

# System Dynamics '90

Volume 1: Abbas – Henderson

Proceedings of the  
1990 International System Dynamics Conference

Chestnut Hill, Massachusetts  
July 10 through 13, 1990

David F. Andersen  
Conference chair

George P. Richardson  
John D. Sterman  
Program chairs

The System Dynamics Society  
Massachusetts Institute of Technology, E40-294  
Cambridge, Massachusetts 02139

and

Nelson A. Rockefeller Institute of Government  
State University of New York  
411 State Street, Albany, NY 12203  
Conference Sponsors

---

© 1990 by the System Dynamics Society

**(NOTE: The Systems Dynamics Society holds no copyright on any of the papers contained in these volumes. All rights are reserved by the individual authors. The format and layout of the Proceedings are copyright © by the System Dynamics Society.)**

ISBN: 0-914341-16-2 (3-volume set)

# Table of Contents

---

## VOLUME 1

<b>Preface</b> . . . . .	xi
<b>A Road Provision Model Using System Dynamics</b>	
Khaled A. Abbas . . . . .	1
<b>The Use of System Dynamics in Modelling Transportation Systems With Respect to New Cities in Egypt</b>	
Khaled A. Abbas . . . . .	16
<b>Issues in Designing Interactive Games Based on System Dynamics Models</b>	
David F. Andersen, Ik Jae Chung, George Richardson, Thomas Stewart . . . . .	31
<b>The Use of System Dynamics to Measure the Value of Information in a Business Firm</b>	
Fred Augustine, Jr., Thomas D. Clark, Jr. . . . .	46
<b>Dynamics of Food Policy in a Centrally-Planned Economy: The Case of Vietnam</b>	
N.L. Bach, J.E. Lukens, Khalid Saeed . . . . .	61
<b>Simulation of Food Grain Storage Management System in Bangladesh</b>	
B.K. Bala, M.A. Satter, Md. Golam Mohiuddin . . . . .	75
<b>Technical Education Modeling and Simulation</b>	
John D. Bernard, D. Henry Pate . . . . .	90
<b>Simulation as a Tool for Planning of Rural Development Programmes: A Case in Southern Sudan</b>	
Tjark Struif Bontkes . . . . .	105
<b>Contrasting Perspectives on Rationality and the Analysis of Performance Outcomes</b>	
Michael G. Bowen . . . . .	119
<b>Exemplary Computer Model for a Natural History Museum</b>	
Charles H. Braden . . . . .	134
<b>Dynamics of Company Excellence Through Motivation of Employees</b>	
Andres E. Breiter . . . . .	141
<b>Using Complex System Dynamic Models; An Example Concerning the Dutch Dental Health Care System</b>	
E.M. Bronkhorst, G.J. Truin, T. Wiersma . . . . .	155
<b>Improving Education in Public Schools: Innovative Teachers to the Rescue</b>	
Gordon S. Brown . . . . .	164
<b>Anarquia Interfacing Hypermedia and System Dynamics for Urban Management</b>	
Antonio Camara, Paula Antunes, Julia Seixas, Lia Vasconcelos . . . . .	174
<b>Exploring "Ideas", A Multidimensional Dynamic Simulation Approach</b>	
Antonio Camara, Francisco Ferreira, Maria Julia Seixas . . . . .	181
<b>The Cost of Instability in Defense Spending</b>	
Rolf Clark . . . . .	191
<b>End User Computing Growth and Management in Organizations</b>	
Thomas D. Clark, Jr., Victoria L. Mitchell, Karen Williams . . . . .	201
<b>A Model for Future HIV/Aids Incidence in New York City</b>	
Catherine Crawford, Fred Wenstop . . . . .	216

<b>A Behavioral Simulation Model of Single and Iterative Negotiations</b>	
Thomas A. Darling, George Richardson . . . . .	228
<b>Introducing System Dynamics in Schools, the Nordic Experience</b>	
Pal I. Davidsen, Margaretha Bjurklo, Hugo Wikstrom . . . . .	242
<b>A System Dynamics Approach to the Structure and the Economy of Fur Farming and Trade</b>	
Pal I. Davidsen, Leif Jarle Asheim . . . . .	255
<b>Building an Organizational Learning Environment</b>	
John P. Davulis, Ulrich Goluke . . . . .	270
<b>Manager Training Environment for Setting Complex Problems</b>	
D.J. de Tombe . . . . .	280
<b>Negotiating Reality: Using Language and Influence Diagrams to Articulate Knowledge</b>	
Julia M. Di Stefano . . . . .	293
<b>Translating Systems Thinking for People in the World of Business</b>	
Linda Dolny . . . . .	304
<b>The Dynamics of Behavior and Motivation</b>	
Gerard Donnadieu, Michel Karsky . . . . .	319
<b>Regional Energy Planning</b>	
Issac Dwyer, I.M. Giraldo, A. Lobo, A. Moreno, D. Valencia . . . . .	333
<b>Casual Tracing: One Technical Solution to the Modeling Dilemma</b>	
Robert L. Eberlein, David W. Peterson, William T. Wood . . . . .	341
<b>Developing a Communication-Oriented Ontology for Using Computer Modeling in Negotiation</b>	
John R. Ehrenfeld . . . . .	355
<b>System Dynamics as a Foundation for Pre-College Education</b>	
Jay W. Forrester . . . . .	367
<b>Policy Design in Oscillating Systems</b>	
Douglas Franco . . . . .	381
<b>An Appraisal of System Dynamics in Assessing the Impact of Computer Information Systems</b>	
A. W. Gavine, E. F. Wolstenholme . . . . .	395
<b>Cognitive Biases, Modeling and Performance: An Experimental Analysis</b>	
Nicholas C. Georgantzas . . . . .	410
<b>A Nonequilibrium, Nonlinear Approach to Organizational Change</b>	
Jeffrey Goldstein . . . . .	425
<b>Freud's Theories in the Light of Far-from-Equilibrium Research</b>	
Jeffrey Goldstein . . . . .	440
<b>Discontinuous Innovation Diffusion Analysis</b>	
M. Govindarajan, N. Ramaswamy . . . . .	455
<b>System Dynamics Combined with Monte Carlo Simulation</b>	
Norodd Hagenson . . . . .	468
<b>The Application of Dynamic Methodology to Assess the Benefit of a Battlefield Information System</b>	
Simon M. Henderson, Eric F. Wolstenholme . . . . .	480

# A Road Provision Model Using System Dynamics

by

Khaled A Abbas  
Department of Civil Engineering  
University of Newcastle upon Tyne  
Newcastle upon Tyne NE1 7RU, U.K.

