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SESION DE TRABAJO N.° 4

"ROAD MAINTENANCE TECHNIQUES"
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"TECNICAS DE CONSERVACION DE CARRETERAS"

ILLUSTRATION OF SDPMS: A GENERIC PAVEMENT MANAGEMENT SYSTEM

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ABSTRACT

In any transport system, financial resources are consumed in constructing, administrating and maintaining the road network to an adequate standard. This paper introduces a Pavement Management System developed using the concepts of System Dynamics methodology SDPMS.

The main objective of the SDPMS is to act as a tool for testing the consequences of different road policies on the development of the road network. The policy analysis is concerned with those aspects of the road system that the decision-maker can control. To demonstrate the utility of the SDPMS for policy analysis, alternative scenarios for allocating and generating road funds were simulated. A set of simulation runs was performed on the computer In an attempt to understand what effects changes in the amount and timing of road funds might have on the performance of the road network. In these runs, road funds was stochastically specified with the same mean and standard deviation. The main change from one run to another was in the initial integer (seed) that randomises the sequential generation of values of road funds in the same manner as repeated Monte Carlo simulation. To compare these alternatives, some of the main indicators that show the structural performance of the road network over time are displayed.

1. INTRODUCTION

Highway planners need to ask the right questions and to attempt to generate a set of responses that approximate to the eventual real outcome. Questions which ought to be addressed are whether investments in the road network are justified, well-spent and sufficient? This paper presents a Pavement Management System developed using the concepts of System Dynamics methodology SDPMS. The SDPMS is meant to predict the effect of alternative strategies on the road network.

The specific objectives of the SDPMS are:

1. to model the process of allocating road funds;
2. to provide a tool for aiding in the management of the road network;
3. to provide insight into the financial and physical aspects of the road system;
4. to assist and support in the planning and management of the road network; and
5. to produce a set of indicators that describe the physical performance and financial aspects of the road network.

System Dynamics (SD), which is both a system analysis and a computer simulation technique, was used in this study to construct the road management model. SD, originally called Industrial Dynamics, was developed at the Massachusetts Institute of Technology, (see Forrester, 1961).

Adapted from Wolstenholme (1989), SD is defined as a rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information flows, organisational structure, delays, policies, decision rules and strategies. It facilitates quantitative analysis of systems, in terms of their behaviours, through computer simulation. SD provides a framework for the testing of policies and the management of systems to achieve improved system behaviour.

Computer simulation models based on SD provide controlled experimental environments. The results from the models are arrived at through a feedback framework. Variables are linked in closed chains of causal relationships forming feedback loops. The models are made up of many such loops linked and interrelated together.

SD caters explicitly for the dynamic behaviour of systems. Since the development of SD, it has been applied successfully to a range of complex problems in different areas. In transport it is steadily gaining momentum. An extensive bibliographical list of the applications of SD to various transport issues is presented in Abbas (1990b).

2. AN OVERALL INTRODUCTION TO THE SDPMS

The SDPMS consists of two main parts; the first is the user interface module, and the second is the SD road management model. In developing the SDPMS the following criteria were considered.

1. The system makes available to users information and decision processes, which may reflect aspects of policy and decision making.
2. The system was designed in a manner that is thought to offer flexibility to users.
3. The road management model was developed as a structural model based on signed causal relations between variables, rather than being purely based on statistically calibrated relations.
4. The system was devised to avoid the need for extensive data.

While the user interface module is meant to satisfy the first two criteria, the road management model is meant to satisfy the other two. Figure 1 shows the main interactions between the user and the SDPMS.

