et al., 1987)***

1.3. THE INDIAN SCENARIO

Transport demand in India has been growing rapidly. Consequently, passenger and freight movement in India over the years have increasingly shifted towards roads than other means of transport. In 2009-10, the road network in the country carried 85.2 per cent of the total passenger movement by roads and railways put together. Similarly, the corresponding figure for freight movement by roads was 62.9 percent. The annual growth of road traffic is expected to be 10 to 11%.

The total road length in India increased more than 11 times during the 60 years between 1951 and 2011. From 3.99 lakh kilometre as on 31st March 1951, the road length increased to 46.90 lakh kilometres as on 31st March 2011. The largest incremental increase of 3.56 lakh kilometres was in the length of rural roads. The second highest addition in road length during to 2011 was by Other PWD roads (1.70 lakh kilometres). Urban roads added a significant length of 1.11 lakh kilometres of roads during the same period. The incremental increase in National Highways, State Highways and Project roads were 4,344 kilometres, 11,663 kilometres and 20,034 kilometres, respectively. All the above facts are according to the **Basic Road Statistics of India, 2008-09, 2009-10 and 2010-2011** publication by Ministry of Road Transport and Highways (MORTH) Transport Research Wing published in August 2012.

While the motor vehicle population has grown from 0.3 million in 1951 to 59 million in 2004, marking a 180 fold increase, the road network has expanded from 0.4 million km to 3.5 million km, a 9 fold increase in terms of length during the same period. New construction as well as upgrading of roads by way of widening of carriage-ways, improving surface quality, strengthening/reconstruction of old/weak bridges, culverts and shoulders, etc. has been carried out to meet up the increasing traffic demand. Hence the current boom in the automobile sector and road sector may even increase the future growth rate of road traffic.

While the traffic has been growing at a fast pace, it has not been possible to provide matching investment in the road sector, due to the competing demands from other sectors, especially the social sectors. Many sections of the highways are in need of capacity expansion, pavement strengthening, rehabilitation of bridges, improvement of riding quality, provision of traffic safety measures, etc. The vast network of roads built over the years with huge investments needs proper maintenance. However, the inadequate flow of funds has not permitted proper maintenance of the existing road network, as also the weak planning, scheduling and monitoring of maintenance operations.

1.4. ORGANISATION OF THE REPORT

In this thesis, Chapter-1 presented the importance of developing an effective maintenance and rehabilitation policy for roads giving emphasis to the condition of road facilities in India. Chapter-2 presents a review of literature pertaining to past work done relating to optimization of maintenance activities of roads and hence the motivation behind the present research work followed by the problem statement. Chapter 3 describes the formulation of the multi-objective optimization model for maintenance and rehabilitation activities of roads with the description of various parameters and constraints used in the model to accomplish the research objectives. Chapter-4 constitutes the model validation portion using NSGA-II along with information about data collection and data tabulation and the results obtained from this research work. Lastly a conclusion and recommendations are given summarizing the whole thesis report with the list of references.

CHAPTER-2

LITERATURE REVIEW, MOTIVATION AND PROBLEM STATEMENT

As explained in the previous chapter, analytical models can best solve the highly complex problem of developing maintenance and rehabilitation programs for road networks. Not only we have to minimize the cost incurred in implementing the maintenance activity in roads but also the benefits from the activity have to be evaluated in return which can be represented accurately by using optimization models.

In this chapter a review is presented on past work related to optimization of maintenance activity of roads and the various parameters observed are grouped together. After that, the motivation behind this thesis work is stated followed by problem statement.

2.1. LITERATURE REVIEW

The purpose of the literature review is to study and analyze the factors which are consider as objective functions, decision variables and constraints in the formulation of an optimization model which are subsequently grouped according to number of authors who used them. Precise descriptions of all the literature are presented below.

Markow et al. (1987) showed that the optimization of pavement maintenance and rehabilitation policy is complicated by several factors management alternatives must therefore be evaluated on the basis of life-cycle costs, with tradeoffs measured in economic as well as technical terms. They discussed an analytic approach, dynamic control theory, which proved to be a very attractive optimization method for managing highway infrastructure including all the key variables of interest with technically correct engineering and economic relationships expressed within the problem formulation (e.g., equations describing changes in pavement condition due to deterioration or repair, or variations in traffic levels due to growth or redistribution) having certain elements of the problem in their basic form to avoid mathematical complications (e.g., traffic is assumed to be constant), and leads directly and efficiently to the solution of optimal maintenance and rehabilitation policy. It was intended to be applied in economic analyses of pavement management alternatives, to assess tradeoffs among pavement design, maintenance and rehabilitation, and to gauge the optimal timing of maintenance and rehabilitation actions.

Ouyang and Madanat (2004) presented a mathematical programming model based on discrete control theory for determining the optimal rehabilitation frequency and intensity on a system of pavements which minimizes the life-cycle cost for a finite horizon by incorporating both nonlinear pavement performance model and integer decision variables into a mixed-integer nonlinear programming (MINLP) to schedule multiple rehabilitation actions in a system of pavement facilities under budget constraints. Two different solutions, a branch-and-bound algorithm and a greedy heuristic, are approached and numerical analysis showed that the heuristic approach provided a good approximation to the exact optima with much lower computational costs which is very useful for large-scale practical problems.

Yin et al. (2008) presented an integrated and robust approach for estimating the investment necessary to maintain or improve the future levels of service and pavement conditions of facilities in a highway network at a significantly lower cost when compared with conservative investment plans. They assumed future travel demands and facility conditions as uncertain and the mathematical program is solved via a cutting plane algorithm. Numerical results from the Sioux Falls network suggest that the approach can potentially address realistic networks. Assuming the amount of capacity expansion and the resurfacing thickness as continuous variables and the occurrence of at most one maintenance and improvement activity during the analysis period impairs the capability of the proposed model.

Lamptey et al. (2008) presented a case study for optimizing decisions on the best combination of preventive maintenance (PM) treatments based on Decision Support System and timings to be applied in the resurfacing life-cycle (interval between resurfacing events) using sensitivity analysis, for a given highway pavement section incorporating key infrastructure management concepts of treatment-specific triggers, performance jump models, and performance trend models. The study results showed that compared to agency costs, user costs are more sensitive to changes in the discount rate which can influence the choice of optimal PM schedule.

Durango-Cohen and Sarutipand (2009) presented a computationally-appealing quadratic programming framework to address the problem of finding optimal maintenance policies for multifacility transportation systems and to capture nonlinearities in cost terms, explicitly capturing the bidirectional relationship between demand and deterioration In the formulation, each facility's deterioration and demand/traffic are identified and represented as a linear system, i.e., an autoregressive moving average model with exogenous inputs (ARMAX) model and then linked as the state of a facility can impact demand at other facilities. A series of numerical examples represented that the linear approximation is valid for the single-origin, single-destination, and two-link substitutable network by analyzing simple network topologies and traffic patterns where it is optimal to coordinate (synchronize or alternate) interventions for clusters of facilities in transportation systems.

Ng et al. (2011) presented an integer programming-based alternative to account for the uncertainties due to maintenance and rehabilitation improvements and deterioration rates assuming that parameters are deterministically known. In the first model, the only source of uncertainty is given by the improvements due to M&R actions. Second model considers both M&R improvements as well as deterioration rates to be uncertain. A numerical case study using real world data from Rockwall County indicated that the price of uncertainty is a non-decreasing function of the level of uncertainty and it increases with the number of uncertainties considered. But high computational requirements and open-loop M&R policies of integer programming models makes it less desirable from a managerial perspective.

Santeroa et al. (2011) showed the rapidly growing interest in pavement life-cycle assessments (LCAs) in improving the sustainability of this critical highway infrastructure system. The existing literature establishes a foundational framework for quantifying environmental impact, but cannot deliver global conclusions regarding materials choices, maintenance strategies, design lives, and other best practice policies for achieving sustainability goals. The pavement LCA literature is evaluated across four key methodological attributes: (1) functional unit comparability; (2) system boundary comparability; (3) data quality and uncertainty; and (4) environmental metrics. These four attributes are considered essential for comparing and aggregating the results of the different studies, and for representation of general conclusions about the environmental impacts of different life-cycle phases, life-cycle components, and pavement types from the collective body of work and improving upon the deficiencies.

Garza et al. (2011) presented the development and implementation of a simpler, yet useful, network-level pavement maintenance optimization model, which is a Linear Program by using a decision-making tool, Frontline Systems' Risk Solver Platform add-in for Microsoft Office Excel which can compute the optimal amount of investment for various pavement treatment type in a given funding period. Within this context, nine treatment types along with their corresponding unit prices ($/Lane-Mile), five pavement condition states, pavement deterioration rates, network-level pavement performance targets, and available annual maintenance budget for a 15-year planning horizon are defined. Pavement condition data pertaining to 500 lane-miles of Interstate road network in one of the District within a state DOT is used to test the model and the results presented show how an annual highway maintenance budget needs to be allocated or determined to achieve the District's value proposition for various scenarios, mainly four, i.e., minimizing lane-miles in very poor, poor, and fair; minimizing lane-miles in very poor, poor, and fair condition including targets; minimizing the total budget required to meet targets; and minimizing the maximum yearly budget required to meet targets with a maximum cap conditions. Comparing the results provide an insight on long-term strategies and the impact of target constraints on budget expenditures. Limitations of this model are as follows; it does not address the project-level maintenance programming problem and does not consider other assets in highway facilities or primary and secondary roads data.

