DEVELOPMENT OF PAVEMENT MANAGEMENT IN A MAJOR CITY - THE HONG KONG EXPERIENCE

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abstract: In 1993, the Hong Kong Highways Department implemented a Pilot Pavement Management System, (PMS), with the objective of studying the practicality of Territory wide introduction. The Pilot PMS generates life cycle cost analysis of pavements using the World Bank's Highways Design and Maintenance Standard HDM-3 model and optimises maintenance investment decision-making. This paper concentrates on the development of the Pilot PMS.

1. BACKGROUND

The Hong Kong Highways network comprises approximately 1600 kilometres of highways ranging from expressways to minor local and village access roads. The network is predominantly urban but there is still a significant length of rural roads in the New Territories.

Over the past decade the Highways Department has concentrated on the generation of a system which would objectively determine the priority of road maintenance works and predict the optimum time for maintenance to be undertaken. A number of surveys, inspection programmes and other initiatives were instigated based on the needs of the network. These were subsequently developed as new technology became available or new needs were identified.

The approaches taken to rationalise maintenance requirements included:

- 1986, the introduction of the computer software for the maintenance priority program, Maintenance Assessment Rating and Costing of Highways, (MARCH), and the compilation of a MARCH database of pavement inventory and condition for the road network.
- 1986, a deflectograph survey was undertaken to evaluate the strength characteristics of flexible pavements and to produce an overall condition assessment of the flexible pavements in the road network. An axle load survey was also commissioned to gauge the effect that commercial vehicle loading had on the life of pavement structures and to assess the adequacy of the axle load predictions generated under the pavement design system.
- 1991, a structural evaluation using a Falling Weight Deflectometer, (FWD), was undertaken on approximately 500 lane km of flexible roads and 100 lane km of concrete roads. The survey was undertaken with the intention to gauge the effectiveness of

maintenance strategies developed subsequent to the 1986 deflectograph survey and to reassess the structural capacity of the network. The results from this survey were also used to develop a mechanistic pavement design system which recognized local material properties, climatic factors and traffic loading. The resultant Pavement Design Manual replaced the existing empirically based pavement design system which had been used for a number of years.

1.1 Study Area

The study area for the PMS Pilot Scheme was the Shatin New Town, a network that comprised 147 Roads making up approximately 1,100 defined MARCH Sections. The network ranged from expressways to unclassified and local roads, with a total carriageway length of about 156 km, and included a 32 km length of Cycleway network. Approximately 90% of the road network were flexible pavements and the remaining 10% were concrete.

1.2 PMS Requirements

The requirements for the Pilot PMS include:

a) the establishment of a database of road inventory and road condition data including; visual inspections data, structural test data and roughness data;
b) the development of systems to directly transfer road defect information from the testing or recording device to the computer database in digital format to reduce manual inputting;
c) the optimisation of total cost involving a selection process to determine the most cost effective treatment for a road section based on preventive maintenance principles;
d) the production of reports outlining the relative priority of maintenance treatments for all maintenance sections;
e) the optimisation of road network condition taking account of budgetary constraints and the production of Budgeted Maintenance Reports recommending annual road maintenance programmes based on rolling five year programmes with a range of budget scenarios.

2. ROAD REFERENCING SYSTEM

Fundamental to efficient cataloguing is the establishment of an accurate, consistent referencing system. The primary objective is to enable road locations (either points or sections) to be readily identified and located both in the field as well as the office and to enable automatic road surveys for the PMS to be calibrated for distance corrected for accumulated errors.

The MARCH Road Referencing System used by the Highways Department was found to be generally suitable as the basis for a PMS. However, as a standard approach MARCH Sections are treated independently without any connectivity. This means that there is no way to distinguish between separate elements or links of the road where, for example, the road divides into separate carriageways. Nor does the MARCH system include a lane numbering convention as survey data are assumed to apply to full sections of road.

2.1 System Established Under Pilot Project

Although the MARCH referencing system was adopted for the Pilot PMS it was considered desirable for an additional unit of "link" to be introduced to allow subdivision of roads where vehicle based surveys required multiple passes. Links are also required for graphics where a single road is made up of several separate graphic elements. This is currently being addressed.