## ABSTRACT

One of the most difficult tasks facing highway administrators is how to efficiently manage the allocation of road funds. In this paper a comprehensible, easy-to-use, highway management tool is presented. This tool takes the form of a computer simulation model which is intended to assist managers of a network of highways to make better decisions concerning the allocation of scarce funds. It mainly simulates the effects of different investment strategies and maintenance options on the road network. This is done by tracing the life-cycle costs of the major activities of providing and maintaining the road system, and by considering the effects that these activities have on the state and performance of the road network.

## 1. INTRODUCTION

The continued development of the road network is looked upon as a necessity that contributes to the prosperity and wellbeing of a country. Construction, maintenance and upgrading of roads constitute a large portion of the transport budget in many countries, yet the growing conflict between the requirements of the road network and the available financial resources is one of the most serious problems that highway authorities have to deal with. There is a need for simplified planning techniques that are capable of testing alternative strategies for investing in the road network system.

This financial stringency requires the development of road management systems to provide support for highway decision-makers so that they can make more rational, informed decisions. These decisions should be targeted towards achieving a better management and control of the road network system.

Road management systems can be described as computerised, analytic tools that consider the whole life-costing of alternative strategies for the road network. These tools enable the testing of alternative management and planning programmes for the highway sector.

## 2. PURPOSE AND APPROACH

The main purpose of this study is to construct a dynamic, simulation model that describes the structural, feedback interactions of the road network system. The model is meant to analyse the impacts of proposed changes in the funding levels, as well as in the structure of the priorities involved in the allocation of road funds.

The System Dynamics methodology, (Forrester 1968), is used in this study as the modelling framework within which the road management model is developed.

The model simulates the effects of different road investment strategies. This is done by tracing the life-cycle costs of the activities which are necessary to develop and maintain the road system, and establishing the impacts that these activities have on the condition and performance of the road network. The main objectives of the model are as listed below.

- (1) To model the process involved in the allocation of road funds. This allocation process is meant to satisfy, (in a relative sense), the financial requirements of the changing physical condition of the road network. The two main constraints that are considered in this process of allocation include: the level of available funds and the priorities for allocating road funds to the main activities of the road network.
- (2) To provide better insight and understanding of the dynamic, feedback nature of the road system.
- (3) To act as an experimental management tool for assessing the short- and long-term consequences of different road strategies on the physical development of the road system. A road strategy involves the determination of; road funding levels, priorities for allocating road funds and time intervention criteria for performing maintenance activities.
- (4) To assist in management and control of the road system.
- (5) To provide a set of performance indicators that describe the state of the road system at any point in its lifetime.

### 3. MODEL DESCRIPTION

The road provision model consists of two main parts, as shown in Figure 1. The first, is the user interface module, the second is the System Dynamics road provision module, see (Abbas 1990).

In this section, the System Dynamics conceptual model is introduced. The feedback interaction between demand and supply of the road network system is explicitly considered. The main assumptions and some of the important variables of the model are explained. Causal diagrams are considered to be an advanced and comprehensible step of the System Dynamics modelling procedure. This paper presents the fundamental, causal mechanisms underlying the structure of the System Dynamics road provision model.

#### 3.1 Managing the Process of Allocation of Road Funds

Each time interval of the simulation, road funds are allocated among five road system activities. Referring to Figure 2 the main activities of the road provision model include:

- (1) road administration activity;
- (2) routine road maintenance activity;
- (3) road construction activity;
- (4) road rehabilitation-reconstruction, i.e. restoration activity; and
- (5) periodic road maintenance activity.

This investment allocation process is performed in a dynamic fashion so as to be relatively consistent with the competing priorities and the changing demands of the road network system. The priorities for the allocation of

- (d) restoration of roads; and
  - (e) periodic maintenance of roads.
- (3) Expenditure and levels of:
- (a) constructed roads;
  - (b) administered roads;
  - (c) routinely maintained roads;
  - (d) restored roads; and
  - (e) periodically maintained roads.

### 3.3 Main Input Values by the Model User

The user interface module can be described as a computerised, friendly dialogue, designed mainly to instigate creativity in constructing alternative scenarios for the road network, and also to work as a medium to facilitate the specification of the model exogenous parameters by the user. The following presents the main input parameters of the model and describes the options available to represent these parameters, through using the user interface module.

- Initial unit cost of:
  - (1) Yearly Road Administration Cost Per Kilometre.
  - (2) Routine Road Maintenance Cost Per Kilometre.
  - (3) Periodic Road Maintenance Cost Per Kilometre.
  - (4) Road Construction Cost Per Kilometre.
  - (5) Road Rehabilitation-Reconstruction Cost Per Kilometre. (Refer to Figure 10)
- Inflation/deflation rates of the previously stated unit costs. (Refer to Figure 10)
- The user can choose from among several forms that are available for inputting road funds. Road Funds can be generated using any of the following options:
  - (1) Empirical function (linear or nonlinear).
  - (2) Deterministic function.
  - (3) Random Stochastic function (stochasticity assumed to be of the Gaussian type, and randomness is based on the pseudo randomisation process).
  - (4) Combination of any of the above i.e. at a time specified by the user, the function of the road funds changes from one form to another. The available combinations include:
    - (a) Empirical function with Deterministic function.
    - (b) Empirical function with Stochastic function.
    - (c) Deterministic function with Stochastic function.
- The life cycle of a road progresses through time from an initial state of being in good condition, passing through a state of fair condition and terminating at a state of poor condition, where the road is almost unusable, due to radical structure failure, i.e. high surface roughness values. The maintenance specifications of the model matches particular

threshold times at which the condition of a road changes from one state to another. The main two threshold times introduced to the model are defined below.

- (1) Good To Fair Period, which represents the period of time the road lasts in a good condition i.e. the time when road condition changes from good to fair, and hence requires periodic maintenance. Refer to Figures 11 (Harral 1988) and 12 (Bhandari 1988)
- (2) Fair To Poor Period, which represents the period of time over which a road life cycle lasts i.e. the time when road condition changes from fair to poor, and hence requires restoration. Refer to Figures 11 (Harral 1988) and 12 (Bhandari 1988)

As mentioned above, both threshold periods are meant to provide the times when the intervention criteria for performing periodic and restoration maintenance activities are satisfied. The user interface module provides several different forms for generating these intervention times at which the above-stated maintenance activities should be performed. These forms are described below.

