PRESENT SITUATION AND PROSPECTS OF PAVEMENT MAINTENANCE MANAGEMENT SYSTEM IN JAPAN

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ABSTRACT

Japanese Ministry of Construction has developed a pavement maintenance management system for the designated portions of national highway network with an intensive cooperative efforts of pavement engineers, researchers and administrators within the ministry during the last decade. The system is fully supported by three fundamental technology and/or concepts; 1) pavement data base system, 2) maintenance control index (MCI), and 3) new automated pavement data collection system.

The existence of well organized ready-to-use pavement data base system enables rational and efficient evaluation of alternative strategies. Comprehensive pavement evaluation index (MCI) has been used by the national government as a key operational index within the framework of the pavement maintenance management system. New automated pavement data collection system was developed for high speed data collection of pavement surface condition. It is mounted on a vehicle and can measure crack ratio, rutting depth and longitudinal roughness at a time with the normal traveling speed. It is substantially economical than the conventional methods, and can conduct measurements of entire network of the ministry in a short period of time.

Total pavement maintenance management system (TPMMS) has been proposed for both the network and the project level rehabilitation and maintenance programing. The system is consist of two sub-system; 1) Long-Term Rehabilitation Programing System, and 2) Priority Ranking and Design Selection System. The system is expected to be used by various levels of the organization of the ministry making it possible for the engineers involved to make more rational decision on budgeting and planning for pavement maintenance and rehabilitation programs.

Key Words: PMS, Maintenance Management, Data Collection, Data Base, Users Cost, Life Cycle Cost, Priority Programing, Optimization

1. INTRODUCTION

Maintenance and rehabilitation planning on pavements is a decision making process which includes the selection of appropriate sections (where), appropriate timings (when), and appropriate measures (how) for rehabilitation on selected roads under the control of a specific highway authority. It is a very complicated process to determine the optimum strategy within the various restrictions. Therefore, the establishment of a Pavement Maintenance Management System (PMMS) is a necessity. The objectives of the PMMS are expressed as follows: to carry out the maintenance and rehabilitation of pavements most effectively within the funding budgets and to provide safe, comfortable, and economic pavements to road users (1). The basic flow of the activities involved in PMMS is presented in Figure-1 in which the survey of pavement conditions, evaluation of pavements, prediction of future performance, priority programing, selection of an alternative strategy, design, implementation, and data feed back constitute the fundamental steps (2).

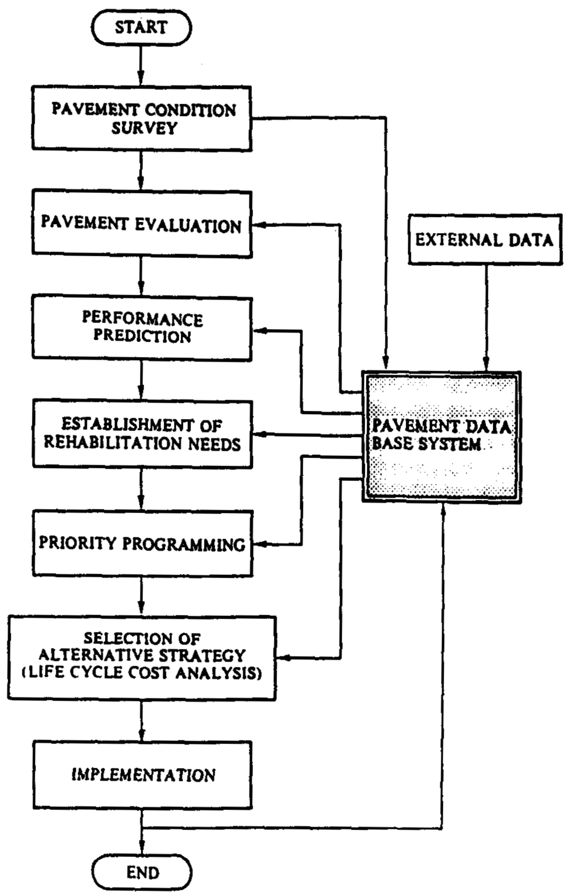


Fig. 1 Basic Flow of the Activities Involved in Pavement Maintenance Management System (PMMS)

2. PAVEMENT DATA BASE SYSTEM

In PMMS, the importance of various data cannot be over-emphasized. With these data, the objective and the quantitative evaluation of alternatives concerning maintenance and rehabilitation, which are the major features of the system, can be realized. The data is stored in a pavement data base system (PDBS) so that users from various levels of the agency can have access to the data.