Under the MARCH system length is measured along the left kerb using a hand-wheel. However, lane lengths are required for vehicle based surveys and there can be an appreciable difference between these two lengths. The introduction of links overcomes this deficiency for automated surveys, automated processing and analysing results and the presentation of results. An important adjunct for automated surveys is the establishment of internal highly visible control or reference points which can be tied into as surveys progress thus reducing accumulated errors for roads longer than about 1 km.

Links are commonly used in other PMS referencing systems including the HDM-3 model. This addition is compatible with the MARCH Roads and Sections Hierarchy and the unit of link has now been adopted with appropriate standardized descriptions. For length control, and to more accurately represent pavement areas, standard chainage representing the cumulative chainage for each MARCH section were determined for each link in the Pilot area by; measuring from the 1:1000 scale MICROSTATION drawings (for the High Speed Roads), measuring using a curvimeter from the 1:1000 hard copy drawings or physically measuring on site the section length using the vehicle oedometer.

Of the three methods, the vehicle oedometer suffered from a lack of repeatability within approximately $\pm 0.5\%$ and the readability of the curvimeter (at 1:1000 scale) was ± 2 or 3 metres. Where the drawings comprised many sheets, the possibility of errors as the meter was repositioned became more significant. In addition, the scale of drawings was found to vary slightly due to copying distortion. Based on the Pilot Scheme experience measuring using MICROSTATION from the 1:1000 graphics is preferred. Where the MICROSTATION drawings are not available the curvimeter should be used with results later being re-assessed from digitized 1:1000 drawings when available.

3. ROAD ROUGHNESS SURVEY

Road roughness surveys were undertaken to establish a system to provide input to the PMS and to assess the application of the survey results towards establishment of condition standards and maintenance intervention levels. The International Roughness Index (IRI) was considered to be the most appropriate measure. The equipment selected (primarily on the basis of cost) was the NAASRA meter from Australia.

Roughness surveys using response type equipment such as the NAASRA meter are required to be carried out at uniform speeds. The usual standard speeds are either 60 or 80 kilometres per hour. Hong Kong's predominantly urban nature of the network dictated the requirement to operate at significantly lower speeds (20 to 50 kph) and to operate at variable speeds as dictated by the traffic conditions. A light van was used in the survey and although it had low speed sensitivity it was relatively insensitive at very low roughness levels. The minimum roughness which could be registered at the typical operation speeds (due to friction and inertia in the vehicle suspension) was about IRI 1.7. It is estimated that only one or two percent of the network has a roughness below this figure with a probable minimum of approximately 1.4.

As far as possible the processing and up-loading of data were to be automated to enable results to be finalised within a short time of the field computer disks being received in the office. To achieve this objective the Australian analysis software was extensively modified to suit Hong Kong characteristics. This involved reducing the standard output interval from 100m to 10m, to suit the relatively short MARCH sections and calibrating for IRI based on the average speed over each 10m segment. The roughness output (using the 10m output interval) provide a convenient way to assess the condition of a road and to highlight sections of concern where more detailed inspections or investigations should be undertaken. In addition a MAPINFO interface was developed from the PC system to the pilot PMS database (ORACLE, running under UNIX). This allows automatic insertion of roughness records to the PMS on a district by district basis, as well as providing full network graphics.

Roughness results Tables 1& 2 provides an objective means of comparison of the overall roughness condition of the district for surface type and road class. Historical trends represented by movements in the distribution graph can also be built up over time to enable changes in maintenance strategy to be objectively assessed.

From the Pilot survey results and by assessing current maintenance strategies the Highways Department's current intervention with respect to roughness could be construed to be in the order of:

- IRI 4 for A Class,
- IRI 5.5 for B Class,
- IRI 9 for U Class

The high value for U Class roads is because this class in the Pilot area includes many of the older road sections mostly with low traffic levels constructed in the early 1970's. This trend may not necessarily be representative of the rest of the highway network throughout the Territory.