- (a) Deterministically scheduled to occur at a time specified by the model user. (\*)
- (b) Stochastically scheduled to occur at a time specified by the model user. Time here is randomly generated, from a normal distribution, with a mean and a standard deviation specified by the model user. This option is introduced, to cater for the relative uncertainty involved in determining the exact threshold times. (\*)
- (c) Condition responsive, according to the HDM III empirical, aggregate model (Paterson 1987), that describes the progression of roughness over paved roads. The HDM III equation is of the following form:

$$RI(t) = [RI_0 + 725[1 + SNC]^{-4.99} NE_4(t)] e^{0.0153t}$$

where

- |                          |   |   |
|--------------------------|---|---|
| RI(t), RI <sub>0</sub> - | - | roughness at times t and t=0 respectively, in m/km IRI,   |
| SNC                      | - | modified structural number,   |
| t                        | - | age of the pavement since restoration or construction,  |
| NE <sub>4</sub> (t)      | - | cumulative equivalent standard axle loadings until time t, using damage factor -4, in million ESA/lane. |

It is to be noted that surface roughness of roads is considered to be the most representable performance indicator of the changing



condition of paved roads over time. (\*\*)

- (\*) Scheduled maintenance is made at a specific time of the life of a road. Scheduled maintenance, sometimes called preventive maintenance, is applied irrespective of the actual condition of the road at the time of maintenance.
- (\*\*) Condition responsive maintenance is performed at a time when the condition of the road has deteriorated to a prescribed threshold level. This conditional level is specified by the user according to his acceptable criteria regarding the performance of roads.

The model is structured to keep the input data to a minimum, yet to produce a comprehensive output of the condition and expenditure of the road network. This information enables a thorough examination by the model user, thus rationalising the decision making, concerning road funding strategies and maintenance combination options.

#### 4. SUMMARY AND CONCLUSION

A simulation model for the dynamic provision of roads is presented. The model simulates the effects of road investment policies on the development of the road network system. The investments are allocated among the construction, maintenance and administrative activities. The maintenance activities involved are routine, periodic and restoration maintenance. The model is a typical policy analysis tool and is meant to give information about the structure and performance of the road network system. The road provision model allows us to analyse the life-cycle costs of a road under a variety of alternative road funding policies, maintenance options, initial unit costs, inflation rates, etc.

System Dynamics, the modelling approach used in this study, seems to fulfill a need, which is not met by the standard planning and programming approaches, namely that of providing for the concept of controllability, (Coyle 1978). System Dynamics is a very strong, policy-orientated modelling technique.

In attempting to present the road provision model, three main topics were addressed. First, to indicate how available road funds would be allocated into major appropriation categories. Second, to introduce a set of uncomplicated, yet reasonably, comprehensive submodels of the road system. These submodels when linked together form the structure of the System Dynamics road provision module. Third, to show the main input parameters required by the model and to explain the options available for inputting each parameter by using the flexible user interface module.

The overall objective of the developed model is to serve as a management tool for designing, testing and assessing strategies that support the decision making process in the field of Highway planning. The model is to be used by transportation system managers, in policy planning, and by government decision-makers in making better decisions concerning the road network system.

## REFERENCES

Abbas, K. A. 1990. Simulation of the Effects of Transport Investment Policies on the Development of Road Infrastructure. In Proceedings of Universities' Studies Transport Group Annual Meeting. Hatfield Polytechnic, Hatfield, U.K.

Bhandari, A. S., and K. A. Sam. 1988. The Road Network Stabilization Programme in Ghana. In Proceedings of the 16th PTRC Summer Annual Meeting, Road Deterioration in Developing Countries, Seminar G, 28-41. Sussex, U.K.

Coyle, R. G. 1978. Management System Dynamics. A Wiley-Interscience Publication.

Forrester, J. W. 1968. Principles of Systems. The MIT Press/Wright-Allen Series in System Dynamics.

Harral, C., and A. Faiz. 1988. Road Deterioration in Developing Countries: Causes and Remedies. A World Bank Policy Study. A World Bank Publication. The World Bank, Washington, D.C.

Paterson, W. D. O. 1987. Road Deterioration and Maintenance Effects, Models for Planning and Management. The Highway Design and Maintenance Standards Series. A World Bank Publication. The John Hopkins University Press