As for the PDBS of the Ministry of Construction, a highway network is basically divided by 100 meter intervals. And as reference key, route numbers and kilopost values, both of which are available for the entire network have been used. The overall structure of the PDBS, which the Ministry of Construction has established for the designated portion of the national highway network has been reported by Kikukawa (3).

3. PAVEMENT SURVEY AND A NEW AUTOMATED PAVEMENT DATA COLLECTION SYSTEM

(1) Classification of Pavement Surveys

The survey of pavements are carried out in order to grasp the present conditions of the pavements, and to estimate the degree of damages, as well as to estimate the remaining service life of the pavement. The survey is classified into the following three categories; 1) regular monitoring of pavements over an entire network, 2) detailed survey of a specific pavement section for design purposes, 3) periodic patrol and inspection. In Japan, crack ratio, depth of rutting, and longitudinal roughness are currently designated as the key characteristics, and they are routinely collected over the entire network and stored in the PDBS. Definitions of these three characteristics are reported by Kikukawa (4).

(2) New Automated Pavement Data Collection System

Recently, the new automated pavement data collection system (APDCS), which measures three surface characteristics (crack, rutting and roughness) at one time at normal traffic speed, have been put into practical use in Japan (5). The specific features of the system are as follows.

1) The system is able to conduct high speed measurements and can effectively process the data.
2) The system possesses a measuring accuracy level high enough to be used for the purposes of pavement management.
3) Since the system is operated while mounted on a vehicle, the measurements can be done on the road without jeopardizing traffic flow.

Table-1 shows the outline of the APDCS.

Table 1 Survey Mechanism of APDCS for Each Surface Characterisitic

Survey Item	Mechanism of Measurement
Crack	Photographes of the road surface are continuously taken while travelling with normal traffic speed. The films are brought back to a laboratory for processing, and a crack ratio of each section is computed using mesh measurement method. The combination of a camera and a lighting source varies depending on the models. The following are typical combinations. a) A slit camera and a halogen lamp b) A special video camera and a laser beam scanning c) A 35 mm camera and a strobe flash light
Rutting	Lateral profiles of a road section are measured on a predetermined interval (i.e., 20 m) while travelling with normal traffic speed. Rutting depth of each section is automatically computed. The equipments used for measurement vary depending on the models. a) A solid-state TV camera and a laser beam scanning b) A TV camera and a optical hair line projector
Roughness	Distances between three sensors mounted under the survey vehicle and the road surface, are measured successively on an interval of 1.5 m. Longitudinal roughness value of each section is, then automatically computed. Specific equipments used for measurements vary depending upon the models. a) Laser range finder b) Accelerometer

4. EVALUATION OF PAVEMENT BY MCI AND MCI PERFORMANCE PREDICTION MODELS

(1) Maintenance Control Index (MCI)

In Japan, Maintenance Control Index (MCI) is used as the means of both evaluating overall pavement conditions and making decisions on whether maintenance work is needed or not (6, 7). In the process of developing MCI, pavement evaluation was made on foot and by highway engineers, and the subjective ratings are correlated with the objective measurements of three pavement characteristics; crack ratio, depth of rutting, and longitudinal roughness. This makes the characteristics of MCI different from the normal serviceability index. The points of the arguments are shown in Figure-2, in which the relationships between the types of rating personnels and their major concerns are illustrated. The equation to calculate MCI is as follow. Table-2 shows the evaluation of pavement conditions by MCI from the view point of rehabilitation needs.