Table 1 Statistical Analysis Roughness Results - Shatin District

Number of March Sections Surveyed	1014
Minimum Section IRI	2.001
Maximum Section IRI	12.303
Range of IRI Values	10.302
Mean IRI (all Sections)	4.049
Variance	1.898
Standard Deviation	1.378

Typical Section Length 150m - 250m

Table 2 Mean Roughness by Road Class - Shatin District

Road Class	Mean Roughness (IRI)	No. of Sections
A (Trunk Roads)	2.87	203
B (Distributors)	3.68	333
U (Local Roads)	4.81	475

The majority of roads in Pilot network are only 10-15 years old and one would expect that the rate of increase in roughness would accelerate as they approach their design lives. This aspect of deterioration can be simulated using the HDM-3 model.

4. FALLING WEIGHT DEFLECTOMETER, (FWD) SURVEYS

The FWD analysis aimed at the development and establishment a system which would enable automatic uploading of the FWD deflections and temperature data to a database format suitable for the derivation of structural parameters. The parameters for flexible pavements comprise the pavement Structural Number (SN) and the Subgrade Modulus (Es), or CBR, which is input into the PMS HDM-3 model to predict future pavement performance. The Structural Number and subgrade modulus can also be used to assess the strength and variability of the pavement prior to detailed mechanistic design. The Structural Number provides a reliable guide to the type of roadbase, in particular if a cement treated material is present.

Structural evaluation of concrete pavement is much less developed internationally than flexible pavements. The objectives with regard to concrete pavements were to build on the previous research carried out using the FWD in the Philippines and to develop an analysis system which would allow the future performance of these pavements to be predicted.

There are two approaches generally adopted for rigid pavements. They are the structural approach where performance is based on a fully mechanistic evaluation using calculated pavement strains and fatigue theory and the functional approach based on the maximum compressive stress on the foundation support (rather than the maximum tensile stress in the concrete for the structural approach).

The Dynatest - ELCON methodology was used as the basis for the analysis with the "functional" approach as proposed by Ullidtz and Stubstad rather than the "structural" approach as previously used in the 1992 Hong Kong Road Testing Programme.

A limited investigation was carried out to compare performance predictions using the Structural approach and the Ullidtz and Stubstad's Functional relationship. This considered eleven sites throughout Hong Kong analysed in 1992 to determine residual life. The sites were selected as having a constant base thickness (230mm) and a granular subbase. At each site the residual life from the Functional relationship was derived and the results using the same FWD data were compared as shown in Table 3.

In general there is good agreement on 6 of the 11 sites. At the five other sites (Nos.2, 11, 19, 20 and 21) there are significant differences. The E_1 value of 51GPa (Site 2) appears high and may be due to an incorrect base thickness used in the back-calculation process.

Ullidtz and Stubstad in their paper based on extensive research in the USA broadly categorised pavements as:

- above 25GPa modulus (E_1) as being "good or intact" and;
- below 15GPa modulus as being "thin or cracked"

The validity of this observation cannot be confirmed for Hong Kong without a more detailed study of Hong Kong rigid pavements. Nevertheless, the Ullidtz and Stubstad findings tend to support the functional approach for four of the five differing results although a more detailed visual assessment of their condition and monitoring of roughness would provide some confirmation.

The testing and analysis using the FWD has a major advantage in that it can be carried out virtually on the same day. The FWD can therefore also be used in a quality control role for both flexible and rigid pavements. It will take a considerable amount of research before results could be used as the basis for acceptance (or otherwise), however, as a screening mechanism it is considered that the FWD has considerable potential.

Table 3 Comparison of Functional and Structural Relationships

Site	Road	From	To	H_1	E_1 GPa	E_2 MPa	E_3 MPa	MSA's/ Year	Funct. Resid. Life	Struct. Resid. Life
1	Castle Peak Road IL	0.000	1.623	230	20.0	200	100	3.0	7	0
2	Castle Peak Road IL	4.529	6.457	220	51.0	245	140	3.0	>25	0
11	Castle Peak Road 2R	15.400	14.915	245	16.5	120	210	10.0	5	39
12	Castle Peak Road 2R	14.483	13.225	245	15.5	550	105	10.0	2	0
13	Castle Peak Road 2R	11.938	7.726	225	30.0	200	85	10.0	4	0
15	Castle Peak Road 5L	32.230	33.688	230	18.5	175	325	2.0	>25	40
19	Castle Peak Road 6L	41.465	41.585	230	15.0	250	85	2.5	7	40
20	Castle Peak Road 6L	42.032	42.133	230	24.5	200	100	2.5	12	0
21	Castle Peak Road 6R	42.137	42.033	220	19.0	150	210	2.5	>25	8
22	Castle Peak Road 6R	41.617	41.466	240	24.3	185	170	2.5	>25	40
28	Lam Kam Road R	2.481	1.377	230	20.3	180	105	5.0	5	0