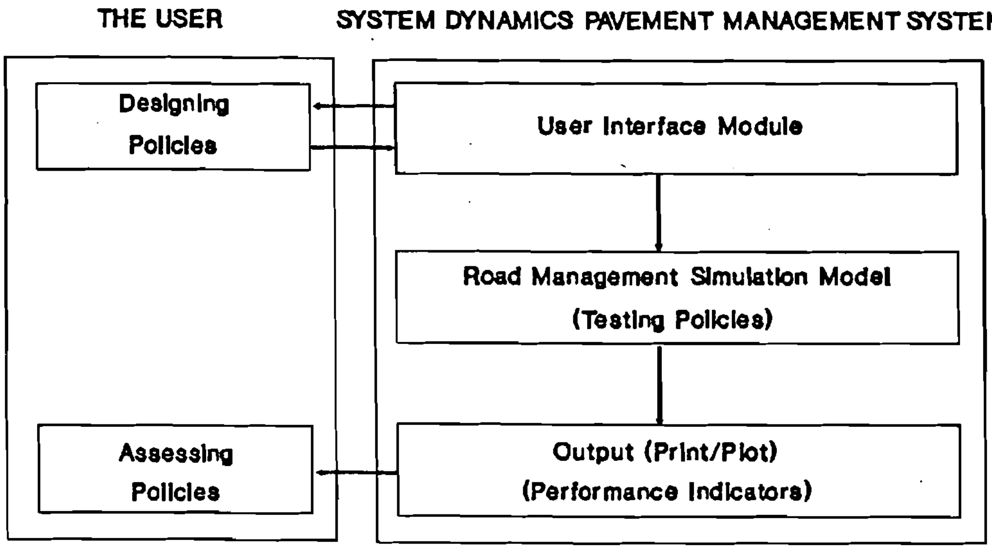

Figure 1: Main interactions between the user and the System Dynamics Pavement Management System

This study adopts the view of the road system as being a dynamic system characterised by three important aspects:

1. physical requirements e.g. required kilometres of roads to be constructed or maintained;
2. financial and accounting characteristics e.g. capital costs for construction or maintenance of roads, capital funds allocated for construction or maintenance of roads and capital expenditures incurred from construction or maintenance of roads; and
3. management and planning e.g. selection of the type, and scheduling of the amount, of maintenance treatment applied to the road network.

These three aspects guided the embodiment of variables that describe and portray the dynamic behaviour of the road system, (see Abbas, 1990a); the choice of information and decision processes to be included in the user interface module, (see Abbas et al., 1990c); and the formulation of the fundamental relationships that constitute the structure of the SD road model.

The main stages of the SDPMS are depicted in Figure 2. Each stage builds on the previous stage, and influences the next one. Stage (1) is concerned with specifying the main inputs required to form a road strategy, as well as to initialise a simulation run. This specification of input is performed through the user-interface module. In stage (2), the requirements and provision, in physical and financial terms, of the five main activities of the road network are simulated on the computer. The main outputs, in the form of financial/economic and road condition performance indicators are computed in stage (3). These output parameters are used in the fourth and final stage to support decision-makers in evaluating the road strategy. This is meant to help decision-makers in their decisions as to whether to accept or reject policies, and also to aid policy-makers in modifying their policies.

3. INITIALISATION OF THE SIMULATION

The SDPMS is structured to keep the input data and required information to a minimum, yet to produce a comprehensive output of the expenditure on, and condition of, the road network. This information enables the system user to rationalise decision making concerning road funding policies and maintenance options.

The only information required to initialise the simulation is to define the existing condition of the road network at the start of the simulation run. In terms of road inventory, the existing condition of the road network is to be described by the number of kilometres of road in the following three categories.

- Good Condition
- Fair Condition
- Poor Condition

This information could be collected by carrying out an on site inspection to visually classify the road network. Figure 3 displays an overall summary of the main alternative options available for the user to design a road strategy.

The options available through the user interface module allow the specification of, and the coupling between, input parameters and variables in different combinations of deterministic, stochastic and empirical forms. The introduction of random stochastic elements into the system and the decision process can explicitly cater for the probabilistic nature that exists in reality. In long term future forecasting, past and present sources of information often become less indicative, and random occurrences become more significant. Rather than merely selecting the specific choice in a deterministic fashion, stochastic models can be used to generate road funds, periods over which the road changes condition from one state to another, and delays in construction of new roads and in restoration of existing ones.

In the course of the simulation, the road management model assesses the condition and performance of the road network. It takes into consideration a set of maintenance options and standards. For each time increment in the analysis period, the model compares the simulated condition and performance of the road network with the specifications prescribed through the user interface module. Whenever a specification is attained, a maintenance measure is to be executed.