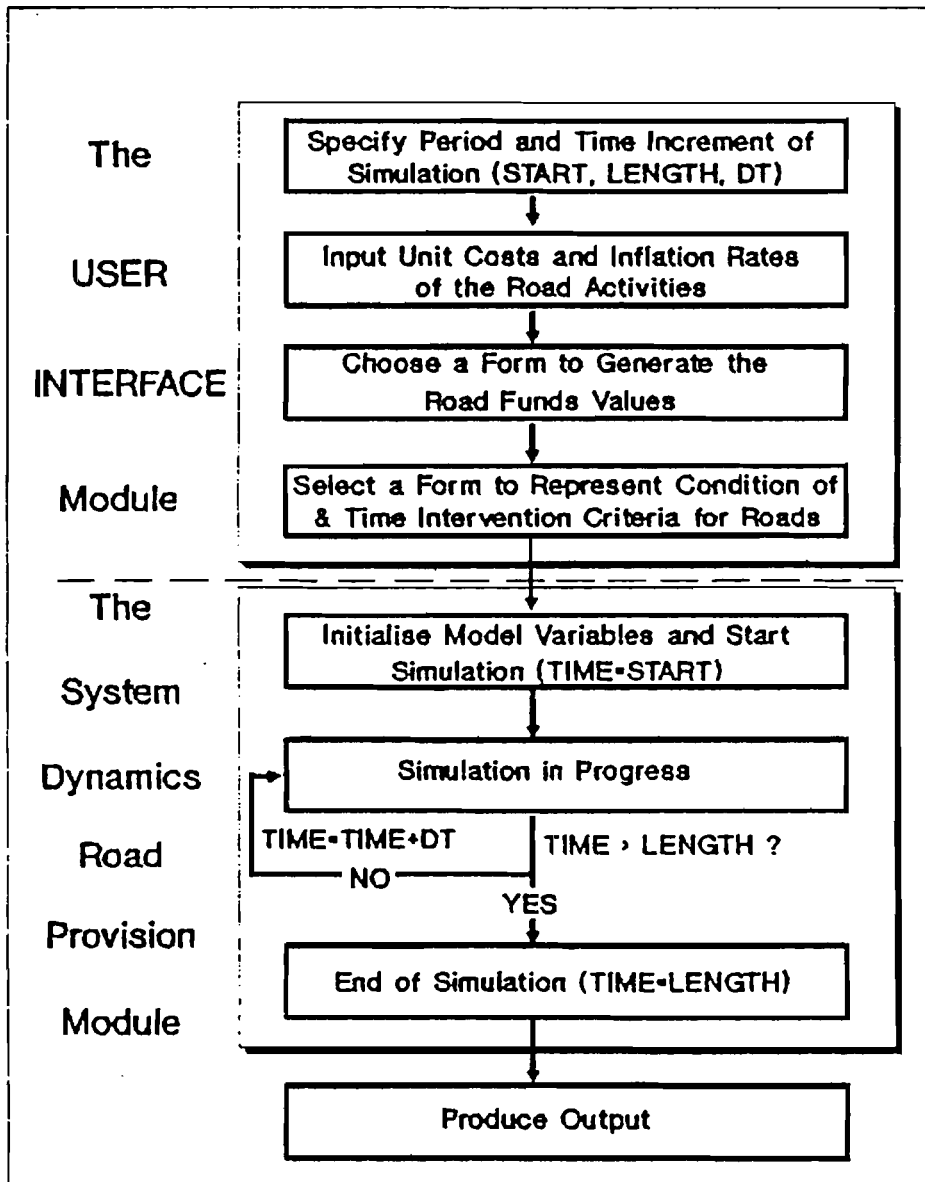


Fig 1: Framework of the Road Provision Model

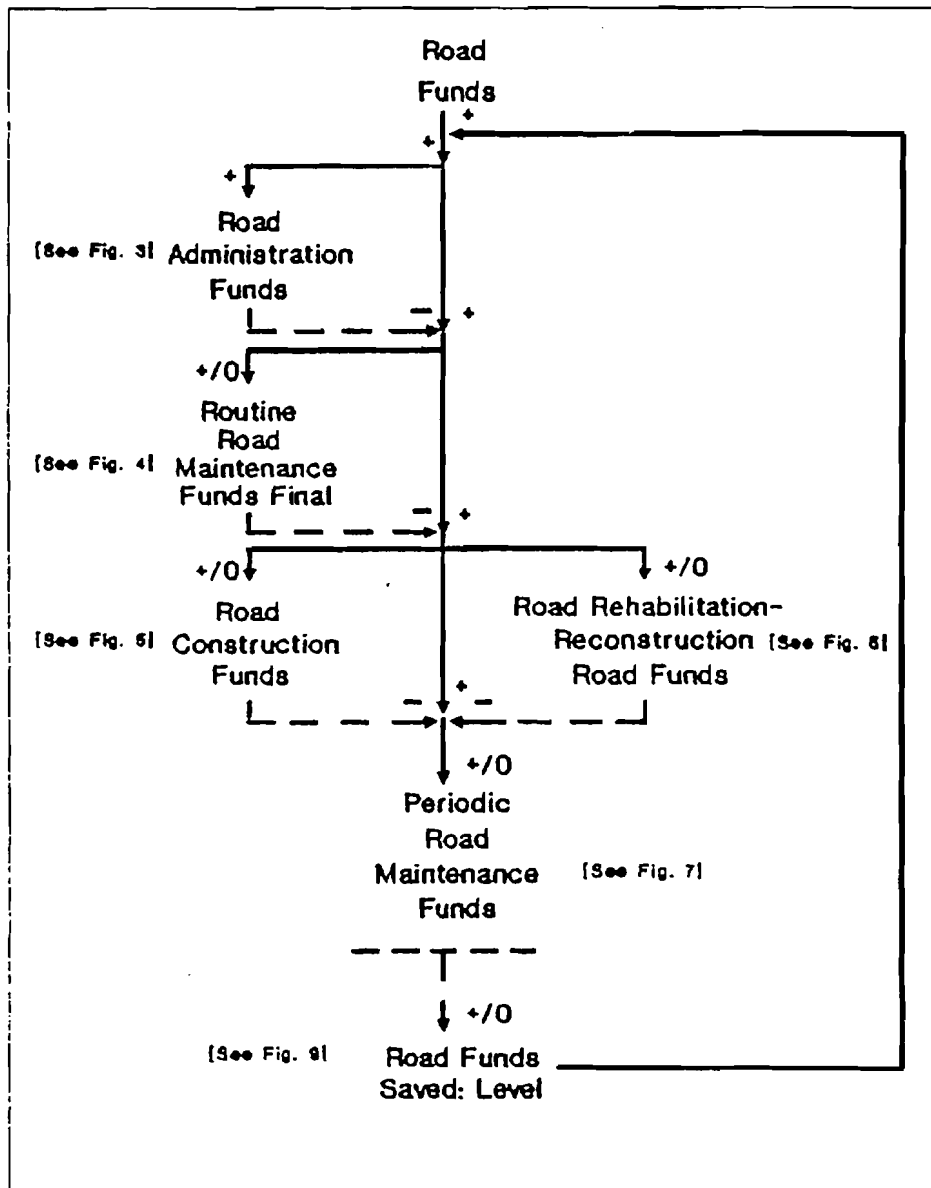