Menesesa and Ferreira (2012) formulated a Multi-Objective Decision-Aid Tool (MODAT) tested with data concerning the main road network of Castelo Branco, a district of Portugal from the Estradas de Portugal's Pavement Management System (PMS). The MODAT considers three different possible goals: minimization of agency costs (maintenance and rehabilitation costs); minimization of user costs; and maximization of the residual value of pavements over the planning horizon while maintaining the road pavements within given quality standards. The MODAT allows PMS to become interactive decision-aid tools, capable of providing answers to road administrations to "what-if" questions in short periods of time and uses the deterministic pavement performance model used in the AASHTO flexible pavement design method that allows closing of the gap between project and network management.

2.1.1. Objective Functions Considered

i) **User Costs** *(Durango-Cohen and Sarutipand, 2009; Ouyang and Madanat, 2004; Lamptey et. al., 2008; Markow et. al., 1987; Meneses and Ferreira, 2012).*

ii) **Agency Costs** *(Durango-Cohen and Sarutipand, 2009; Ng et. al., 2011; Ouyang and Madanat, 2004; Lamptey et. al., 2008; Meneses and Ferreira, 2012).*

iii) **Salvage Value of the road at the end of planning period in terms of User costs and Agency costs** *(Durango-Cohen and Sarutipand, 2009; Lamptey et. al., 2008; Meneses and Ferreira, 2012).*

iv) **Cost function for expanding the road** *(Yin et. al., 2008).*

v) **Cost function for resurfacing the road** *(Yin et. al., 2008).*

vi) **Annual Maintenance Expenditure** (*Markow et. al., 1987*).

vii) **Terminal Rehabilitation Costs** *(Markow et. al., 1987).*

viii) **Number of lanes in condition 'k' at the end of period 'i'** *(Garza et. al., 2011).*

ix) **Intervals between Rehabilitation** *(Markow et. al., 1987).*

2.1.2. Decision Variables Considered

i) **Effective Capacity** *(Durango-Cohen and Sarutipand, 2009).*

ii) **Demand or Traffic on the Road** *(Durango-Cohen and Sarutipand, 2009; Yin et. al., 2008).*

iii) **Initial Condition the Road** *(Durango-Cohen and Sarutipand, 2009).*

iv) **Pavement Roughness or Condition** *(Ouyang and Madanat, 2004; Yin et. al., 2008; Meneses and Ferreira, 2012).*

v) **Money Spent on Particular Maintenance Work** *(Garza et. al., 2011; Ng et. al., 2011).*

vi) **Binary Variable for Rehabilitation Decision** *(Ouyang and Madanat, 2004; Lamptey et. al., 2008; Meneses and Ferreira, 2012)***.**

vii) **Rehabilitation Intensity** *(Ouyang and Madanat, 2004)***.**

viii) **Number of lanes in condition 'k' at the end of period 'i'.** *(Garza et. al., 2011)*

ix) **Year in which treatment is carried out** (*Lamptey et. al., 2008).*

x) **User Equilibrium Flow Distribution associated with a particular travel demand'd'.** *(Yin et. al., 2008).*

2.1.3. Constraints Considered

i) **Rate of Pavement Deterioration** *(Durango-Cohen and Sarutipand, 2009; Garza et. al., 2011; Ouyang and Madanat, 2004; Markow et. al., 1987).*

ii) **Demand or Traffic** *(Durango-Cohen and Sarutipand, 2009; Yin et. al., 2008; Markow et. al., 1987).*

iii) **Effective Capacity** *(Durango-Cohen and Sarutipand, 2009; Markow et. al., 1987).*

iv) **Utilization of Facilities or v/c ratio** *(Durango-Cohen and Sarutipand, 2009; Yin et. al., 2008)***.**

v) **Maintenance and Rehabilitation activities conducted** *(Ng et. al., 2011; Lamptey et. al., 2008; Meneses and Ferreira, 2012).*

vi) **Pavement condition greater than minimum acceptable condition** *(Ng et. al., 2011; Ouyang and Madanat, 2004; Yin et. al., 2008; Meneses and Ferreira, 2012).*

vii) **Total Expenditure less than budget allocated** *(Garza et. al., 2011; Ouyang and Madanat, 2004; Lamptey et. al., 2008; Meneses and Ferreira, 2012)***.**

viii) **Rehabilitation Intensity or effectiveness** *(Ouyang and Madanat, 2004; Yin et. al., 2008; Lamptey et. al., 2008)*

ix) **Pavement damage function in absence of annual maintenance** (*Markow et. al., 1987*)

x) **Binary Variable for Rehabilitation Decision** *(Markow et. al., 1987; Meneses and Ferreira, 2012).*

xi) **Expansion amount and Resurfacing intensity within reasonable limits** *(Yin et. al., 2008; Meneses and Ferreira, 2012)*

xii) **Rehabilitation costs just before repair** (*Markow et. al., 1987*).

xiii) **Effect of routine maintenance on pavement deterioration depending on receptivity of pavement and maintenance** (*Markow et. al., 1987*).

xiv) **Number of lanes in very poor, poor or fair condition must be less and good, excellent condition must be more** *(Garza et. al., 2011)*

xv) **Flow distribution must be greater than 0**. *(Yin et. al., 2008)*

2.2. MOTIVATION

It is evident from all the literature reviewed in this chapter that in spite of adapting different types of optimization models, there were some common factors of same significance considered for objective functions, decision variables and constraints but with different names which can be grouped and used as one factor with some modifications.

Secondly, there are some variables which are well thought-out to be objective functions, decision variables and constraints, but they cannot be considered as same and are also not necessary as other factors are sufficient to describe the model in practical.

Thirdly, an optimization model can be more useful if along with reduction of maintenance cost, the road condition also improves in terms of safety and comfort for road users and being serviceable for a longer duration during the design period. But this aspect of benefit is ignored in almost all the models which have considered the benefit in terms of reduction of total costs including user costs, agency costs, road salvage value costs etc. Thus both the characteristics of a maintenance activity are considered as the objective of the proposed optimization model.

2.3. PROBLEM STATEMENT

The problem of this thesis can be broadly stated as "to formulate a multi-objective optimization model considering all necessary and sufficient factors responsible in 'maintenance and rehabilitation activities' of highway facilities so as to minimize the total cost and increase the total return subject to all the practical limitations".

In particular, different options of maintenance activity will be considered and evaluated in terms of total cost incurred during any maintenance activity and return or benefit in terms of improved road condition taking into account all the practical constraints.

Further, the model also tries to use a structure which requires lesser computation and can be adapted easily to represent different scenarios of maintenance activity, in general.

CHAPTER-3

MODEL FORMULATON

As concluded from the previous chapter that optimization models can be useful in representing the real-world problem of maintenance activities of roads. Hence in this chapter a mixed-integer multi-objective optimization model is proposed and formulated using some physical parameters considering some practical and assumed constraints encountered while implementing any maintenance program for roads.

3.1. BACKGROUND

A model is a representation of the reality that captures "the essence" of reality. Any mathematical model with valid representation of the performance of the system can provide the solution to the system problems from solution obtained from the model by applying the appropriate analytical techniques.

3.1.1. Optimization Model

A mathematical optimization model consists of an objective function and a set of constraints expressed in the form of a system of equations or inequalities representing real-world problems in almost all as well as vast areas of decision-making processes such as engineering design, financial portfolio selection, management science and operations research sectors. The basic goal of the optimization process is to find values of the variables that minimize or maximize the objective function while satisfying the constraints. This result is called an optimal solution.

Optimization problems are made up of four basic ingredients:

i) The mathematical (i.e., analytical) model that describes the behaviour of the measure of effectiveness is called the objective function. That is, the quantity or goal to be maximized or minimized is called the objective function. Most optimization problems have a single objective function or more than one objective called multi-objective function.

ii) A decision variable is a variable that can be directly controlled by the decision-maker and which affects the value of the objective function. If there are no variables, we cannot define the objective function and the problem constraints.

iii) The uncontrollable inputs are called parameters of the model. The input values may be fixed numbers associated with the particular problem.

iv) Constraints are relations between decision variables and the parameters. A set of constraints allows some of the decision variables to take on certain values, and exclude others.

Many optimization problems involve integer and discrete variables and some continuous variables as well with nonlinearities in the objective function and constraints and can be modelled as Mixed Integer Nonlinear Programming problems (MINLPs). The use of MINLP is a natural approach of formulating problems where it is necessary to simultaneously optimize the system structure (discrete) and parameters (continuous). The function to be optimized in this context usually involves costs and profits from the design. MINLP problems are precisely so difficult to solve, because they combine all the difficulties of both of their subclasses: the combinatorial nature of mixed integer programs (MIP) and the difficulty in solving non-convex (and even convex) nonlinear programs (NLP).