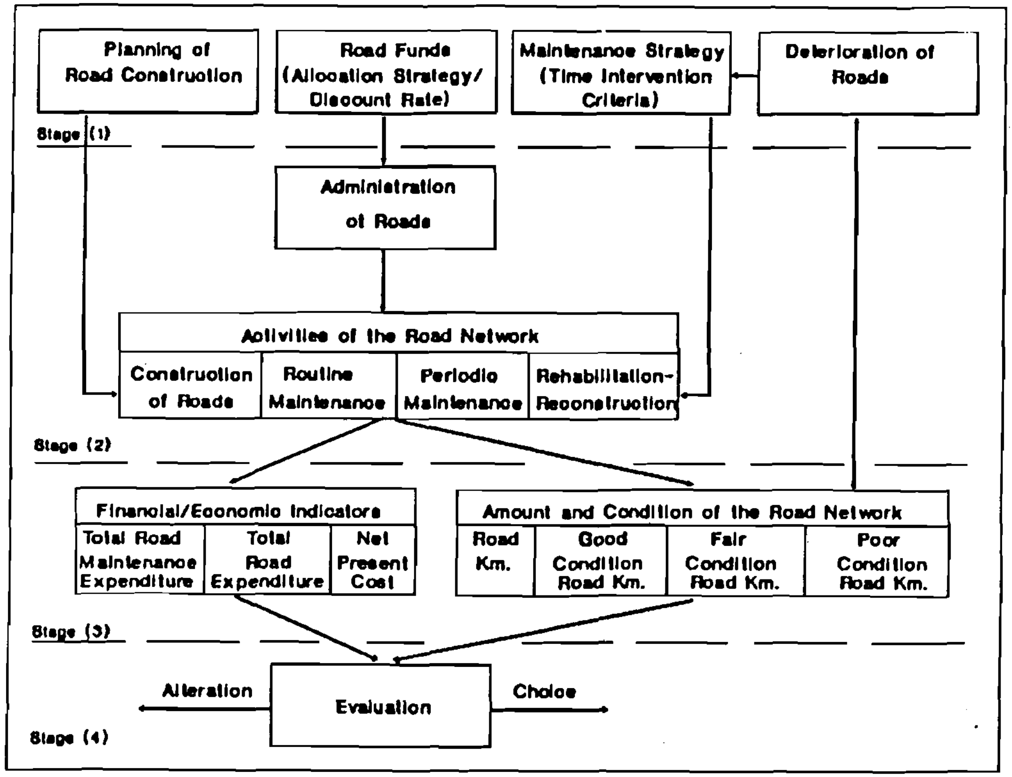

Figure 2: Flow chart of the System Dynamics Pavement Management System

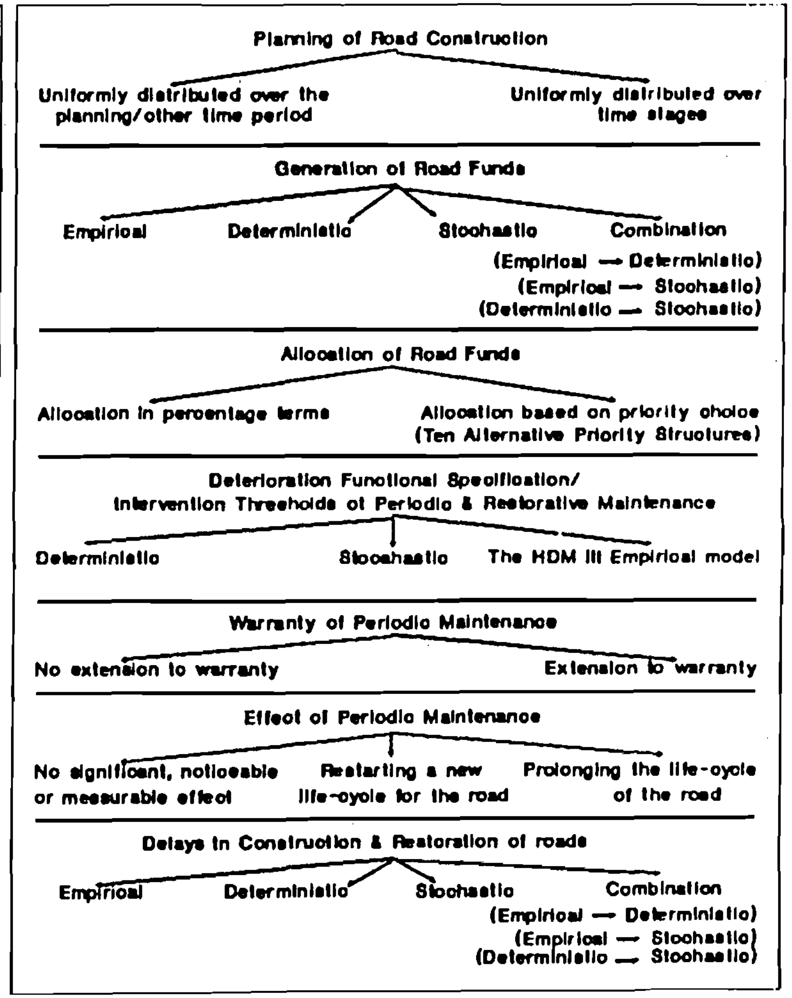

Figure 3: Summary of the alternative options available through the user interface module

4. MAIN OUTPUT OF THE SDPMS

The main output and performance indicators produced by the SDPMS are listed below.