$$MCI = 10 - 1.48CR^{0.3} - 0.29RD^{0.7} - 0.47LR^{0.2}$$

where, CR: Crack ratio (%), RD: Depth of rutting (mm)
LR: Longitudinal roughness (mm)

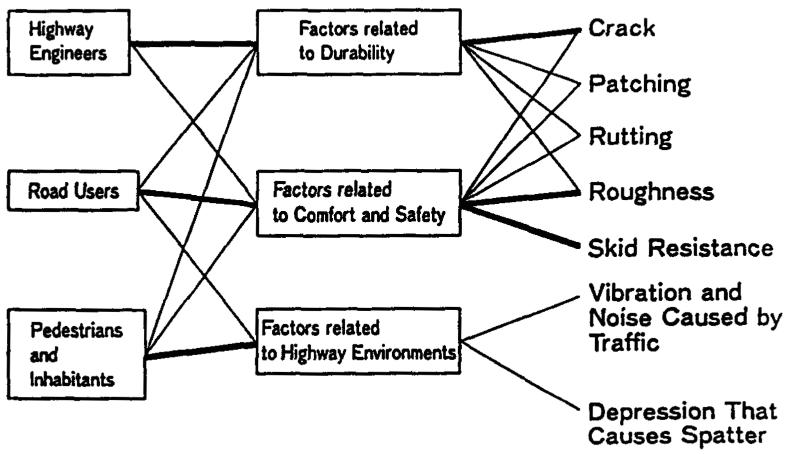


Fig. 2 Rating Personnels and Their Major Concerns

Table 2 Evaluation of Pavement Condition Based on MCI

MCI	Required Scale of Rehabilitation
$MCI > 5.0$	Unnecessary to Repair
$4.0 < MCI < 5.0$	Maintenance
$3.0 < MCI < 4.0$	Minor Rehabilitation
$MCI < 3.0$	Rehabilitation

(2) Performance Prediction Model of MCI

The following two methods are generally employed for the development of long-term performance prediction models; 1) statistical analysis of pavement condition data collected over a long period of time, 2) theoretical evaluation of pavement based on surface deflection data along with stress, strain, and repeated fatigue curves on pavement layers.

Table-3 shows the MCI prediction equations which were developed by the first method using data from the PDBS (8). In the model, pavement sections are firstly classified into two climatic zones (snowy and cold region, ordinary region) and three types of rehabilitation alternatives (surface treatment, overlay, reconstruction). Then, correlation analysis was performed to find the best-fit curves that express the relationship between MCI and three explanatory variables.

Table 3 Performance Prediction Models of MCI
(National Highway Network)

(ORDINARY REGION)	
NEW CONSTRUCTION AND RECONSTRUCTION	$MCI = 9.2 - 4.8 \cdot a - 0.34 \cdot 10^{-4} \cdot b - 0.22 \cdot 10^{-1} \cdot c$
OVERLAY	$MCI = 9.3 - 0.51 \cdot a - 0.49 \cdot 10^{-4} \cdot b - 0.22 \cdot 10^{-1} \cdot c$
SURFACE TREATMENT	$MCI = 8.7 - 0.65 \cdot a - 0.63 \cdot 10^{-4} \cdot b - 0.22 \cdot 10^{-1} \cdot c$
(SNOWY AND COLD REGION)	
NEW CONSTRUCTION AND RECONSTRUCTION	$MCI = 10.1 - 0.41 \cdot a - 0.18 \cdot 10^{-2} \cdot b - 0.10 \cdot 10^{-1} \cdot c$
OVERLAY	$MCI = 9.7 - 0.42 \cdot a - 0.27 \cdot 10^{-2} \cdot b - 0.45 \cdot 10^{-1} \cdot c$
SURFACE TREATMENT	$MCI = 10.2 - 0.71 \cdot a - 0.44 \cdot 10^{-2} \cdot b - 0.28 \cdot 10^{-1} \cdot c$

a: AGE IN YEARS
b: TRAFFIC VOLUME (VEH./LANE/DAY)
c: LARGE VEHICLE MIXING RATIO (%)