Fig 2: Management of the Road Funds

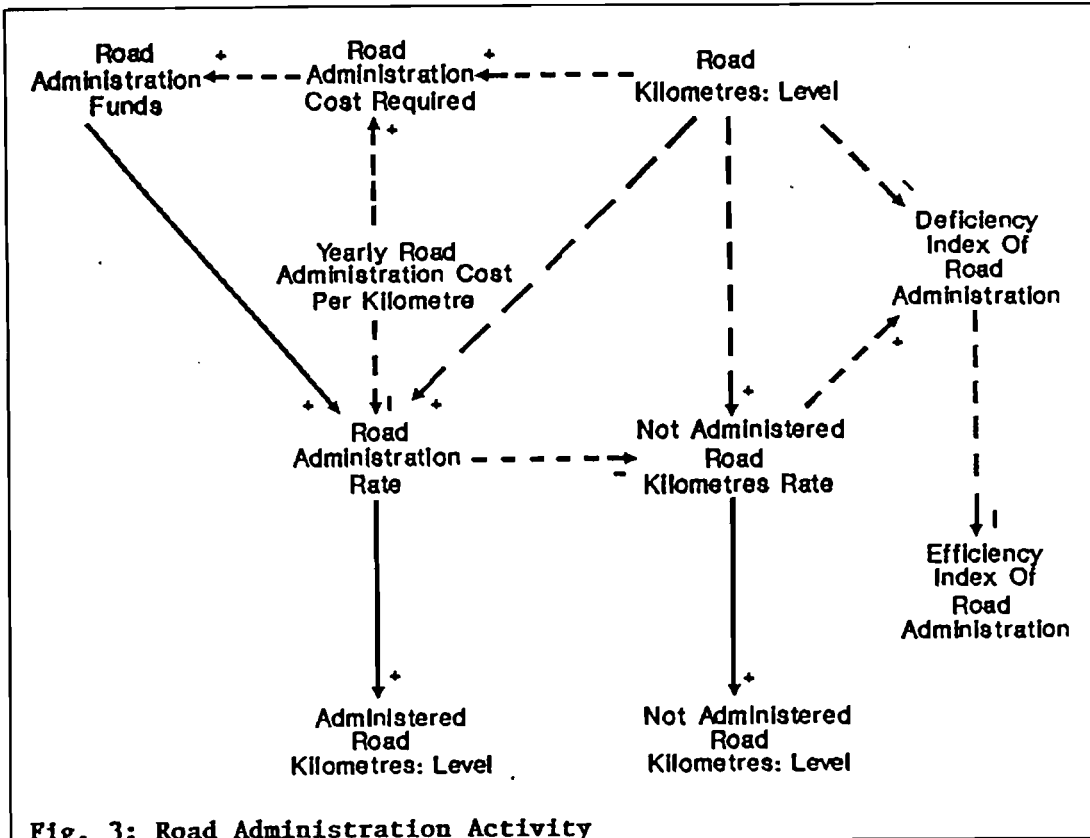


Fig. 3: Road Administration Activity