The general form of a MINLP is

Minimize f (x, y)

Subject to g (x, y) ≤ 0

$x \in X$

$y \in Y$ integer

The function f (x, y) is a nonlinear objective function and g (x, y) a nonlinear constraint function. The variables x, y are the decision variables, where y is required to be integer valued. X and Y are bounding-box-type restrictions on the variables.

3.1.2. Proposed Model in Generic Form

Optimize $Z_1 = f_1(x_1, x_2, x_3, ...x_n)$

$Z_2 = f_2(x_1, x_2, x_3, ...x_n)$

$\vdots$

$\vdots$

$Z_m = f_n(x_1, x_2, x_3, ...x_n)$, where

n: number of decision variables

m: number of objective functions

Optimize: (maximize, minimize)

Subject To,

$C_1(x_1, x_2, x_3, ...x_n)\ \Phi\ 0$

$C_2(x_1, x_2, x_3, ...x_n)\ \Phi\ 0$

$\vdots$

$\vdots$

$C_r(x_1, x_2, x_3, ...x_n)\ \Phi\ 0$,where

r: number of constraints

$\Phi : (<, >, =, \leq, \geq)$

3.2. COMPONENTS OF THE MODEL

3.2.1. Road Condition Parameters

Pavement surface characteristics are vital to both the safety of the pavement structure and surface and the comfort of the drivers. Traditional pavement design and analysis has centred on the structural capacity of the roadway for many years as pavement strength was considered as the single variable used to predict pavement performance and safety over time. Pavement systems have been designed to withstand specific levels of repetitive loading over the design life. However, the inclusion comfort characteristics, i.e. pavement surface friction and rideability, into the design process have not been seriously considered. They are also important variables for pavement system performance and should be incorporated not only to the design and analysis process but also to the pavement maintenance process as well.

In this section all three parameters considered in the model formulation signifying safety and comfortability of roads are discussed and their analytical representation with respect to road condition is presented to clearly understand their behaviour in field conditions.

3.2.1.1. Strength parameter

The strength of the pavement is a complex function of the interactions between the material properties, layer thickness and depth, subgrade stiffness and pavement condition. The modified structural number is found out be most statistical measure of pavement strength influencing the deterioration of pavements. It is developed by Paterson in 1987 based upon the concept of AASHTO's structural number in which the summation of the product of thickness of each layer with their structural layer coefficient meant to represent the layer's contribution to pavement performance is taken and the contribution of subgrade to the pavement strength depending upon its CBR value is also included. Mathematically,

$$S_T = 0.0394 \sum_{i=1}^{nlayer} a_i h_i + SNSG$$

Where

S_T= Structural Number

nlayer = Number of pavement layers above subgrade

a_i= Layer coefficient of ith layer

h_i= Thickness of ith layer in mm

$SNSG$= Subgrade strength contribution

$$SNSG = \begin{cases} 3.51 \log_{10} CBR - 0.85(\log_{10} CBR)^2 - 1.43 \; for \; CBR \geq 3 \\ 0 \; for \; CBR < 3 \end{cases}$$

CBR= California Bearing Ratio

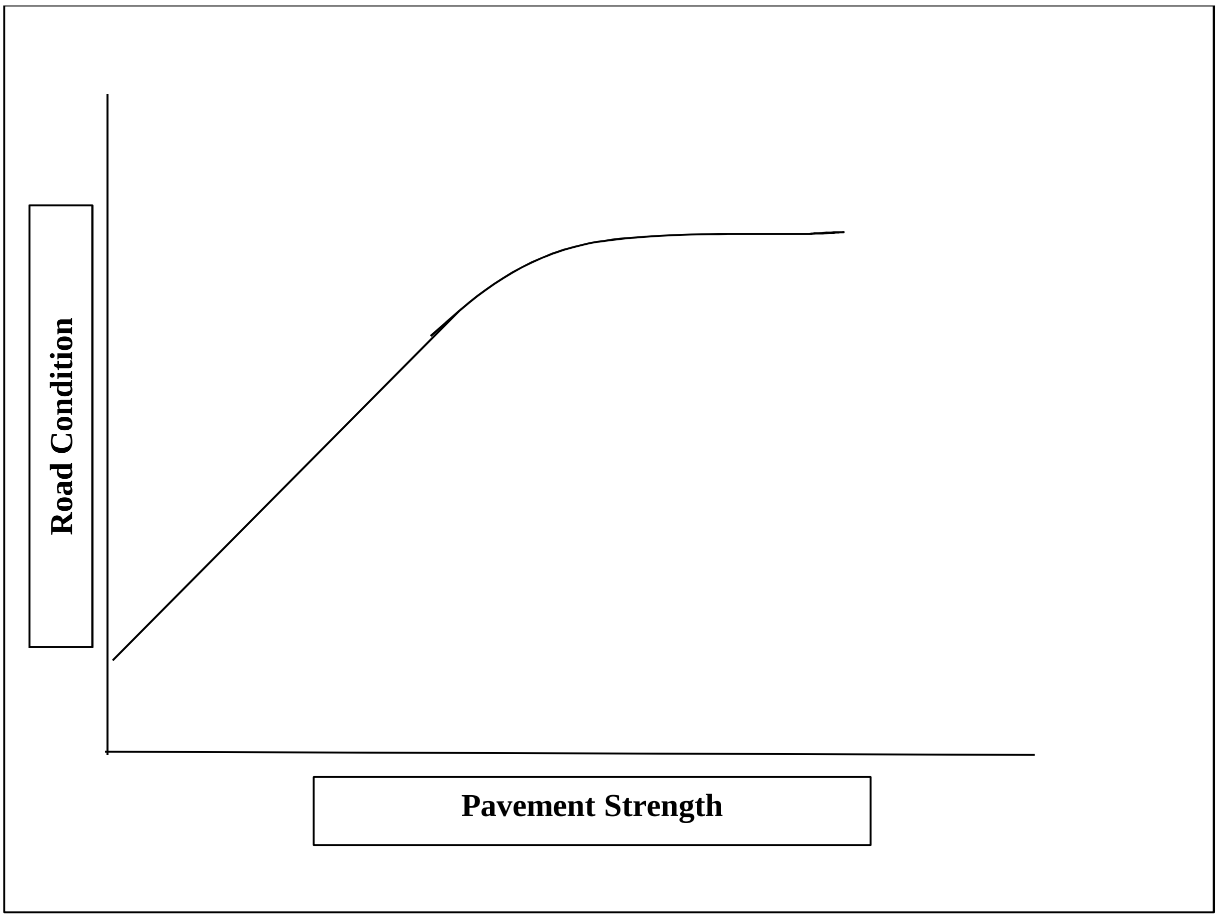

Figure 3. Analytical representation of variation of pavement strength with improvement in road condition.

The analytical variation of pavement strength with respect to improvement road condition is shown in figure 3. It shows that on improving the structural capacity of roads, the pavement strength also increases to certain extent after which no significant increase in pavement strength is observed even if there is improvement in road condition. This implies that maintenance carried out to improve the strength of pavement should be done efficiently so as to avoid unnecessary expenditure on over-maintenance.

3.2.1.2. Cracks/potholes and patches parameter

Cracking begins at the bottom of the asphalt surface (or stabilized base) where tensile stress and strains are highest under wheel loads. The cracks propagate to the surface initially as a series of parallel longitudinal cracks. Sometimes hardening of asphalt on the surface can lead to block cracking. Patching is done to repair existing pavement and it adversely affects riding quality. Rutting, corrugations, potholes etc. are also considered as surface distresses. Maintenance is applied according to the severity of cracks (low, medium, high) and the area affected. However longitudinal and transverse cracks are linearly measured. Moreover transverse cracks are given more weightage than longitudinal cracks as a driver can avoid longitudinal cracks by shifting to other lanes but cannot avoid transverse cracks. Mathematically,

$$\boldsymbol{S_C = R_1 l_L + R_2 l_T + R_3 . A}$$

Where

S_C= Surface Cracks/Potholes/Patches Parameter

R_1, R_2, R_3=Weights of different types of cracks which is user defined depending upon the severity of cracks

l_L= Length of longitudinal cracks

l_T= Length of transverse cracks

A= Area of alligator or block cracks, potholes, patches etc.