L = Lean Concrete roadbase, R = granular roadbase, H_1 = Base layer thickness
E_1,E_2,E_3 = Pavement Layer Moduli

5. VISUAL CONDITION SURVEY

The objectives of the visual survey were to review and assess the Highways Department's recent and previous experience with visual condition surveys and to develop and implement a system which would efficiently and accurately visually define the condition of the road pavement. The standard defects were those defined in the Highways Department's, Catalogue of Road Defects, (CORD) with the general methodology to be conducted in accordance with the Highways Department's, Road Inspection Manual, (RIM).

The condition rating system was to include an accurate referencing system, and be suitable for the full range of road conditions in the Hong Kong network. Most importantly, the system was to be capable of interfacing with automated subsystems to facilitate analysis and processing with a minimum of manual intervention.

Previous referencing (within each of the MARCH Section) was carried out using a measuring wheel, with data input by means of data loggers. MARCH survey data were automatically analysed without the capability or the flexibility to present the data in a range of formats, or to show distress graphically either on a project, or network basis. This capability is now regarded as essential for a comprehensive visual condition rating system.

5.1 PMS Vodel Visual Condition Rating System

The VODEL (Voice Defect Logging) system was selected as the most appropriate inspection and cataloguing system for Hong Kong. The system offers the following advantages:

- relatively low cost (below approximately US$7,000 including all hardware and software);
- location chainage interfaced directly to the vehicle odeometer with the capability to automatically correct any distance inaccuracy (based on comparison with accurately located reference markers or control points);
- full "hands off" operation allowing the inspector to concentrate on the road, reducing tedium and fatigue;
- elimination of all manual processing, with the exception of editing (if necessary);
- ability to be used in either English, Cantonese or any other language;
- menu driven and relatively simple to train inspection staff and to operate the equipment;
- use of three levels of severity of each defect and three levels of transverse extent;
- user definable defect configuration file, which enables the system to be also used for surveys other than pavement condition (such as roadside furniture, slope stability, land use, terrain type etc);
- use of a fully integrated WINDOWS based graphical analysis software package Graphical Defect Review, (GRADER);
- storage of data on (dBase) database suitable for initial processing using MAPINFO software developed under the project before uploading to the PMS ORACLE database;
- use the latest technology microphones (such as ear microphones) which eliminate external noise interference, a major problem in densely trafficked areas.

VODEL can be easily installed and fitted to any vehicle with an electronic speedometer or an oedometer probe. Because of the hands-off operation, it can also be installed on a bicycle or motor scooter. The system worked well for the Pilot network despite defects being reported in English by Cantonese native speakers with no previous experience. The level of detail of the results and the general accuracy and repeatability was good and exceeded expectations.

5.2 Visual Survey Analysis

The objectives of the visual survey analysis were to present the results graphically on a project by project basis, to derive mean condition parameters for each MARCH section in the network and to provide a translation facility and an interface to the existing MARCH system. In addition it was required to display the network results graphically using "shade by value' to highlight particular condition or surface type ranges and to provide an interface to the ORACLE PMS database and the HDM-3 prediction model. Finally it was considered to be necessary to display the results in standard report formats to allow comparisons between districts, or for the assessment of changes in condition with time.

The VODEL software includes the Graphical Defect Logging (GRADER) module which enables a standardised summary plot to be produced. This requires setting up standard plot files to meet the user's requirements. The network analysis module allows the facility to automatically process the visual survey results and to graphically display them. It also allows the field survey to proceed without the need to locate individual MARCH section boundaries. This significantly increases field survey progress.

A range of outputs is available including, graphical presentation and formal and ad-hoc queries using SQL from the ORACLE (UNIX) and MAPINFO (PC - WINDOWS) Databases. The data can also be uploaded to the PMS database

6. PAVEMENT STRUCTURE/PROFILE

Pavement structure or profile is an important component of pavement design systems and a PMS. Possible sources of data relating to the pavement structure include historical and maintenance records, back analysis using pavement design charts, original design drawings, cores or test pits and observations from excavations. Ground Penetrating Radar is a recent innovation that has recently been evaluated in Hong Kong and shows considerable potential for future surveys.