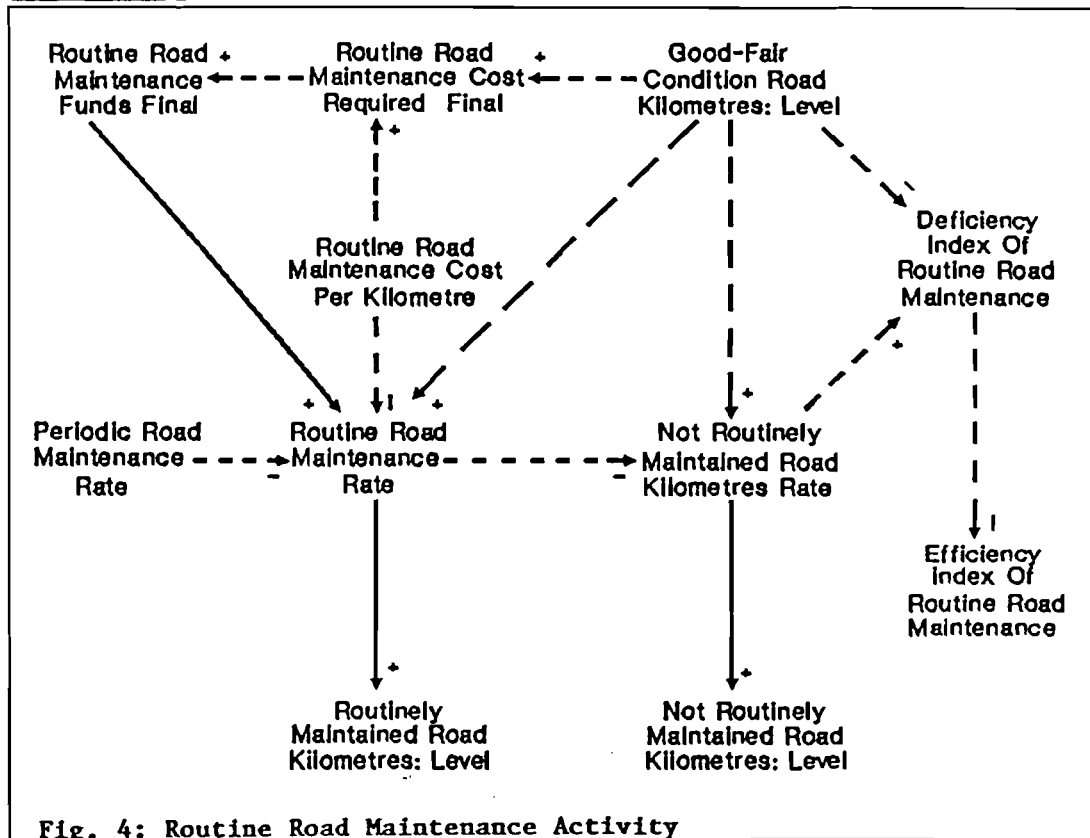


Fig. 4: Routine Road Maintenance Activity

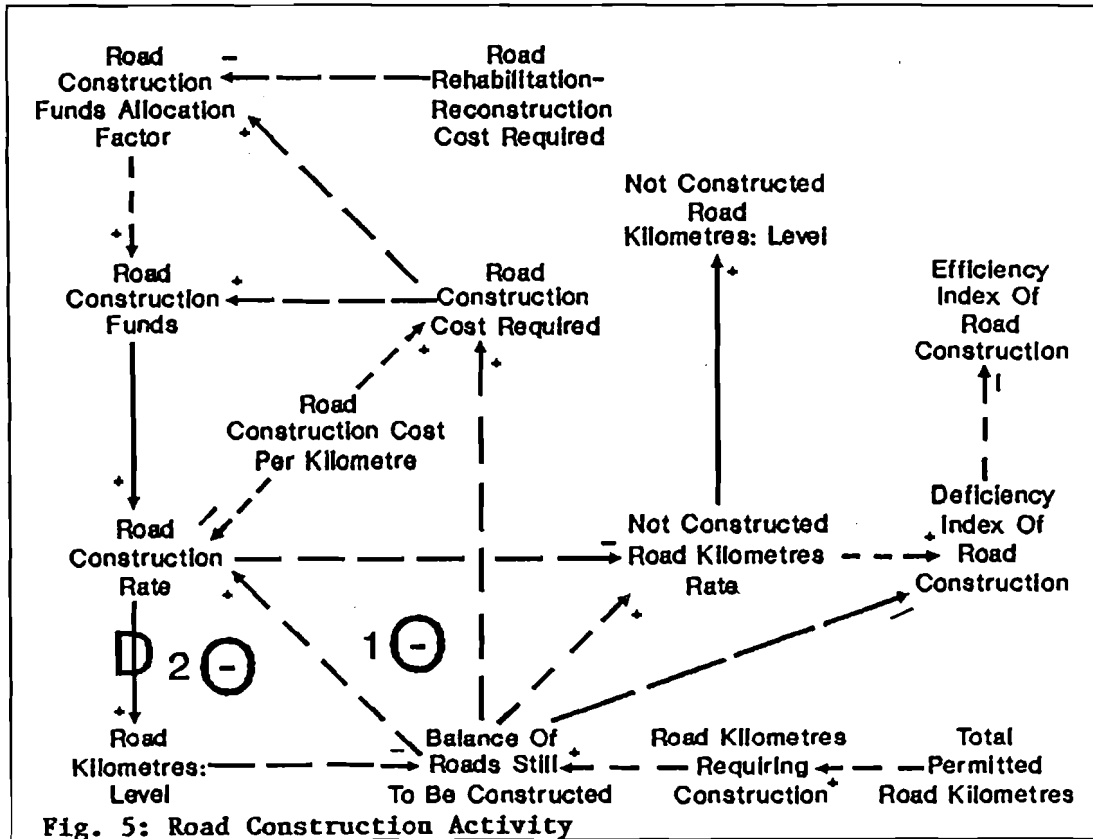


Fig. 5: Road Construction Activity