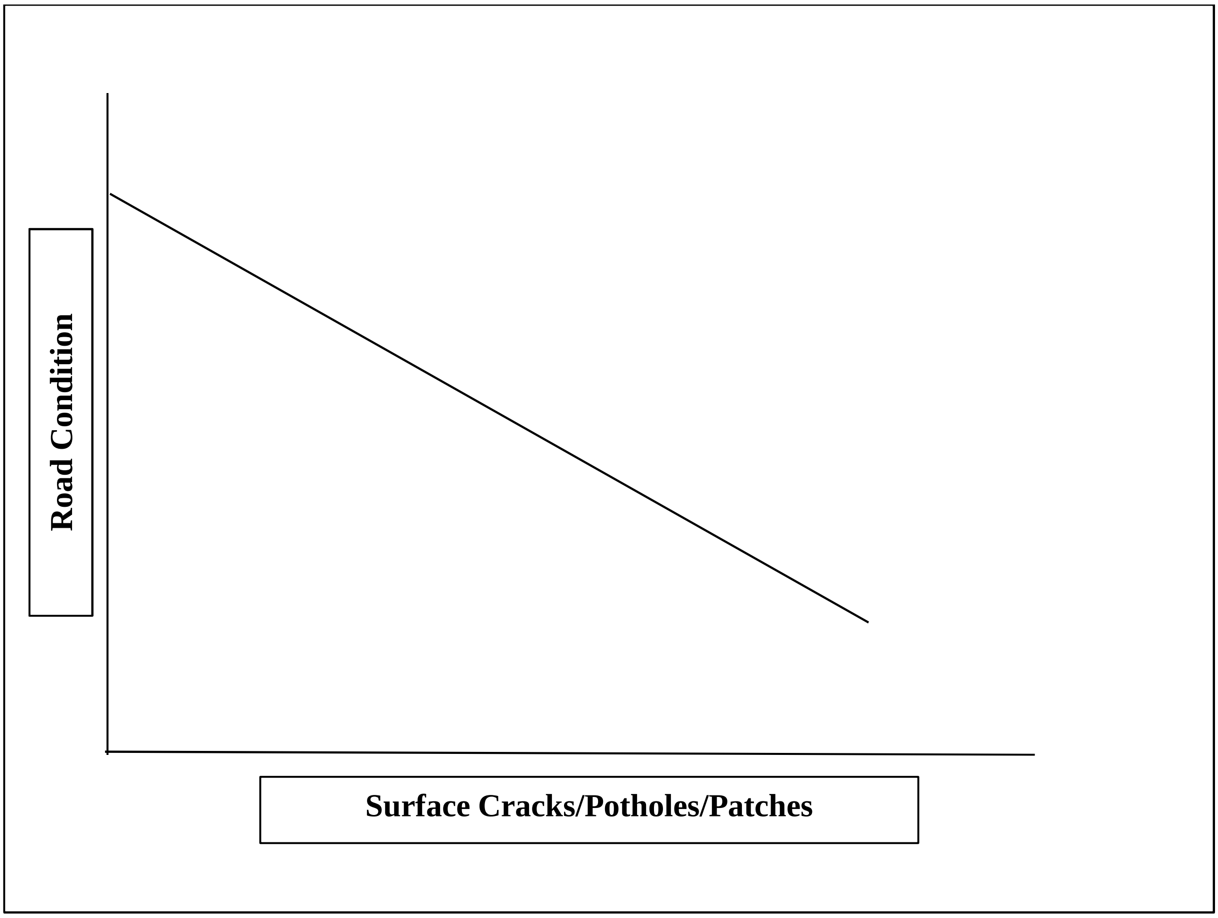

Figure 4. Analytical representation of variation of surface cracks/potholes/patches parameter with decreased road condition.

The analytical linear variation of surface cracks/potholes/patches parameter with respect to improvement in road surface conditions is presented in figure 4. Deterioration in road condition implies increase in cracks, potholes, patches and other such visible surface deformations which if not corrected can eventually lead to total pavement failure.

3.2.1.3. Road roughness parameter

Surface evenness of highway pavements refers to the uniformity of surface finish both in longitudinal and transverse direction. Road roughness affects both comfortability and safety of road users and hence can be used to evaluate the quality and performance of roads after construction and during maintenance carried out for roads. With the use of some low cost instruments as straight edge, bump integrator, dipstick profiler, etc. and non-destructive tests, the roughness of the pavement, commonly designated as Unevenness Index value, can be easily found out. Almost in all major highway works executed, control of surface evenness has been introduced as a mandatory requirement

$$\boldsymbol{S_R = R_4 - R_5 \cdot UI}$$

Where

S_R= Road Roughness parameter

R_4, R_5= Equation constants

UI= Unevenness Index

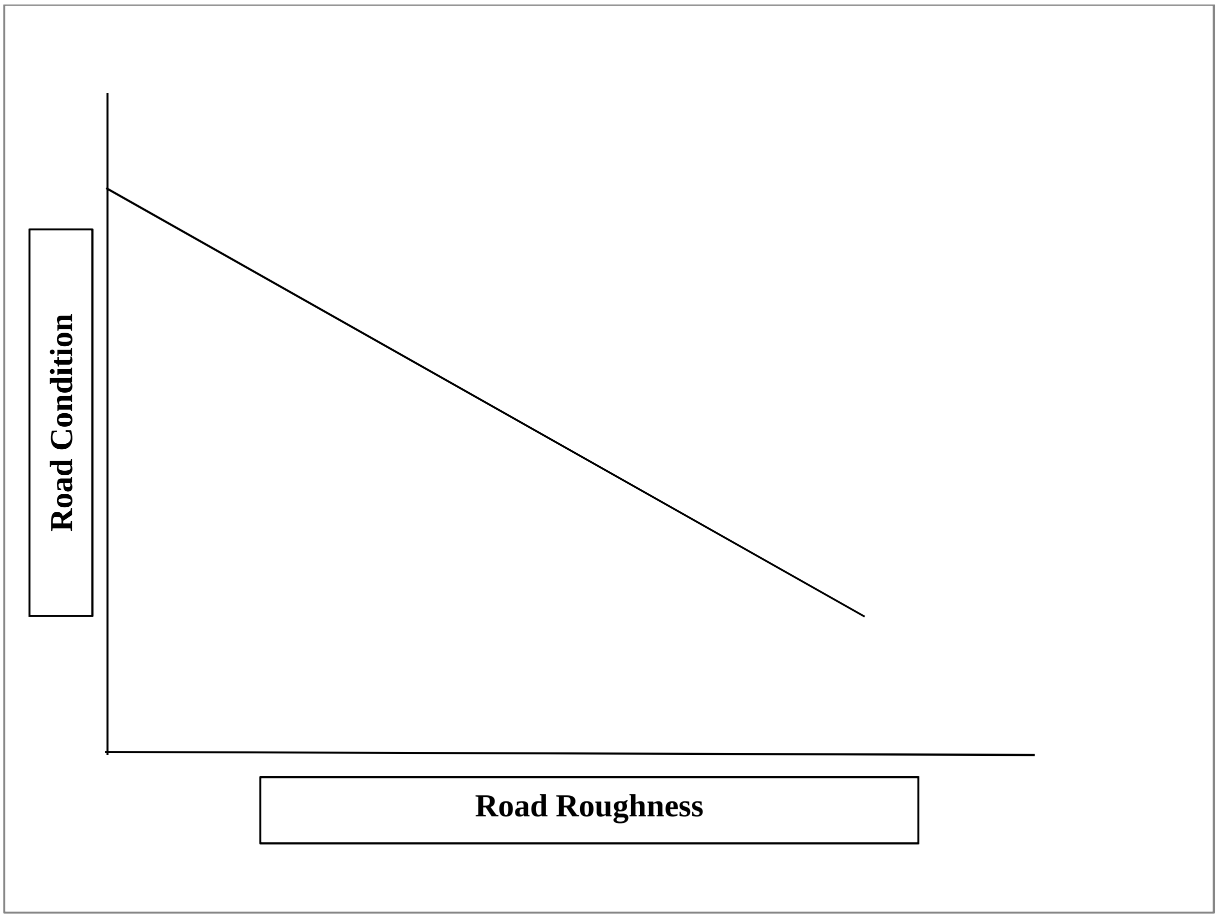

Figure 5. Analytical representation of variation of road roughness parameter with decrease in road condition.

The analytical linear variation of road roughness with respect to improvement in road surface condition is presented in figure 5. It indicates that optimum road condition is observed at zero roughness and with increase in road roughness, the road surface condition deteriorates. Theoretically it is assumed linear for simplicity. But actually zero roughness means excessive smoothness which is not desirable as it indicates decrease in road friction which may lead to accidents. In contrast, higher values of roughness indicate lesser smoothness which is also not desirable as it reduces the riding quality. Hence a skewed normal distribution function can best represent the variation of road roughness with a positive skew towards smoothness.