1. Incremental and cumulative requirements, in physical and financial terms, of administration, construction, routine maintenance, restoration and periodic maintenance of roads.
2. Funds allocated to administration, construction, routine maintenance, restoration and periodic maintenance of roads.
3. Levels of administered, constructed, routinely maintained, restored and periodically maintained kilometres of road.
4. Levels of not administered, not constructed, not routinely maintained, not restored and not periodically maintained kilometres of road.
5. Incremental and cumulative financial expenditures on administration, construction, routine maintenance, restoration and periodic maintenance of roads.
6. Shortages in the financial provision for administration, construction, routine maintenance, restoration and periodic maintenance of roads.
7. Incremental and cumulative effectiveness of, and deficiency in, administration, construction, routine maintenance, restoration and periodic maintenance of roads.
8. Number of kilometres of roads in good, fair and poor condition. These are computed both in absolute and relative terms.
9. Land-use performance indicators. These include: actual to maximum land area occupied by roads, fraction of land occupied by roads (accessibility index), and fractions of land occupied by kilometres of road in good, fair and poor conditions.

5. DEMONSTRATION OF THE SDPMS

To demonstrate the usefulness of the SDPMS for policy analysis, alternative strategies for allocating and generating the road funds are simulated. To compare these alternatives, some of the main indicators that show the performance of the road network over time are displayed. The strategies considered represent just some of the possible options that the user may choose to examine using the SDPMS. It is not the intention of this research to establish specific road management policies, rather the intention is to produce an indication of trends that are most likely to occur, the dynamic interactions between the main activities of the road system, and the areas in which informed policy decisions can lead to improved performance. Policies are selected according to their ability to produce a level of service that is acceptable to decision-makers.

5.1 ALLOCATION OF ROAD FUNDS

There are two main options available for allocating road funds. The first, after satisfying the financial requirements of administration of roads, allocates the remainder of the road funds among the other four activities (construction, routine maintenance, restoration and periodic maintenance) of the road network based on percentage terms specified by the model user. The second allocates road funds among the activities of the road network based on a priority structure chosen by the user.

To demonstrate the utility of the SDPMS, ten simulation runs were performed on the computer, a run for each of the priority strategies considered in the allocation of road funds. For each run, the same initial conditions were supplied to the model. This included the same annual sequence of road funding, which was stochastically generated with the same initial random integer (seed) for the ten runs. The model is aged by time periods of one year, so as to produce profiles of some of the variables that explain the condition of the road network over time. This enables the testing and analysis of alternative combinations of priorities for the allocation of road funds, and the establishment of their impacts on the road network. This type of priority sensitivity analysis can establish the optimum priority funding strategy required to achieve a set of conditions for the road. This will, eventually, assist in the management and control of the road network.

A comparative evaluation of strategies is conducted. Basically, there are three actors interested in the performance of the road network over time, namely the road users, the administrators and