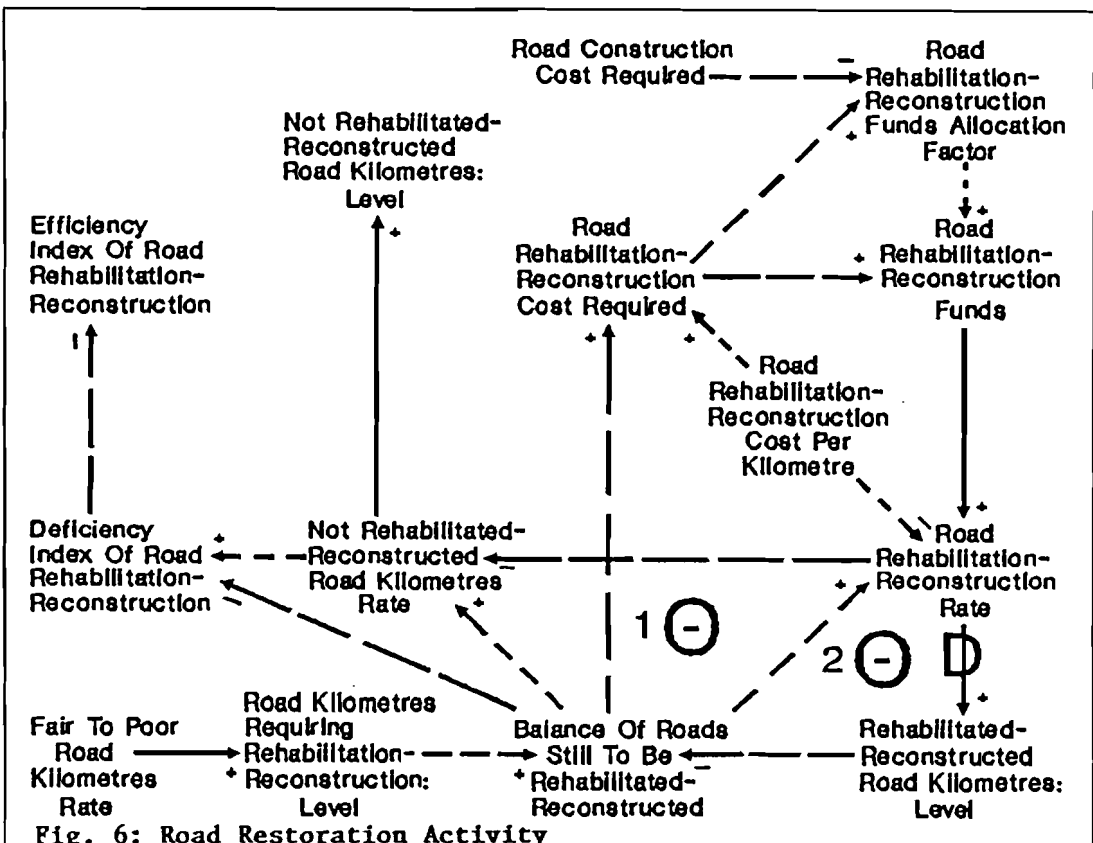
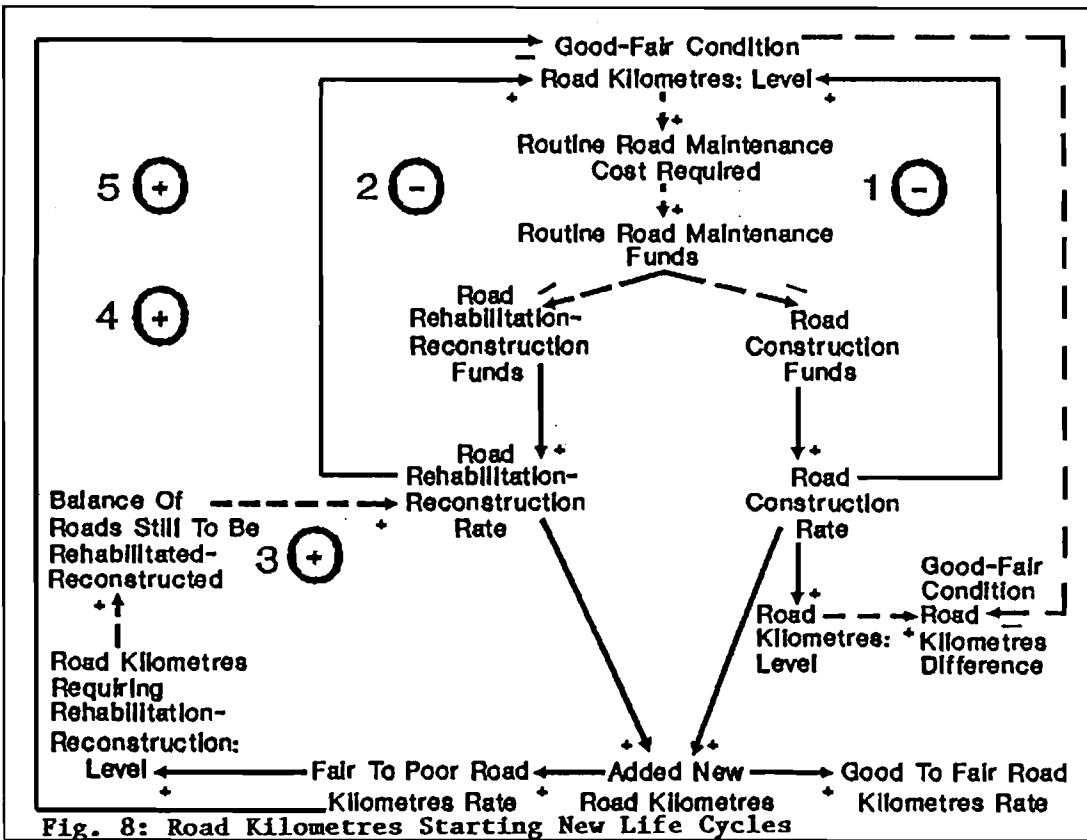
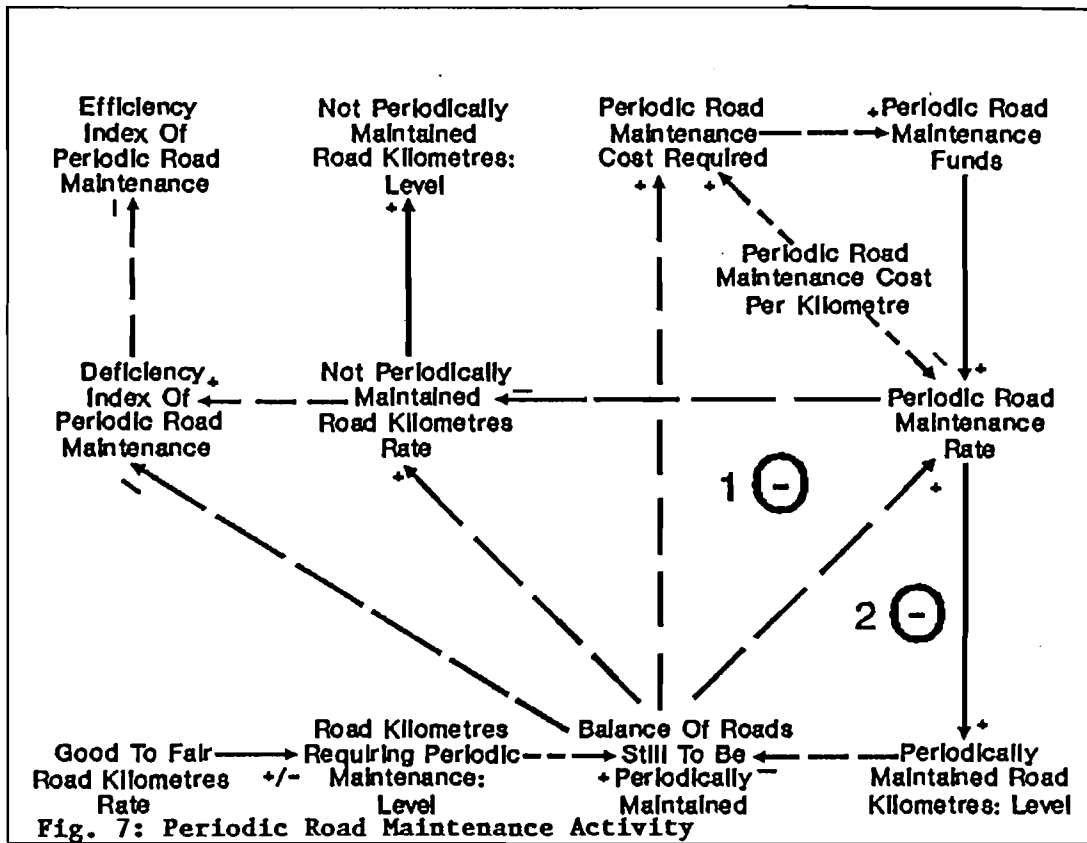