The influence and sensitivity of the overall pavement structure to the HDM-3 model's predictions is not very important for flexible pavements. Although the model requires details of the surfacing (number of layers, thickness, age, previous cracking) and the subgrade, it does not require thicknesses of base or subbase layers. For Cement Treated Bases, or Lean Concrete Bases, however, the model does require an estimated base thickness and the Modulus of the base. However, default values can be used for these if actual data is not available.

6.1 Coring - Investigation Programme

To determine representative pavement profiles throughout the network, 46 coring test sites were identified covering a range of pavements varying from A class to U class roads. In addition Dynamic Cone Penetrometer (DCP), evaluations were undertaken at selected representative sites, penetrating through unbound layers to a nominal depth of 900mm. This depth was specified to avoid the possibility of intersecting buried utilities. The 28 DCP tests through base and subgrade materials involved some considerable manual effort. However, they are much faster and a lower cost alternative to excavating test pits. The results from the core and DCP, were used as the basis for the allocation of the pavement profile for the full road. In cases where (based on the FWD-SN results), the core result was considered to be clearly unrepresentative, an assumed profile was used based on the hierarchy of the road, and the structural test results.

7. VEHICLE CATEGORIES AND ROAD USER COSTS

The categorisation of representative vehicle groupings and the derivation of appropriate vehicle performance, axle loadings and operating costs represents an important aspect of pavement management. Axle loadings directly affect pavement damage and future condition and the vehicle operating cost/road user costs determine the overall economic benefit of road improvements. Vehicle groupings should be appropriate for the range of vehicle types operating over the network and be selected to enable maximum sensitivity for vehicle characteristics. The grouping should also be selected such that field surveys using either manual or automatic counts can conveniently and efficiently divide traffic into the appropriate category (or Bin).

During the Pilot Scheme, existing sources of traffic data were reviewed and a categorisation system proposed for use in the pilot PMS were developed. Representative vehicle performance parameters, axle loads and operating costs were allocated to each group, suitable for use by the HDM-3 prediction model.

8. COMPUTER GRAPHICS

The Pilot PMS system uses the ORACLE Relational Database Management System, the World Bank's HDM-3 prediction model to derive pavement life cycle costs, and the World Bank's Expenditure Budgeting model (EBM) to determine works programmes under budgetary constraints.

Graphics development for the Pilot Scheme included both UNIX and PC applications. MICROSTATION/MGE/MGA running under UNIX have major advantages in terms of ability to manage very large files, in processing speed and the ability to interface with the ORACLE Database. The main disadvantage of a UNIX based system such as this is that it is difficult for non-specialists to access and use on a daily basis. For such applications, a simpler PC based system is preferred provided it can be integrated within the overall graphics system.

The PC graphics is considered to have the greater potential for widespread application than the Unix graphics and the MAPINFO system was selected as being the most appropriate system. MAPINFO offers significant benefits in user friendliness, in software cost and in ability to communicate with INTERGRAPH products (MGE in particular).

Centre-line Graphics were developed and the network was dynamically segmented into the 1,117 Shatin MARCH sections for the 147 roads in the network. Other examples that can be plotted include road classification, width, surface type, surfacing age etc.

The enhanced centre-line graphics as developed for the Shatin district during the Pilot Scheme shows each carriageway as a separate graphic element, with defined links and sections. The 1:1000 topographic maps are very useful as background for the centre-line graphics and to assist in referencing and project definition. The latest version of MAPINFO (version 3) can display these maps in RASTER format.

9. HDM-3 CALIBRATION

The HDM-3 model is used to predict the future pavement condition and life cycle costs (both Agency, and Road User). Within the PMS, it is automatically interfaced to the ORACLE database, with all operations carried out automatically. The model requires calibration to suit local environmental conditions. This is performed by modifying a set of seven HDM-3 "Deterioration Factors" such as ; cracking initiation, cracking progression, ravelling initiation, roughness - age term, pothole progression, rut depth progression and roughness progression. The default values that were obtained from the 17 years of research during the development of HDM-3 by the World Bank (IBRD), have been found by international researchers to be generally applicable to tropical and sub-tropical conditions (such as Hong Kong) for standard pavement materials.