3.3. DESCRIPTION OF THE MODEL

3.3.1. Decision Variables

i) $\boldsymbol{M_{RH}}$
ii) $\boldsymbol{M_{RP}}$
iii) p
iv) h

i) Binary Decision Variable for Rehabilitation "RH"

$$\boldsymbol{M_{RH}} = \begin{cases} \mathbf{0} \ \boldsymbol{if\ rehabilitation\ decision\ is\ not\ taken} \\ \mathbf{1} \ \boldsymbol{if\ rehabilitation\ decision\ is\ taken} \end{cases}$$

ii) Binary Decision Variable for Repair "RP"

$$\boldsymbol{M_{RP}} = \begin{cases} \mathbf{0} \ \ \boldsymbol{if\ repair\ decision\ is\ not\ taken} \\ \mathbf{1} \ \ \boldsymbol{if\ repair\ decision\ is\ taken} \end{cases}$$

iii) p = Repair Interval

iv) h = Rehabilitation Interval

3.3.2. Objective Function

i) **Minimize** $\boldsymbol{TC = (\sum_{h=1}^{r_{RH}} C_h^{RH} \, . \, M_{RH} + \sum_{p=1}^{r_{RP}} C_p^{RP} \, . \, M_{RP}) \, . \, n_l}$ **………(1)**

ii) **Maximize** $\boldsymbol{TB = \sum_{l=1}^{n_l} \sum_{y=1}^{N} w_l \, . \, w_y . \, RC_{y,l}}$ **………(2)**

Where

i) TC = Total Cost

ii) C_h^{RH} = Cost of Rehabilitation

iii) C_p^{RP} = Cost of Repair

iv) Frequency of Rehabilitation within design period

$$\boldsymbol{r_{RH} = \frac{N}{h} - 1}$$

v) Frequency of Repair within design period

$$\boldsymbol{r_{RP} = \frac{N}{p} - 1 - r_{RH}}$$

vi) n_l= Total number of lanes

vii) N= Design Period ≅ 20 years

viii) w_l , w_y = Relative Weightage for each lane & each year respectively

ix) TB = Total Benefits in terms of improved road condition $''RC_{y,l}''$ depending upon the pavement strength and riding surface

$$\boldsymbol{RC_{y,l} = (C_1 \, . \, S_T + C_2 \, . \, S_C \, . \, f_1(r_{RP}) + C_3 \, . \, S_R \, . \, f_2(r_{RP})) \, . \, f_3(r_{RH})} \quad \textbf{......... (3)}$$

Where

S_T = Strength parameter determined from Benkelman Beam Defection Test Method

S_C = Cracks/Potholes/Patches parameter determined from cubic measurements

S_R = Road Roughness parameter determined from Bump Integrator deflections

C_1, C_2, C_3= Relative Weights of various parameters as road strength, cracks/ potholes and roughness as perceived by user.

3.3.3. CONSTRAINTS

i) $\boldsymbol{TC \leq BD_{max}}$	**………(4)**
ii) h = I. p	**………(5)**
iii) $\boldsymbol{RC_{post}\big\vert_j > CI_1 \;\; \forall j,\; j =}$ **1 to N**	**………(6)**
iv) $\boldsymbol{RC_{pre} > CI_2}$	**………(7)**
v) $\boldsymbol{(CI_3 - RC_{pre}) + K_1(1 - M_{RP}) > 0}$	**………(8)**
vi) $\boldsymbol{(CI_4 - RC_{pre}) + K_2(1 - M_{RH}) > 0}$	**………(9)**
vii) $\boldsymbol{M_{RP} + M_{RH} \leq 1}$	**………(10)**

Where

i) BD_{max}= Maximum budget allocated for maintenance work within design period

ii) I = Integral multiplicative of repair interval "p"

iii) CI_1 = Road Condition Index just after repair or rehabilitation work

iv) CI_2 = Road Condition Index just before repair or rehabilitation work

v) CI_3 = Road Condition Index for repair work

vi) CI_4 = Road Condition Index for rehabilitation work

vii) RC_{post}=Road condition just after repair or rehabilitation work

viii) RC_{pre} = Road condition just before repair or rehabilitation work

ix) K_1, K_2 = very large positive numbers

x) j = particular year in which maintenance work is carried out.

3.4. DEVELOPMENT OF THE MODEL

The model formulated above is a mixed integer, non-linear multi objective optimization model considering both cost and benefits as objective function for maintenance and rehabilitation activities of roads as given in equation (1) and (2). The purpose of first objective function is to minimize total cost of repair and rehabilitation carried out at definite intervals within a design period for all lanes of the road. Second objective function is to maximize total benefits in terms of improved road condition for all lanes of the road within the whole design period.

The parameter "$RC_{y,l}$" defined as road condition depending upon the pavement strength and riding surface given by equation (3), is used to evaluate the benefits of road in terms of rider safety and comfortability. It consists of a strength parameter "S_T" which is assumed to be linearly increasing with improvement in road condition for which structural number is taken as measuring parameter. Cracks/Potholes/Patches parameter is given by "S_C" and is assumed to be linearly decreasing with increase in road condition for which length, area and severity of cracks is considered. Road Roughness parameter is given by "S_R" and is also assumed to be linearly decreasing with increase in road condition for which unevenness index is used as measuring parameter. The parameters used above are already discussed in section 3.2.

In this model, four decision variables are considered. First two are binary decision variables which take the value as '1' if the decision is taken and "0" otherwise, both for repair and rehabilitation. Last two are repair and rehabilitation interval in years, respectively. They determine the frequency of repair and rehabilitation within design period. All the four variables are user-defined, i.e., their value will be decided by the user and accordingly the model will help to optimize the total cost and benefits of any maintenance activity of roads.

The model is also constrained to some practical and theoretical limitations as given from equation (4) to (10). Equation (4) implies that at any time during the design period, the money spent on all repair and rehabilitation work carried out should be within the maximum budget allocated for the required work. Rehabilitation interval should be an integral multiplicative of repair interval, where “I”, as stated in equation (5), is an integer. Equation (6) puts a constraint on road condition just after maintenance work which should be greater than a minimum acceptable road condition given by condition index"CI_1", which is user defined. Similarly constraint (7) implies that road condition just before repair or rehabilitation should be greater than a minimum acceptable road condition given by condition index"CI_2", which is again user defined. This constraint also helps to know whether the road condition was actually acceptable between repair or rehabilitation intervals. Constraint (8) and (9) again puts a check on road condition just before repair or rehabilitation. If the road condition just before maintenance work is less than certain minimum road condition index "CI_3" as given in equation(8), then repair work will be carried out. On contrary, if the road condition just before maintenance work is less than certain minimum road condition index "CI_4" as given in equation(9), then rehabilitation of the road should be carried out. These two constraints also help the user to decide upon whether repair or rehabilitation will be carried out based on road condition. Lastly constraint (10) states that at least one of the maintenance work, either repair or rehabilitation, should be carried out in a particular year within the design period but they shouldn’t take place simultaneously, i.e. if rehabilitation is done the there is no need of repair.

CHAPTER-4

MODEL VALIDATION

The developed model must be calibrated and validated in order to prove its proximity to the real-world problem and to compare with the actual field data. Hence in this chapter, it is described about the region of data collection obtained from NH Division, Dhenkanal, Odisha and the data collected are tabulated under different heads of parameters used in the formulation of objective functions, decision variables and constraints. The model is then validated using a Non-dominated Sorting Genetic Algorithm (NSGA-II) code in C adapted from Indian Institute Of Technology, Kanpur’s research laboratory “Kanpur Genetic Algorithms Laboratory” (KanGAL).

4.1. DATA COLLECTION

4.1.1. Overview of National Highways in India

National Highways (NH) are the arterial roads of the country for inter-state movements of passengers and goods. They criss-cross the length and breadth of the country connecting the National and State capitals, major ports and rail junctions and link up with border roads. The National Highways Authority of India (NHAI) is an autonomous agency of the Government of India, responsible for management of a network of over 70,000 km of National Highways in India. It is a nodal agency of the Ministry of Road Transport and Highways created through the promulgation of the *National Highways Authority of India Act, 1988*. In February 1995, the Authority was formally made an autonomous body. It is in charge of the development, maintenance, management and operation of National Highways, totalling over 71,772 km (44,597 mi) in length. construction and maintenance of National Highways (NHs), administration of Motor Vehicles Act, 1988 and Central Motor Vehicles Rules,1989, formulation of broad policies relating to road transport, environmental issues, automotive norms, etc. besides making arrangements for movements of vehicular traffic with neighbouring countries.

The NHAI has the mandate to implement the National Highway Development Project (NHDP) in phases. Phase I includes the Golden Quadrilateral (GQ), portions of the NS-EW Corridors, and connectivity of major ports to National Highways, at an estimated cost of Rs.300 Billion, approved in December 2000. Phase II includes the completion of the NS-EW corridors and another 486 km (302 mi) of highways, at an estimated cost of Rs.343 Billion, approved in December 2003. Phase IIIA and IIIB includes an upgrade to 4-lanes of 4,035 km (2,507 mi) and 8,074 km (5,017 mi) of National Highways , at an estimated cost of Rs.222 Billion and Rs.543 Billion, approved in March 2005 and April 2006 respectively. Phase V includes upgrades to 6-lanes for 6,500 km (4,000 mi), of which 5,700 km (3,500 mi) is on the GQ, entirely on a DBFO basis, approved in October 2006. Phase VI will develop 1,000 km (620 mi) of expressways at an estimated cost of Rs.167 Billion which has been approved in November 2006. Phase VII will develop ring-roads, bypasses and flyovers to avoid traffic bottlenecks on selected stretches at a cost of Rs.167 Billion which has been approved in December 2007.

4.1.2. Region of Data Collection

Data on various parameters of the model was collected from National Highway Division, Dhenkanal, Odisha. The general information about various maintenance activities carried out by the concerned department is as follows;

Rehabilitation or strengthening, termed as ‘Improvement of Riding Quality (IRQP)’ of National Highways (NH), is done in between 5 years to 8 years interval after the construction of new highway. This includes pavement overlays, slab replacements etc. Another part of this maintenance work is called ‘Periodic Renewal (PR)’ which is carried out in between 3 years to 4 years interval after the construction of new highway which involves major repairs as maintenance of shoulders, potholes, depression, and road markings etc. Apart from all these, minor repair works are carried out every year after construction. All the maintenance work is carried out according to Ministry of Road Transport and Highways (MORTH) and Indian Roads Congress (IRC) specifications. Design period of National Highways are generally considered to be 10 years.