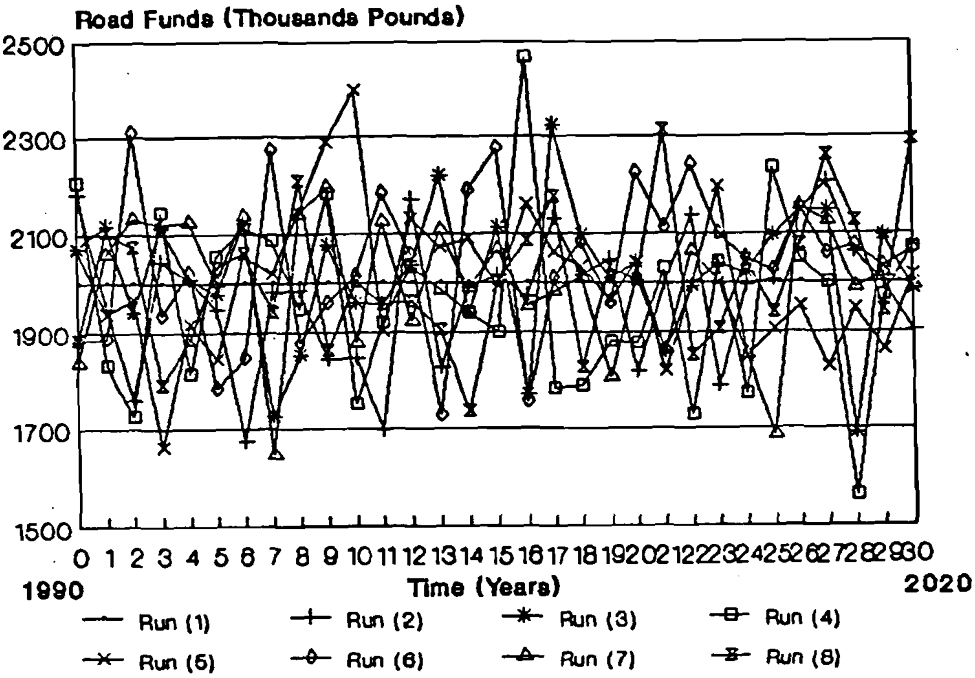

Figure 4: Eight road funds sequences

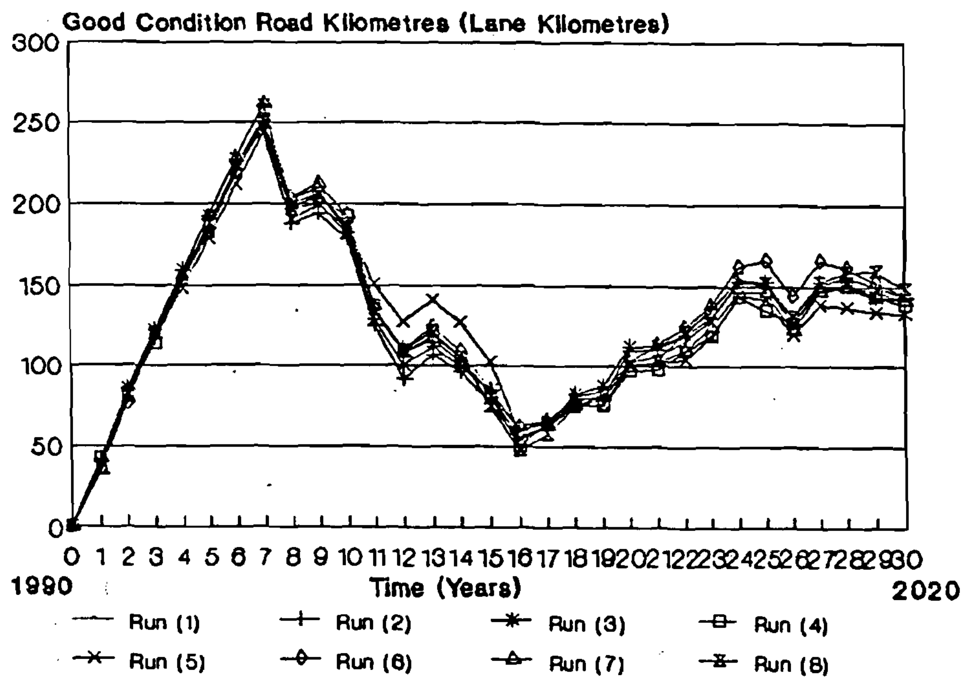

Figure 5: Road kilometres in good condition for eight road funds sequences

the politicians. Each of these actors has a criteria to be satisfied, which might sometimes conflict with each other. It is assumed, in this study, that both the road users and the administrators would be interested in the strategy that maximises the number of kilometres of road in good and fair condition, and minimises the number of kilometres of road in poor condition across the network. Keeping a road network in such standards is almost guaranteed to reduce vehicle operating costs, as well as to provide road users with a good and safe riding quality. While this would increase the routine and the periodic maintenance costs, road administrators would still be interested in keeping the network within such standards, as this would probably cause future savings in the road life-cycle maintenance costs in terms of delaying and reducing the need for restoration of roads. Construction of roads consumes the bulk of financial resources provided, and under scarcity of funds this leads to inhibition of maintenance measures. Regardless of the state that the road network is likely to reach if not enough and timely maintenance is conducted, most politicians regard construction of new roads as a glamorous and prestigious activity appreciated by the public.