For a pilot project, a detailed calibration was not required, however it is required to broadly validate the models, to investigate the performance of non-standard materials, and to set out what is involved with respect to the future detailed calibration. For use with the PMS, the deterioration factors can be varied for a particular surfacing type and it is also possible to change the factors on an individual section by section basis.

Of the above factors, the ravelling initiation is not used for bituminous pavements in that the HDM-3 model only predicts the onset and progression of ravelling for surface treatments/sprayed seals. Ravelling initiation is much more influenced by project specific and localised aspects such as manufacturing, mix design and laying temperature. This finding has been supported by Australian research, although once ravelling had commenced, the progression and severity were found to be weakly correlated to time.

Calibration of the HDM-3 model is usually carried out by the process of "reverse prediction". This involves selecting test sections for which reliable historical and functional structural data is available, modelling the performance commencing from the date of construction (or last strengthening) and comparing the predicted condition for the current year with that actually recorded during the latest condition survey.

This is a detailed process and to undertake it fully and comprehensively is a major research undertaking. For the pilot PMS, an initial preliminary calibration was undertaken based on analysis of 13 sites where the surfacing age and pavement profile could be reliably estimated without intensive investigations.

The Shatin survey network results provide the best means of calibration of the HDM-3 model. The referencing of structural surveys and condition surveys represented an improvement on the previous (1992) surveys due to equipment and hardware advances and the carrying out of a full roughness survey.

The performance algorithms used in the HDM-3 model, as described by Watanatade et al, adopted an "initiation period" for cracking which is dependent on many factors, but principally; the type of pavement; the traffic loading; the strength of the pavement (SNC); and (for resurfacing) the extent and severity of cracking in the underlying surfacing. Similarly, the progression of roughness is a function of the strength, the traffic loading and the predicted condition of the pavement (onset of cracking, potholes etc).

To assess the validity of the HDM-3 model, the Shatin network results were sub-divided into several categories. These were, annual Traffic Loading (3 ranges), pavement Strength (a high medium and low range for each traffic loading), defined by SNC, pavements divided into original surfacing, and overlays/inlays, (almost all of the latter category were inlays) and base types (bituminous/granular or lean concrete).

For lean concrete bases fewer examples were studied, hence there is a need for a more detailed analysis in the future, including an assessment of the back-calculated modulus. HDM-3 has the provision to utilise the lean concrete modulus in its analysis of cement treated bases and this feature has been included in the customisation of the PMS to suit Hong Kong conditions.

Each range is relatively large and can cover a wide grouping of other quite significant variables such as thickness of bituminous surfacing, extent of previous cracking (for inlays/overlays) and variations in routine maintenance and initial roughness. For these reasons, as well as because of localised variations within the pavement and subgrade, there was a considerable degree of scatter of results. Because of the limited number of ages plotted, there was also a considerable amount of overlap of points (particularly where cracking equals zero). As expected there are a number of outliers which should be checked during future detailed calibration. The fundamental relationships, however, are apparent for the cases of original construction, and overlays/inlays for both base types.

Because of the relatively small significantly cracked data set, and the relatively young ages of the Shatin network, it is not possible to assess the crack progression. It is probable that because of the relatively thick bituminous surfacing which are typically much thicker than for the typical surfacing on which HDM-3 was derived, the predicted progression rates will be too high. This required a small reduction in the default deterioration factor for crack progression.

Results for the lean concrete bases, which comprised 19 percent of the Shatin network indicated that there was also a pronounced crack initiation period, although as expected, there was often cracking of the order of 2 - 5 percent commencing as early as 3 years. This is considered to be characteristic transverse shrinkage cracking which is not modelled by HDM-3. The HDM-3 algorithms for the case of the relatively thick bituminous surfacing used in Hong Kong (typically 100-150mm), were previously known to give crack initiation times often far in excess of actual results. This is because the original HDM-3 data set comprised bituminous surfacing over much thinner cemented bases (typically 40 - 75mm). Extrapolation of these algorithms to surfacing of 100mm plus, obviously cannot be done. Either new algorithms have to be derived, which is the best long term solution, or much lower crack initiation deterioration factors have to be used which is the short term solution.