Maintenance work of National Highways involves some field tests to ascertain the extent of deterioration of the road and to find out the amount of maintenance necessary so that the road functions satisfactorily by using some standard instruments and methods given by MORTH and IRC. Generally roughness of the road before maintenance work is measured through Fifth Wheel Bump Integrator which gives results on average deflections with respect to the longitudinal profile/lane of the road measured in mm/km. Sometimes the roughness measurement is also carried out post maintenance to check whether the maintenance done was able to correct the road deficiency or not. The strength of the road is ascertained through Benkelman Beam Deflection test and the standard procedure for finding the thickness and type of overlays to be provided is followed, using the data obtained from Benkelman Beam Deflection test. The cracks, potholes and depressions are measured in cubic meters and the total volume of the affected region in a particular stretch is found out. Data is collected for four stretches of NH-42 and NH-200.

National Highway 42 (or NH 42) is a National Highway of India entirely within the state of Odisha. It links NH 5 northeast of the city of Cuttack with NH 6 in Sambalpur connecting some primary locations as Dhenkanal and Angul. It runs for a total length of 261 km (162 mi). Average crust available is 425 mm and sandy sub-grade soil type. It is a two lane road, with traffic Intensity of 1413 commercial vehicles per day (CVD). It has been approved for four laning with paved shoulders in Phase-IV of NHDP in 2011. IRQP data collected was obtained for the stretch from KM 161/0-176/0, i.e. from Boinda to Rairakhol of NH-42 for the year 2007-2008.

National Highway 200 (NH 200) is a National highway in India that connects Raipur, the state capital of Chhattisgarh to Chandikhole in Odisha linking Talcher, Keonjhar with Paradip Port via Chandikhol on NH-5A and some primary locations as Simga, Bilaspur, Sarangarh, Raigarh and Deogarh**.** It covers a distance of 740 km (460 mi).It has 300 km of it in Chhattisgarh and a major part of 440 km in Odisha. It is also a two lane road of intermediate width (5.50 meters) with traffic intensity of 1732 CVD. Traffic volume in this NH is increasing day by day owing to rapid industrial growth and also due to the mining traffic from mines in Talcher and Keonjhar to Paradip Port for shipping. The sub-grade soil type is of red earth. It has been approved for four laning with paved shoulders in Phase-III of NHDP. PR data was obtained for KM 301/893-309/0 and 319/0-332/0 of NH-200, i.e. from Pitiri to Kamakshanagar to Bhuban stretch for the year 2009-2010. Another set of PR data to stretches from KM 342/0-352/0 of NH-200, i.e. from Kamakshanagar-Bhuban, carried out in 2009-2010 was also obtained. PR data to stretches from KM 301/893-309/0 of NH-200, i.e. for the stretch from Pitiri-Kamakshanagar, carried out in the year 2002-2003 was also obtained.

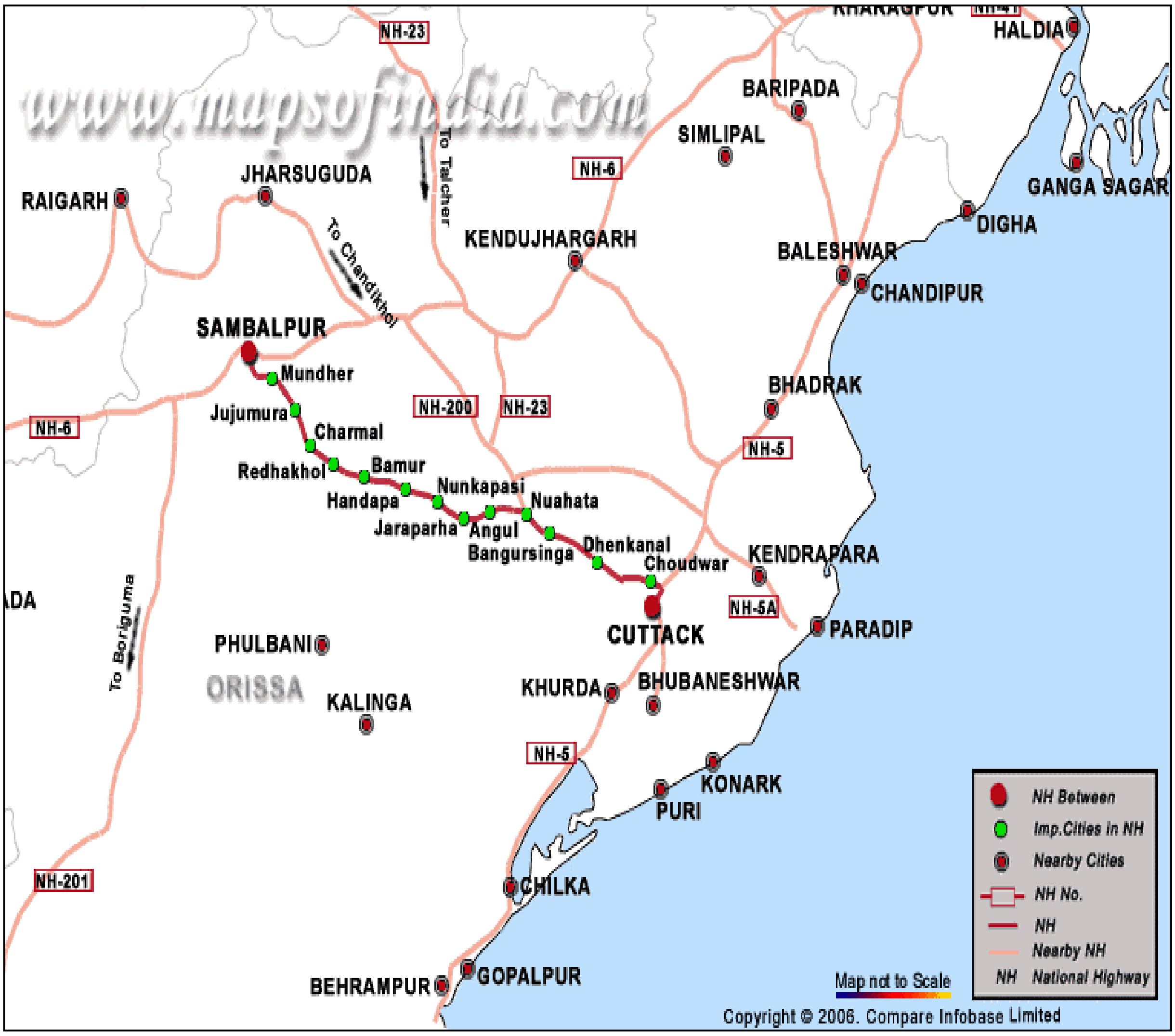

Figure 6. Map showing the geographical location of NH 42 and the connecting important cities (courtesy: www.mapsofindia.com).