5. USER COSTS CONCERNING PAVEMENT

It is clear that there are considerable differences between damaged rough roads and rehabilitated roads with smooth surface with respect to the fuel consumptions and the depreciation costs of vehicles. As well, in the case of the urban highway network with heavy traffic volume, user costs, incurred by delays in travel time caused by traffic congestions associated with rehabilitation works, are too much to be ignored. Consequently, in order to optimize the maintenance and rehabilitation of pavements, both the highways authority's expenditures (maintenance and rehabilitation costs) and user costs, which consist of vehicle operating costs and time delay costs, have to be evaluated in the overall economic analysis. The intensive analysis was made in order to utilize the data contained in the report (9) by J.P. Zaniewski. As a result, vehicle operating costs versus MCI curves, which reflect actual vehicle costs and fuel costs in Japanese market, were developed. Figure-3 shows the vehicle operating costs (VOC) for a small car, in which VOC curves are given for several representative traveling speeds (10). In the models, SI (serviceability index) is converted to MCI using a set of longitudinal roughness data obtained both in Japan and in the U.S. The figure shows that the VOC increases sharply when MCI drops to the level of 4 or less, whereas MCI changes in the range of 7 or more, does not significantly affect VOC.

Time delay costs caused by traffic congestion due to rehabilitation works, are calculated using the data concerning the average travel time delay which was obtained from a previous study conducted in Japan (11).

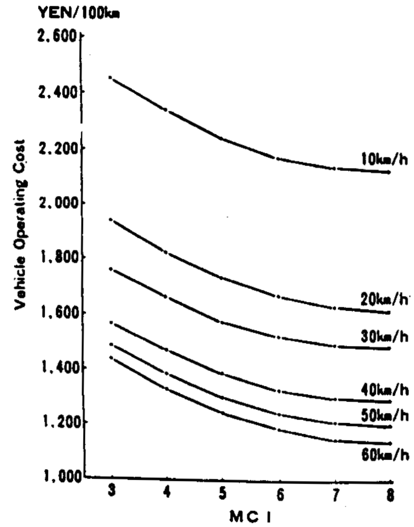


Fig. 3 Vehicle Operating Cost (VOC) and MCI (Small Vehicles)

6. LIFE CYCLE COST ANALYSIS OF PAVEMENTS

The life cycle cost of pavements include all kinds of costs, which occur during the life cycle of a pavement (12). In PMMS, maintenance cost, rehabilitation cost, salvage value, and user costs (vehicle operating cost plus time delay cost) are factors considered in the life cycle cost analysis of pavements. The present value of the life cycle cost is calculated by the followings equation.

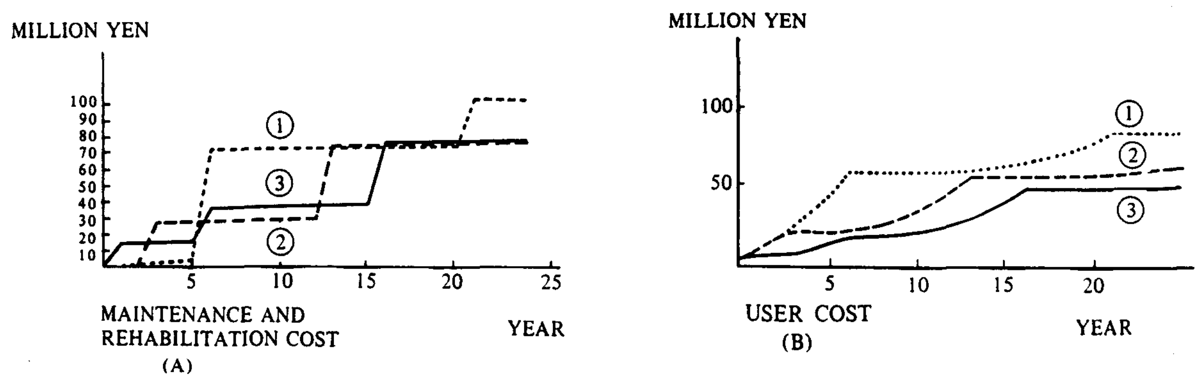
$$LCC = \sum_{t=1}^{n} MT/r^{t-1} + \sum_{t=1}^{n} Rt/r^{t-1} + \sum_{t=1}^{n} VOCt/r^{t-1} + \sum_{t=1}^{n} TDCt/r^{t-1} - SV/r$$