The funding strategy characterised by having construction of roads given precedence over the maintenance measures produces the maximum number of kilometres of road in good, fair and poor condition, and hence of total constructed kilometres of road. This strategy could be considered as being the best from a politician point of view. While this strategy satisfies one of the road users/administrators criteria for choosing the most optimum strategy, namely the criterion of maximising the number of kilometres of road in good and fair condition across the road network, it does not satisfy the other criterion, namely the criterion of minimising the number of kilometres of road in poor condition across the road network. On the other hand it was plausible to deduce that the strategy characterised by having the maintenance measures given precedence over construction of roads is the best strategy that satisfies the users/administrators criteria, (see Abbas, 1990d).

5.2 GENERATION OF ROAD FUNDS

Using the most acceptable (optimum) strategy for allocation of road funds from the road users/administrators perspective, an attempt was made to understand what effects changes in the amount and timing of road funds might have on the performance of the road network.

Figure 4 displays the patterns of road funds over time for eight alternative simulation runs. In each of these runs, with the exception of run (1), road funds was stochastically specified with the same mean and standard deviation. The main change from one run to another was in the initial integer (seed) that randomises the generation of values and sequence of road funds in the same manner as repeated Monte Carlo simulation. In run (1), road funds was specified as a constant deterministic value throughout the analysis period. Figures 5 to 7 display three selected outputs of the model. While it seems obvious that the patterns of the first two output variables do not significantly differ from one simulation run to another, Figure 7 showing the profile of the kilometres of roads in poor condition indicates that this variable might be relatively sensitive to random changes in road funds. Hence, it was decided to thoroughly investigate the sensitivity of this variable.

Thirty simulation runs, in the manner of Monte Carlo simulation, were performed to determine the confidence intervals of variability in the parameter kilometres of road in poor condition. A different initial seed for generating road funds was used for each of the thirty runs. Each time a different random sequence of road funds was generated. Figure 8 displays the 95% confidence intervals of road funds i.e. the boundaries between which 95% of the values of generated road funds would lie. Figure 9 shows the 95% confidence intervals of road kilometres in poor condition. These intervals are computed based on output data generated from the thirty performed simulation runs.

$$\text{Confidence intervals} = \text{Mean}_{(t)} \pm 1.96 * \text{Standard deviation}_{(t)}$$

It seems probable to infer from Figure 9 that the extent of variability in kilometres of road in poor condition starts fairly small and gradually increases with the advance of time. However, the general conclusion still is that most of the model output have limited sensitivity to random changes in the process of generating road funds.