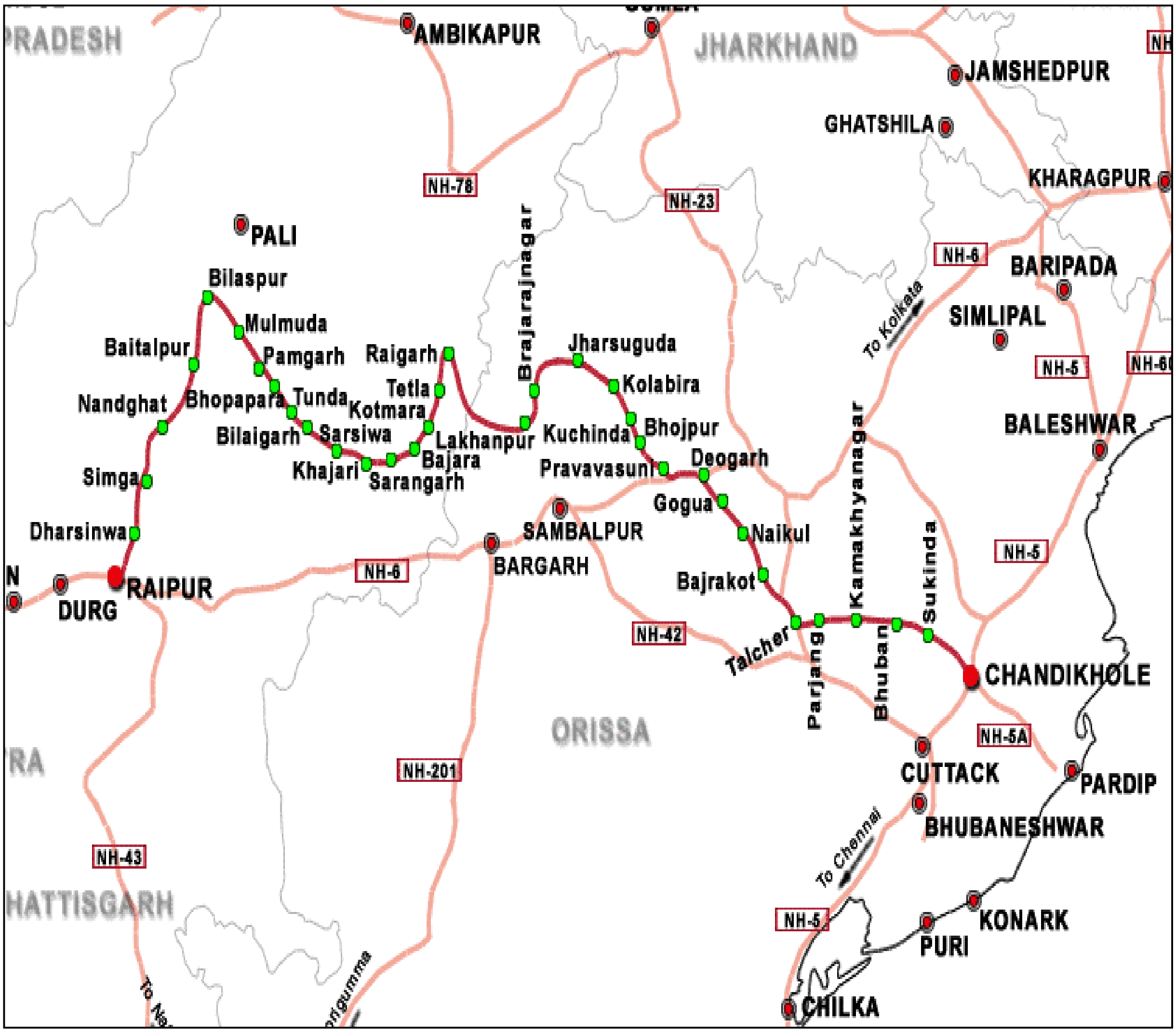

Figure 7. Map showing the geographical location of NH 200 and the connecting important cities (courtesy: www.mapsofindia.com).

4.2. DATA TABULATION

All the data collected from the above mentioned stretches of road of NH-42 and NH-200 are gathered and tabulated as shown in the following tables. 64 data points are obtained according to chainage of the road stretch and tabulated under different heads representing the various parameters used in the development of the objective functions, decision variables and constraints of the optimization model.

Table 1. 1. Field values of the parameters considered in the objective function

	CHAINAGE	OBJECTIVE FUNCTIONS				
		TOTAL COST		TOTAL BENEFITS		
		repair cost (rupees in lakhs)	rehabilitation cost (rupees in lakhs)	strength parameter	road roughness parameter	cracks/pot holes parameter (m)
NH-42 2007-2008(Strengthening)	161-162		512.73	1.11	4235.21	
	162-163			1.01	3771.97	
	163-164			1.36	4748.99	
	164-165			1.14	4200.56	
	165-166			1.13	4880.29	
	166-167			1.13	4313.79	
	167-168			1.18	4982.43	
	168-169			1.06	3792.92	
	169-170			1.01	3834.65	
	170-171			1.22	4085.56	
	171-172			1.11	4195.6	
	172-173			1.05	4090.6	
	173-174			1.08	3719.38	
	174-175			1.02	3750.98	
	175-176			1.03	3708.82	
NH-200 2009-2010(Periodic Renewal)	301.893-302	309.56				715283.88
	302-303					715283.88
	303-304					706487.81
	304-305					714848.83
	305-306					715033.03
	306-307					715277.28
	307-308					705141.28
	308-309					715128.68
	319-320					485164.05
	320-321					485151.26
	321-322					485152.22
	322-323					485138.75
	323-324					485175.18
	324-325					485207.36
	325-326					485119.36
	326-327					485117.43
	327-328					485115.78
	328-329					485122.14
	329-330					485132.71
	330-331					485611
	331-332					485110.49

Table 1. 2. Field values of the parameters considered in the objective function

	CHAINAGE	OBJECTIVE FUNCTIONS				
		TOTAL COST		TOTAL BENEFITS		
		repair cost (rupees in lakhs)	rehabilitation cost (rupees in lakhs)	strength parameter	road roughness parameter	cracks/pot holes parameter (m)
NH-200 2009-2010(Periodic Renewal)	342-343	153.2				1591739.25
	343-344					1591466.81
	344-345					1590014.8
	345-346					1586059.45
	346-347					1586059.45
	347-348					1590173.7
	348-349					1586059.45
	349-350					1586059.45
	350-351					1592105.7
	351-352					1586059.45
NH-200 2002-2003(Periodic Renewal)	301.893-30	40.31			8561.23	445769.4285
	302-303				8225.1	445769.4285
	303-304				6642.1	445769.4285
	304-305				7176.86	445769.4285
	305-306				7604.33	445769.4285
	306-307				4394.05	445769.4285
	307-308				2906.04	445769.4285
	308-309				4172.56	445769.4285
	309-310				8822.51	445769.4285
	310-311				7832.39	445769.4285
	311-312				9235.2	445769.4285
	312-313				8736.53	445769.4285
	313-314				9352.1	445769.4285
	314-315				6813.54	445769.4285
	315-316				8180.26	445769.4285
	316-317				5995.02	445769.4285
	317-318				6621.67	445769.4285
	318-319				8583.69	445769.4285

Table 2. 1. Field values of the parameters considered as decision variables

	CHAINAGE	DECISION VARIABLES	
		repair interval (in years)	rehabilitation interval (in years)
NH-42 2007-2008(Strengthening)	161-162	2	8
	162-163	3	8
	163-164	3	8
	164-165	3	8
	165-166	2	8
	166-167	2	8
	167-168	2	8
	168-169	2	8
	169-170	2	8
	170-171	2	8
	171-172	2	8
	172-173	2	8
	173-174	2	7
	174-175	2	7
	175-176	2	7
NH-200 2009-2010(Periodic Renewal)	301.893-302	5	10
	302-303	4	10
	303-304	4	10
	304-305	4	10
	305-306	4	10
	306-307	4	10
	307-308	4	10
	308-309	4	10
	319-320	4	10
	320-321	4	10
	321-322	4	10
	322-323	4	10
	323-324	4	10
	324-325	4	10
	325-326	4	10
	326-327	4	10
	327-328	4	10
	328-329	4	10
	329-330	4	10
	330-331	4	10
	331-332	4	10

Table 2. 2. Field values of the parameters considered as decision variables

	CHAINAGE	DECISION VARIABLES	
		repair interval (in years)	rehabilitation interval (in years)
NH-200 2009-2010(Periodic Renewal)	342-343	5	8
	343-344	5	8
	344-345	5	8
	345-346	5	8
	346-347	5	8
	347-348	5	8
	348-349	5	8
	349-350	5	8
	350-351	5	8
	351-352	5	8
NH-200 2002-2003(Periodic Renewal)	301.893-302	5	
	302-303	5	
	303-304	5	
	304-305	5	
	305-306	5	
	306-307	5	
	307-308	5	
	308-309	5	
	309-310	5	
	310-311	5	
	311-312	5	
	312-313	5	
	313-314	5	
	314-315	5	
	315-316	5	
	316-317	5	
	317-318	5	
	318-319	5	

Table 3. Field values of the parameters considered in constraints

	CHAINAGE	CONSTRAINTS	
		budget allocated (rupees in lakhs)	Condition Index after repair (roughness in mm/km)
NH-42 2007-2008(Strengthening)	161-162	495.27	
	162-163		
	163-164		
	164-165		
	165-166		
	166-167		
	167-168		
	168-169		
	169-170		
	170-171		
	171-172		
	172-173		
	173-174		
	174-175		
	175-176		
NH-200 2002-2003(Periodic Renewal)	301.893-302		5453.41
	302-303		5449.2
	303-304		3810.58
	304-305		3890.5
	305-306		4798.05
	306-307		3297.93
	307-308		6448.19
	308-309		5764.06
	309-310		5399.94
	310-311		4265.8
	311-312		5210.62
	312-313		5078.8
	313-314		5146.03
	314-315		3543.83
	315-316		3622.52
	316-317		2789.33
	317-318		3700.97
	318-319		4304.88

4. 3. MODEL VALIDATION

4. 3. 1. Overview on Evolutionary Algorithms

The presence of multiple objectives in a problem gives rise to a set of optimal solutions known as Pareto-optimal solutions, instead of a single optimum solution which are not dominated by rest of the solutions in the search space. In the absence of any further information, one of these Pareto-optimal solutions cannot be said to be better than the other which demands to find as many Pareto-optimal solutions as possible.

Classical optimization methods for solving multiple objectives have limitation of converting the multi-objective optimization problem to a single-objective optimization problem by emphasizing one particular Pareto-optimal solution at a time. Hence, to generate multiple optimal solutions, the classical optimization model has to be used for several times increasing the complexity of the problem and is also time consuming.