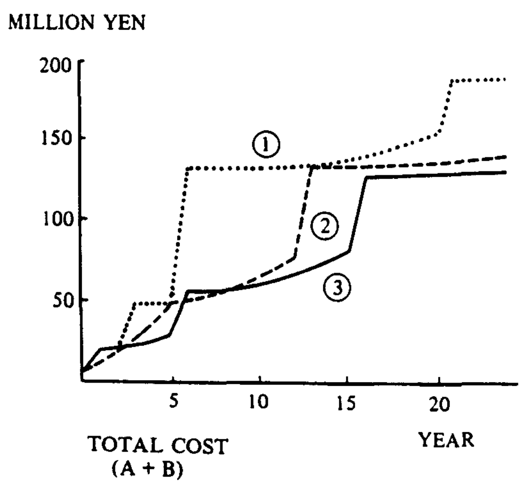
Where, LCC : life cycle cost
n : analysis period
Mt : maintenance costs at t year
Rt : rehabilitation costs at t year (at the year of no rehabilitation, Rt = 0)
VOCt: vehicle operating costs at t year
TDCt: time delay cost caused by rehabilitation work at t year
SV : salvage value
r : (1 + discount rate)

Using the performance prediction equations described in Table-3 of the previous section, sample calculations of life cycle costs were conducted. For the estimation of user costs, VOC versus MCI curves described in the previous section were used assuming that the VOC incurred when a vehicle travels on a perfect smooth road (MCI=10) is equal to zero. Following three strategies (rehabilitation patterns) which reflected the actual rehabilitation practices in Japan were selected for the sample calculation.

1. Large scale rehabilitation works (reconstruction) are applied repeatedly after MCI drops to 3.
2. Medium scale rehabilitation works (overlay) and reconstruction are applied alternately when MCI drops to 4 (overlay) and 3 (reconstruction) respectively.
3. Surface treatments and overlays are applied alternately when MCI drops to 5 (surface treatments) and 4 when MCI drops to 5 (surface treatments) and 4 (overlay) respectively.

Accumulations of the annual expenditure discounted back to the base year during the analysis period (25 years), are shown in Figure-4. The diagrams in the figure show the annual accumulation of the following three costs; 1) maintenance and rehabilitation costs, 2) user costs, and 3) the total of the two costs (maintenance and rehabilitation costs, and user costs). The figure clearly indicates that rehabilitation strategy 3 is the most beneficial for road users, and that it is also the most economical strategy in terms of the total costs.





(Assumptions)
- Number of traffic lanes: 4
- Section length: 500 m
- Road width: 15 m
- Traffic volume: 20,000 vehicles/day
- Heavy vehicle mixing rate: 20%
- Average traveling speed: 40 km/h
- Current MCI value: 5.1
- Discount rate: 6%

Fig. 4 Life Cycle Cost Comparison

7. TOTAL PAVEMENT MAINTENANCE MANAGEMENT SYSTEM

(1) Framework of the Total Pavement Maintenance Management System (TPMMS)

The Ministry of Construction has been developing a TPMMS for the designated portion of the national highway. The designated portions of the national highway is an important part of the arterial road system in Japan. It is spread throughout the country and has a total length of approximately 20,000 km. The central government is directly in charge of the maintenance and rehabilitation of the network, and work is allocated among the 8 regional bureaus of the ministry. Work offices and branch offices which belong to a regional bureau actually perform the maintenance and rehabilitation works.