Fig. 6: Road Restoration Activity



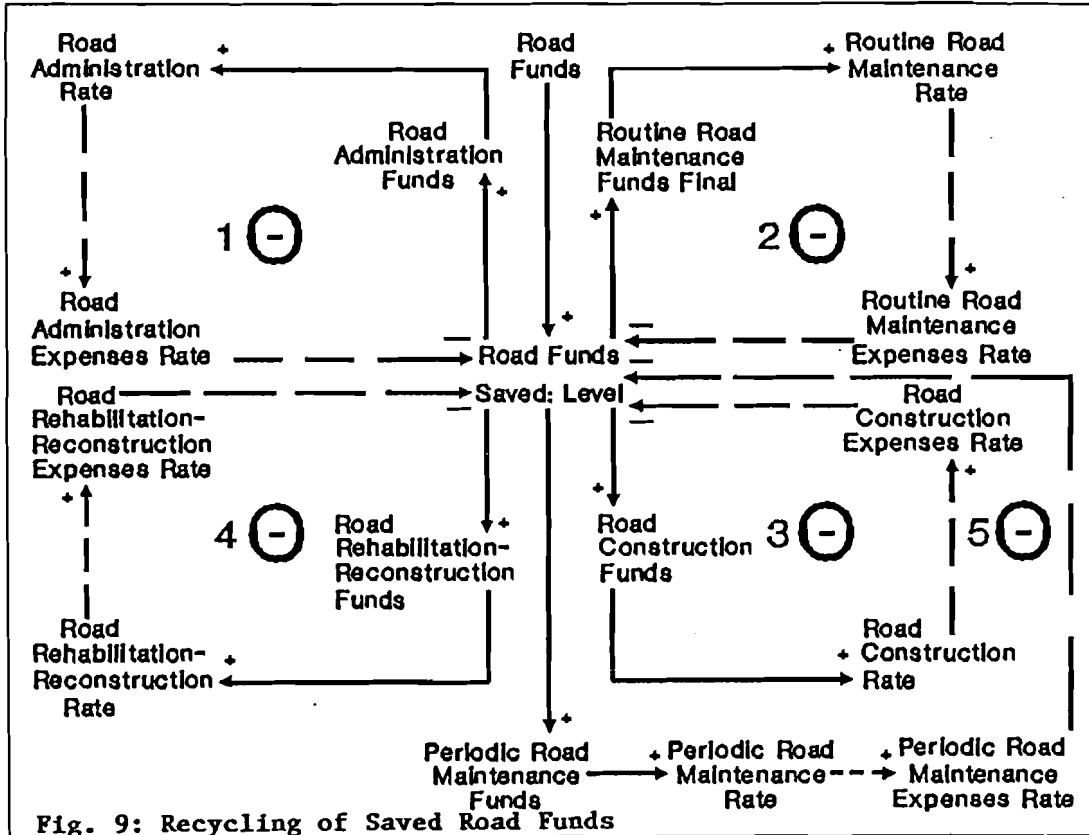


Fig. 9: Recycling of Saved Road Funds

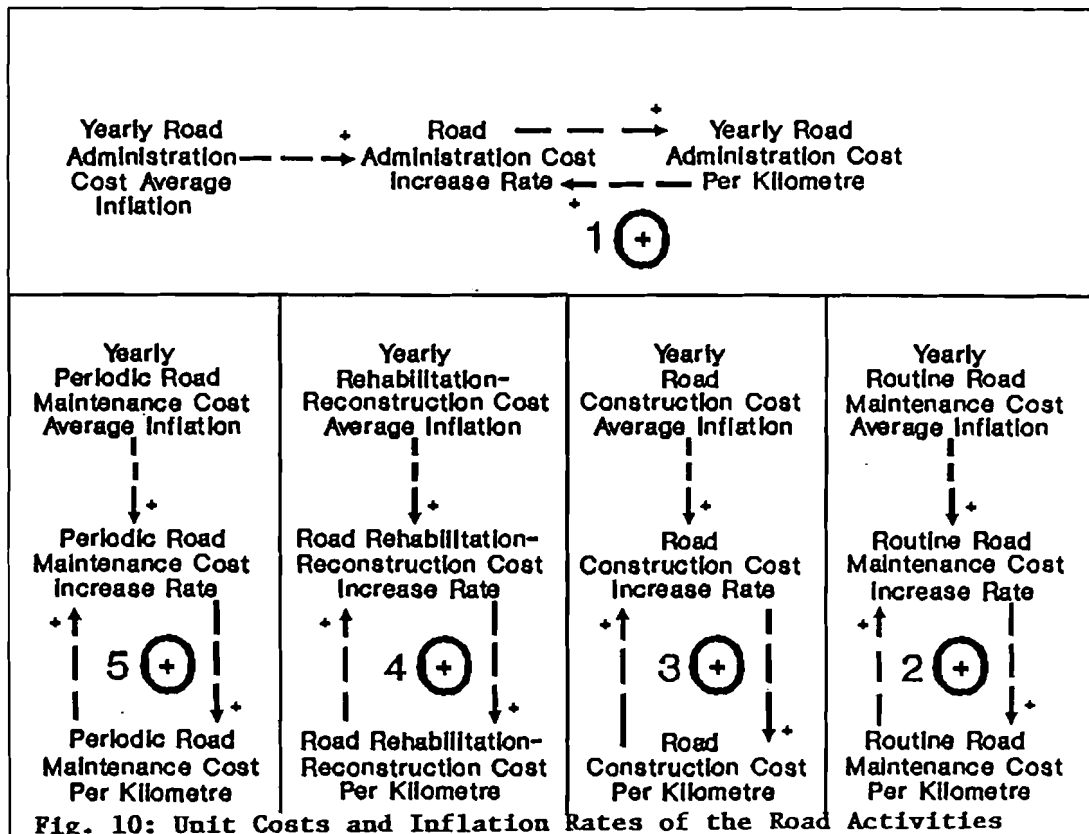


Fig. 10: Unit Costs and Inflation Rates of the Road Activities



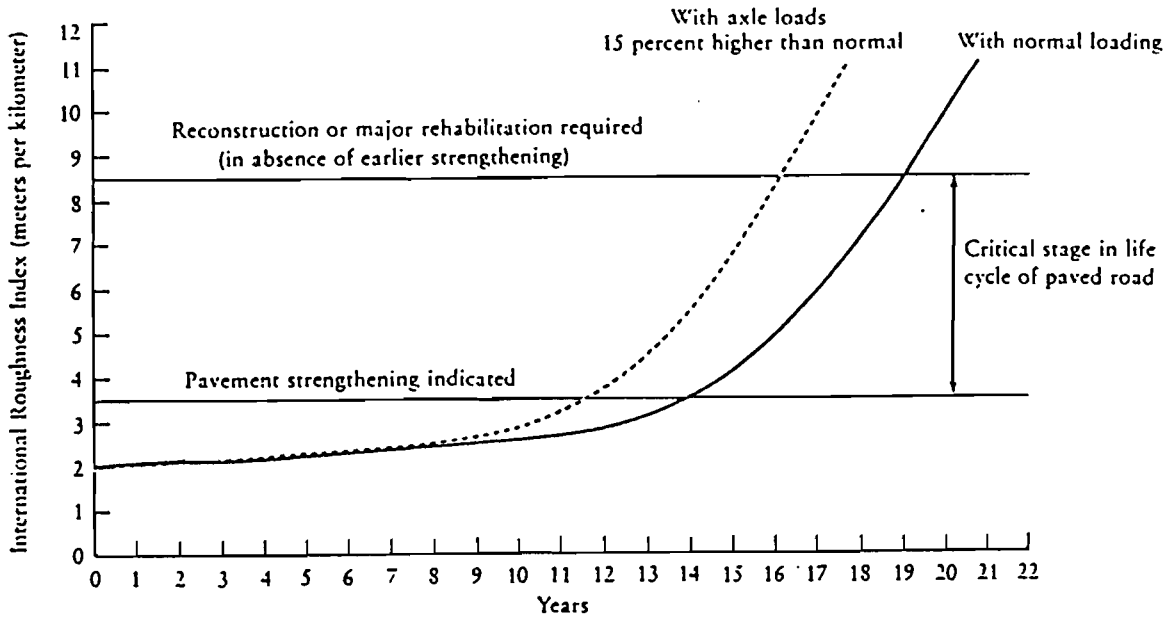


Fig. 11: Deterioration of Paved Roads Over Time

Source : (Harrel 1988)

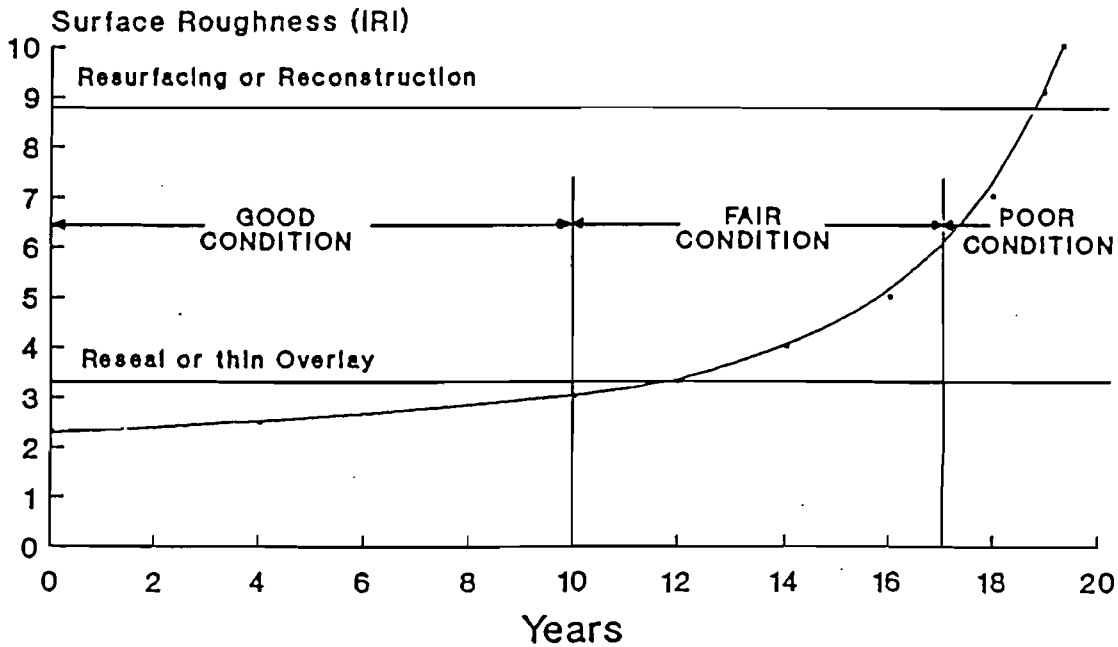


Fig. 12: Condition of Paved Roads Over Time

Source : (Bhandari 1988)