Over the past decade, a number of multi-objective evolutionary algorithms (MOEAs) have been suggested which are non-classical, unorthodox and stochastic search and optimization algorithms. Evolutionary algorithm (EA) mimics nature's evolutionary principles to drive its search towards an optimal solution, i.e. the true Pareto-optimal region. They have the ability to find multiple Pareto-optimal solutions in one single simulation run saving time and decreasing complexity. Since evolutionary algorithms (EAs) use a population of solutions in each iteration, instead of a single solution, a simple EA can be extended to maintain a diverse set of solutions. There exists four different evolutionary algorithms (EAs) such as genetic algorithms (GAs), evolution strategy (ES), evolutionary programming (EP) and genetic programming (GP).

Genetic Algorithms (GAs) have been extensively used as search and optimization tools in various problem domains, including science, commerce and engineering. The primary reasons for their success are their broad applicability, ease of use and global perspective. A number of multi-objective Genetic Algorithms were developed in last few years as Multi-Objective GA (MOGA) by Fonseca and Fleming in 1993, Niched Pareto-GA (NPGA) by Horn, Nafploitis, and Goldberg in 1994, Non dominating Sorting Genetic Algorithm (NSGA) by Srinivas and Deb in 1995, Pareto-Archived Evolution Strategy (PAES) by Knowles and Corne in 1999, NSGA II by Deb in 2000 etc.

4. 3. 2. NSGA-II

The main drawbacks of the NSGA approach were its high computational complexity of non-dominated sorting; lack of elitism helps in preventing the loss of good solutions once they are found and speed up the performance and need for specifying the sharing parameter. So a parameter-less diversity-preservation mechanism is desirable.

NSGA II is an elitist non-dominated sorting Genetic Algorithm to solve multi-objective optimization problem using a parameter less niching operator. NSGA II has been successful in converging to the global Pareto-optimal front and maintaining the diversity of population on the Pareto-optimal front with less computational complexity than other multi-objective evolutionary algorithms. The diversity among non-dominated solutions is introduced by using the crowding comparison procedure, which is used in the tournament selection and during the population reduction phase. Since solutions compete with their crowding-distance which is measured as the distance of the biggest cuboids containing the two neighbouring solutions of the same non-dominating front in the objective space, no extra niching parameter (as needed in the NSGA) is required. Higher the value of crowding distance better is the probability of the solution to be selected for the next generation as given in Deb et al. (2002).

4. 3. 3. The Validation Program

A Multi-Objective NSGA-II Code in C known as Dev C++, taking care of both real and binary decision variables along with constraint handling technique is adapted. The software is developed by the Kanpur Genetic Algorithm Laboratory "KanGAL" of Indian Institute of Technology, Kanpur (courtesy: http://www.iitk.ac.in/kangal/codes.shtml).

All the necessary information about the proposed model in the present research work and some other information needed to validate the model are given as inputs to the program and then compiled and run. The GA Parameters information provided to the program is as follows:

The Population Size is given 64 as 64 data points were obtained from data collection. Number of objective functions is given 2 and number of constraints is 7as per the model. Number of binary-coded decision variables is given 2 and number of real-coded variables is given 2 as per the model. Number of generations selected was 100 and selection strategy is Tournament Selection with chromosome length of 20.

For the first binary-coded variable for rehabilitation, number of bits assigned is 10 with lower limits and upper limits given as 0.0 and 1.0 respectively. For the second binary-coded variable for repair, number of bits assigned is 10 with lower limits and upper limits given as 0.0 and 1.0 respectively same as first binary-coded variable.

For the first real-coded variable representing repair interval of the formulated model, lower limit and upper limit is given as 2.0 and 5.0 respectively and for the second real-coded variable representing rehabilitation interval of the formulated model, lower limit and upper limit is given as 8.0 and 10.0 as per the field data collected. Variable bounds for both the real-coded variable are not rigid.

Crossover selected on binary strings is uniform X-Over. Crossover parameter in the SBX (simulated binary) operator is given as 50.0 and Crossover probability is given as 0.60. Mutation Probability for binary strings is given as 1.0 and mutation probability for real-coded vectors is given as 0.10. Random Seed is given as 0.10.

4.4. RESULTS AND DISCUSSION

The above computer program is executed giving the necessary GA parameters as described above. The result from the program is as follows:

1. For the first real-coded decision variable representing repair interval, the result recommended using $\mathbf{4.1 \simeq 4}$ as the optimum repair interval.
2. For the second real-coded decision variable representing rehabilitation interval, the result recommended using $\mathbf{8.3 \simeq 8}$ as the optimum rehabilitation interval.

The above optimum repair and rehabilitation interval obtained from the computer program is matched with the collected field data and it was observed that the optimum repair interval of 4 years from the program matched with the field data by 32.81 % and the optimum rehabilitation interval of 8 years from the program matched with the field data by 54.35 %.

CONCLUSION AND RECOMMENDATIONS

The multi-objective optimization model formulated for maintenance and rehabilitation activities of roads satisfied the research objectives described in this thesis to a reasonable level as both the cost as well as benefit in terms of improved road condition was considered in the optimization model. Moreover the constraints described in the model can be used to put a check on whether the previous maintenance activities carried out was effective to enhance the performance of the road or not. It also ensures that the future maintenance and rehabilitation activities are at least up to an acceptable condition enforced by introducing condition index for repair and rehabilitation separately.

The model validation done by using a Non-dominated Sorting Genetic Algorithm (NSGA-II) code in C adapted from Indian Institute Of Technology, Kanpur's research laboratory "Kanpur Genetic Algorithms Laboratory" (KanGAL) with GA parameter inputs as observed from the field data was seen to be giving satisfactory optimum values for two real-coded decision variables of repair and rehabilitation interval. Optimum repair interval of 4 years from the program matched with the field data by 32.81 % and the optimum rehabilitation interval of 8 years from the program matched with the field data by 54.35 %. With more data available, it can be expected that the Non-dominated Sorting Genetic Algorithm II (NSGA-II) can accurately predict the optimum solutions to the problem of developing a suitable maintenance and rehabilitation activities of roads.

Owing to the difficulties faced while formulating and validating the proposed model, this research work can be further extensive if the multi-objective optimization model developed can be reduced to a single-objective optimization model by assigning weights to the two objectives, reducing the complexity of the model. Also further if the parameters considered in the constraints can be made linear with fewer assumptions, then also the model can be solved easily to give good results in less time.

REFERENCES

1. Markow, M.J., Brademeyer, B.D., Sherwood, J. and Kenis, W.J. (1987).The economic optimization of pavement maintenance and rehabilitation policy. In *2nd North American Pavement Management Conference.*

2. Ouyang, Y. and Madanat, S. (2004). Optimal scheduling of rehabilitation activities for multiple pavement facilities: exact and approximate solutions. *Transportation Research Part A 38*, pp. 347–365.

3. Yin, Y., Lawphongpanich, S. and Lou, Y. (2008). Estimating investment requirement for maintaining and improving highway systems. *Transportation Research Part C 16*, pp. 199 – 211.

4. Lamptey, G., Labi, S. and Li, Z. (2008). Decision support for optimal scheduling of highway pavement preventive maintenance within resurfacing cycle. *Decision Support Systems 46*, pp. 376–387.

5. Durango-Cohen, P.L. and Sarutipand, P. (2009). Maintenance optimization for transportation systems with demand responsiveness. *Transportation Research Part C 17*, pp. 337–348.

6. Ng, M., Zhang, Z. and Waller, S.T. (2011). The price of uncertainty in pavement infrastructure management planning: An integer programming approach. *Transportation Research Part C 19*, pp. 1326–1338.

7. Santeroa, N., Masanetb, E. and Horvath, A. (2011). Life-cycle assessment of pavements. Part I: Critical review. *Resources, Conservation and Recycling 55*, pp. 801–809.

8. Garza, J., Akyildiz, S., Bish, G. and Krueger, D. (2011). Network-level optimization of pavement maintenance renewal strategies. *Advanced Engineering Informatics 25*, pp. 699–712.

9. Meneses, S. and Ferreira A. (2012). New optimization model for road network maintenance management. *Procedia - Social and Behavioral Sciences 54*, pp. 956 – 965.

10. Basic Road Statistics of India 2008-09, 2009-10 and 2010-11 (2012). Ministry of Road Transport and Highways, Transport Research Wing, New Delhi, India.

11. Road Information Management Systems (2000). "Implementation of Predictive Modelling For Road Management, *Technical Report DT/99/07-2, First Revision, Ingenium, HTC Infrastructure Management Ltd., Auckland, New Zealand.*

12. "Pavement Condition Index Distress Identification Manual Asphalt and Surface Treatment Pavement" (1986). *Technical Report, Second Revision, Metropolitan Transportation System, Oakland, California.*

13. IRC: SP: 16 (2004). "Guidelines for Surface Evenness of Highway Pavements". *IRC: SP: 16-2004, First Revision, Indian Roads Congress Publication.*

14. Deb, K., Pratap, A., Agarwal, S. and Meyarivan T. (2002). A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation, Vol. 6, No. 2*, pp. 182-197.

15. Deb, K. (2002). "Multi-Objective Optimization Using Evolutionary Algorithm". *First Edition, John Wiley and Sons, Ltd., England*, pp. 13-163.