Figure-5 shows the overall structures of the TPMMS. At first, daily maintenance, which is usually done routinely by patrols, is dealt with separately, whereas various data, obtained from the patrol and routine maintenance, is sent to the data base. The pavement data base is positioned at the center of the system and plays a key role as the major source of information for the whole system. Systematic maintenance and rehabilitation programing, which starts from the data base, is divided into two different programing sub-systems; Long-Term Rehabilitation Programing System (LTRPS) and Priority Ranking and Design Selection System (PRDSS). LTRPS is used to prepare long-term investment plans at various levels of the organization. PRDSS, on the other hand, is used to establish priority from among the networks controlled by specific work offices or branch offices, and it also contains a system which helps make selections of particular rehabilitation alternatives.

(2) Long-Term Rehabilitation Programing System (LTRPS)

LTRPS is a network-level mathematical programing model which has versatile functions including; 1) to estimate the long-term needs for a rehabilitation budget, and to evaluate the economic effects of predetermined rehabilitation investment levels, 2) to determine the best candidate projects within-project alternative and its best year of implementation. Figure-6 shows the structure of the system. The details of the system is reported in several papers (7, 13, 14).

LTRPS was applied to the entire national highway network and the effects of the different budgeting levels for 15 years were examined. In the analysis, four budgeting levels were assumed; level I (580 billion yen for 15 years), II (810 billion yen), III (1,000 billion yen) and IV (1,250 billion yen). Figure-7 shows the average MCI versus the year curves of the entire network for four budget levels throughout the programing period (1986 to 2000). This figure illustrates that an average MCI drops below 3.5 from an original level of 5.6 in 15 years when a budget level I is assumed. With the budget level III, the original MCI level can be maintained, and when a rather ample budget level of IV is assumed, an average MCI increases gradually and reaches 6.3 at the year 2000.

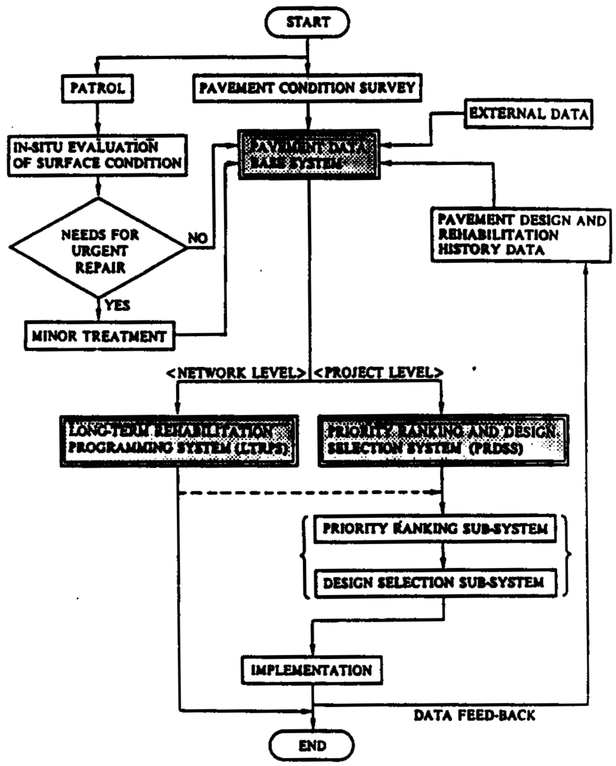


Fig. 5 Flow of the Activities Involved in Total Pavement Maintenance Management System