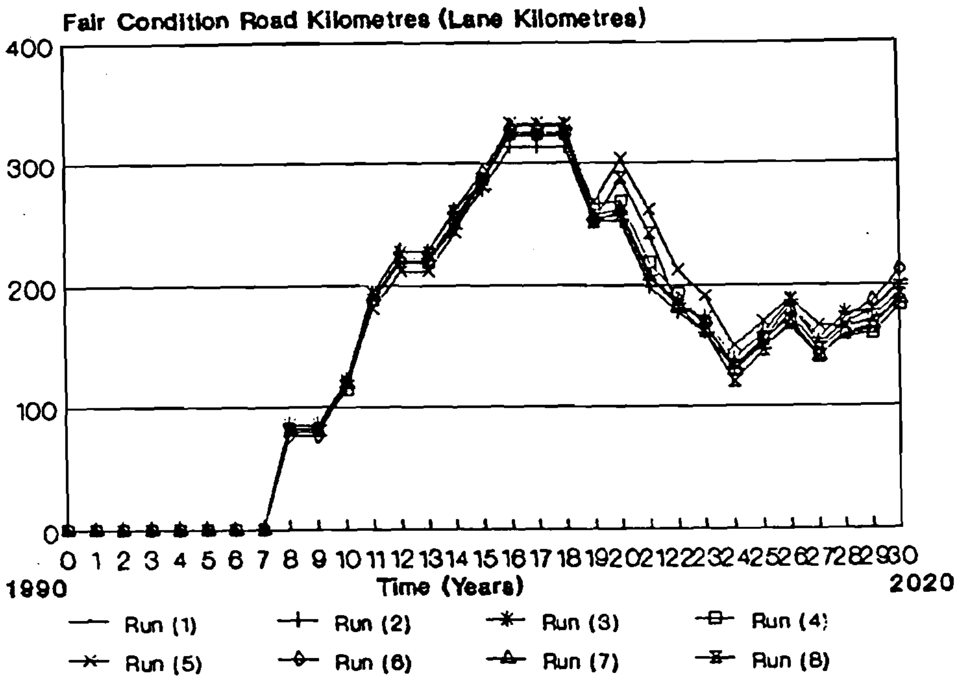

Figure 6: Road kilometres in fair condition for eight road funds sequences

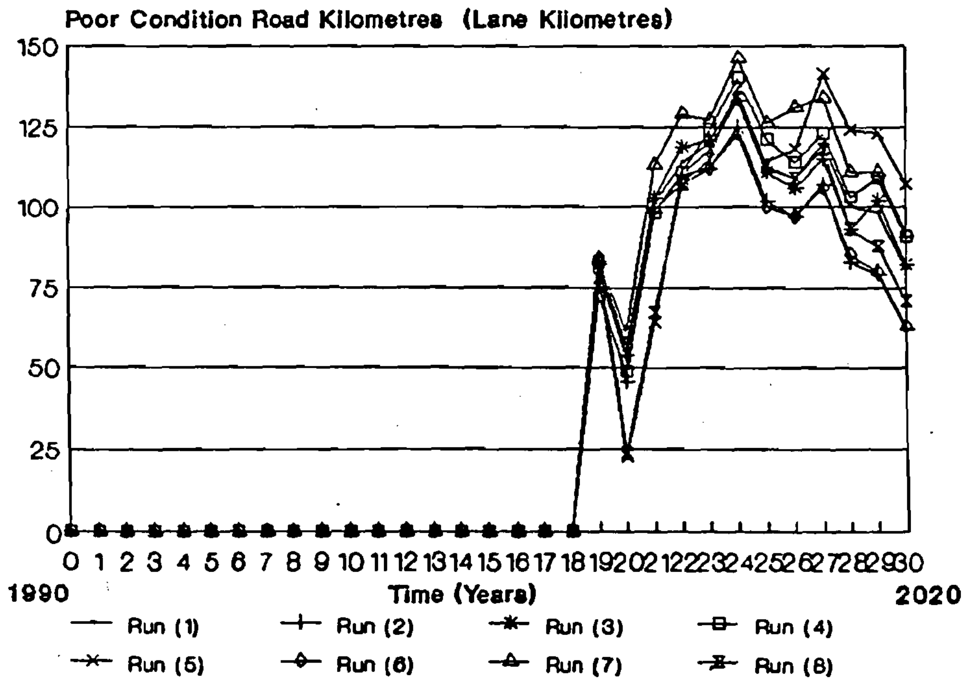

Figure 7: Road kilometres in poor condition for eight road funds sequences

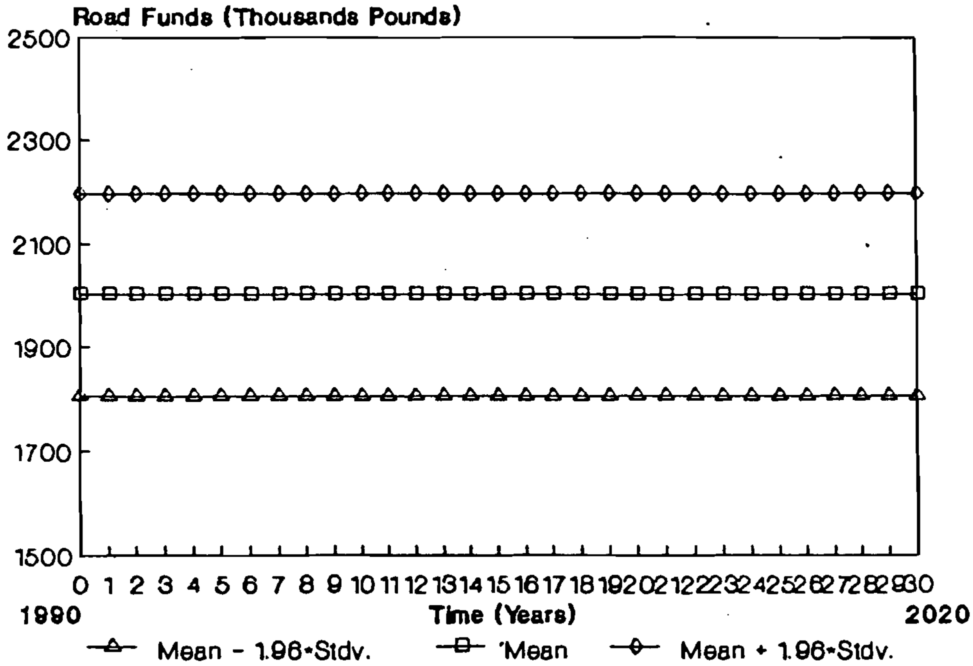

Figure 8: 95 per-cent confidence intervals for the road funds sequences

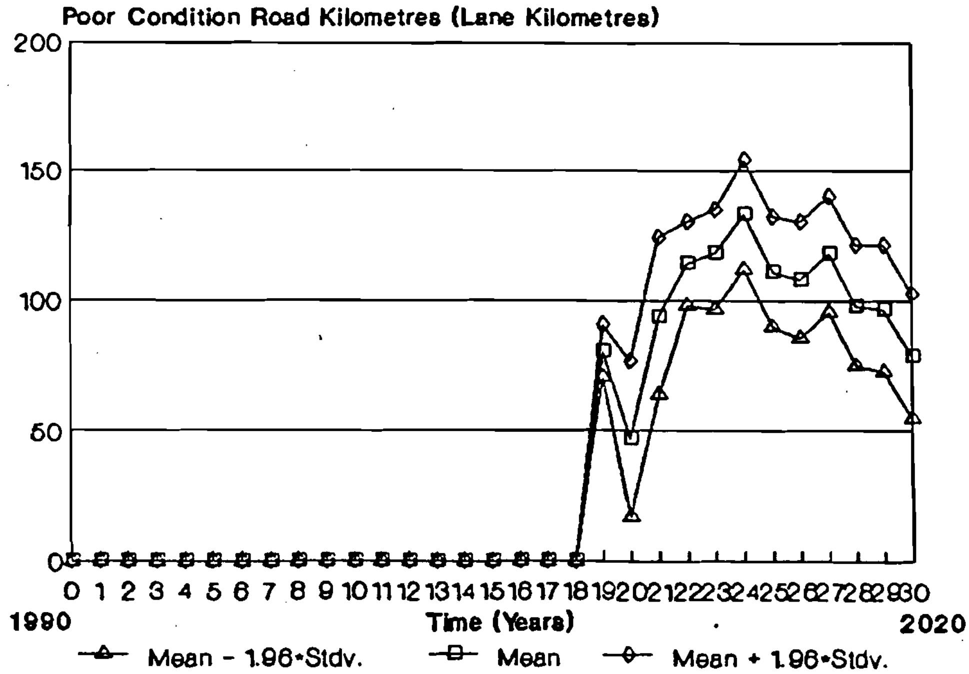

Figure 9: 95 per-cent confidence intervals for kilometres of road in poor condition

6. CONTROLS FOR MANAGING THE ROAD NETWORK

Building models using the SD approach helps in identifying controls in the systems modelled. These are meant to guide the efforts of policy makers as to which parameters, and/or structure of a system could be managed and controlled to produce better performance of the system. The following represents the main controls identified for management of the road network.

1. The amount and the timing of funds allocated to the road network.
2. The priorities for allocating road funds among the activities of the road network.
3. Attempting to minimise, or avoid, the lags (delays) expected in construction, and/or restoration of roads.
4. In the case of scheduled maintenance, the expected periods chosen by the user for the road to stay in good condition and in fair condition.
5. In the case of considering an extended warranty time for deferring the performance of periodic maintenance, the period specified by the user of this deferment.

7. CONCLUSION

In this paper a highway management system has been presented. The system comprises two main parts; the first is the user interface module, and the second is the SD road management model. The user interface module facilitates a user-friendly dialogue. The road management model takes the form of a computer simulation model.

In attempting to present the SDPMS, four topics were addressed: first, an introduction of the framework of the system; second, a presentation of the main input parameters and specifications required by the system and a listing of the main outputs; third, a demonstration of the SDPMS in policy analysis; and fourth, a listing of identified controls for managing the road network.

An important characteristic of the SDPMS is that it possesses a generic structure. The basic structure of the road management model, with slight adjustments, can be used for managing and controlling the activities of purchasing, administrating and maintaining many other physical systems for example elevators, vehicles, rail tracks, locomotives, ships, aeroplanes, etc.

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