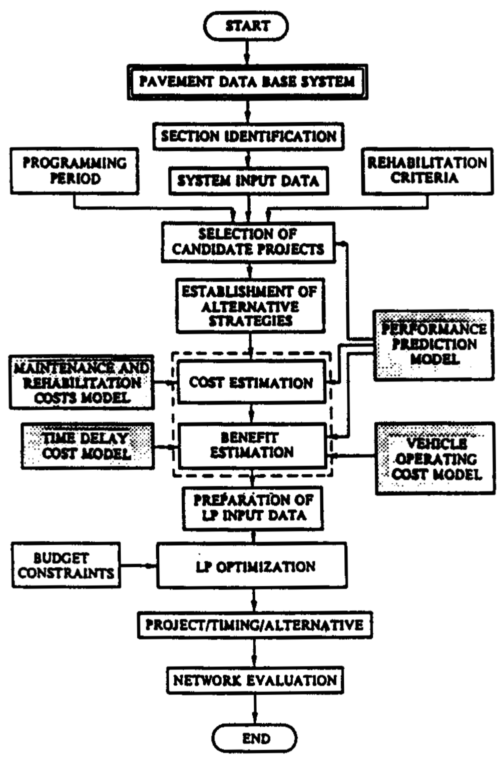


Fig. 6 Flow of Long-Term Rehabilitation Programming System (LTRPS)

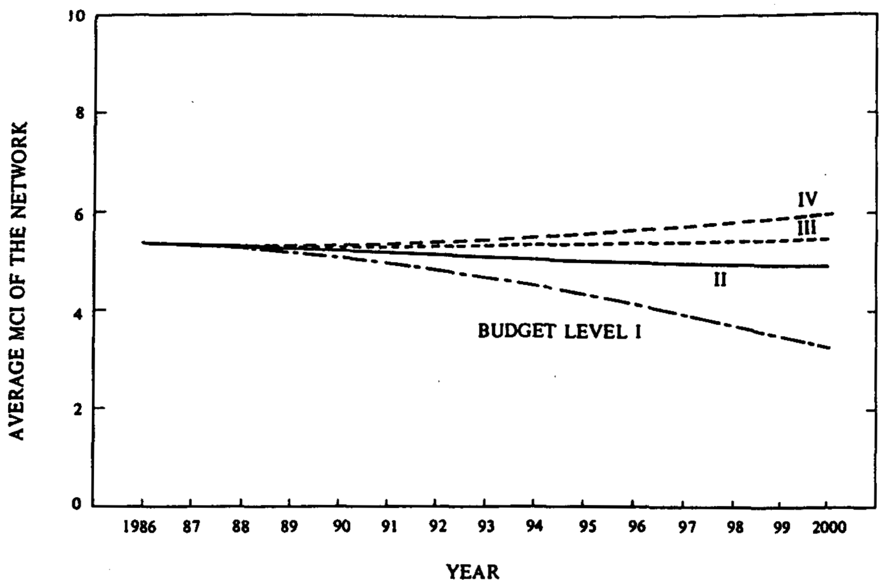


Fig. 7 Future Condition of the National Highways for Different Budget Levels (System Output)

(3) Priority Ranking and Design Selection System (PRDSS)

PRDSS is a system which enables more rational and objective decision making with regards to maintenance and rehabilitation programs at the work office level (3). The difference between the traditional way of rehabilitation planning and the PRDSS is, while the former depends mainly on engineers' technical judgments and experiences, the PRDSS employs a quantitative evaluation of alternative strategy based on the data provided by the data base system. PRDSS consists of two sub-systems, Priority Ranking System and Design Selection System.

The priority ranking system determines the priority of rehabilitation projects within the network according to the ranking index, which is calculated based on pavement condition, traffic, and environmental conditions.

The design selection system selects the best possible rehabilitation alternative and/or design thickness for the candidate projects, as determined by the priority ranking system. In the system, selection of an alternative strategy and its design for a specific pavement section is made after comprehensive evaluations of various factors is completed in terms of the deteriorated existing pavement, traffic and subgrade conditions, etc. Currently, an intensive effort is underway to develop a micro-computer based EXPERT system that will help make decisions on the selection of rehabilitation alternatives.

8. AFTERWARD

In Japan, significant advancements have been achieved in the areas of pavement data collection and data base system management in the last decade. The intensive efforts are now being directed to the development of decision making systems for rehabilitation programing that is to be built upon the existing data base. The outline of such systems were presented in this paper. However, it should always be noted that PMMS must be improved on a continual basis responding both to the new needs within the agency and to the innovations in related technical areas. Obviously, recent developments in computer techniques will provide Japanese PMMS with a more flexible and more powerful tool for data processing and feedback.

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