An example of the results of the Shatin analysis are shown in Figure 1, which comprises the medium category for original surfacings on bituminous bases.

10. MAINTENANCE STRATEGIES

The System considers road maintenance in terms of recurrent maintenance, which is carried out to address individual distresses on a routine day to day basis, and, in terms of whole block treatments such as overlays, inlays and reconstructions.

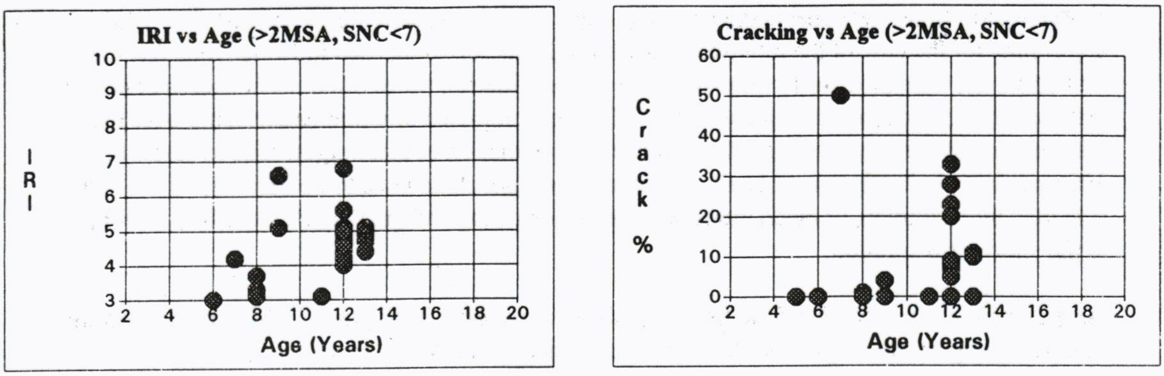
The aim of the PMS is to optimise the selection of whole block treatments (i.e. produce an optimised works program) while ensuring that the cost of carrying out the works does not exceed the available budget. Alternatively a number of budget scenarios can be run to determine the budget required to achieve the desired level of service. During the modelling process the system assumes a level of recurrent maintenance for each block which is a function of types and levels of distresses developed by the simulation model over the life of pavement. The amount of attention which is given to addressing recurrent maintenance problems varies from authority to authority and is therefore user definable. This also requires calibration to reflect actual recurrent expenditure.

10.1 Recurrent Maintenance

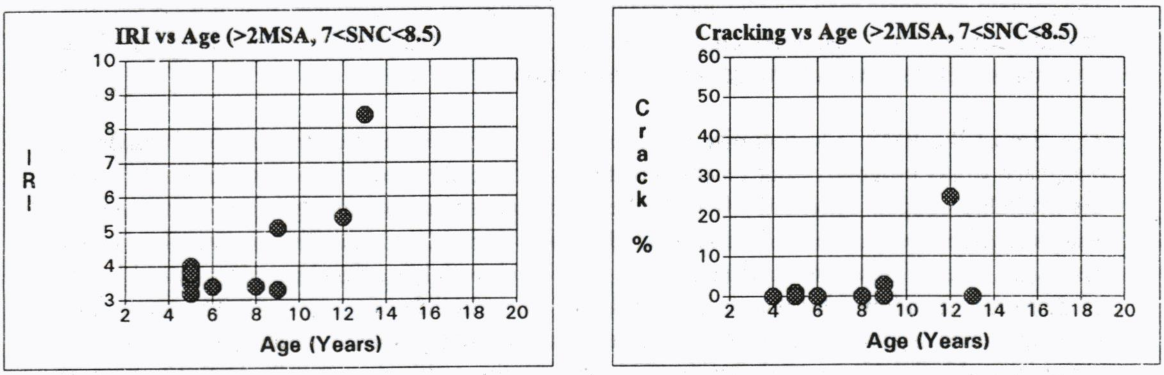
Under the HDM definitions, recurrent maintenance is divided into two components. The first component addresses (in order of priority) potholes, patching of badly cracked areas (wide cracks only) and patching of badly ravelled areas. The level of recurrent maintenance undertaken by the authority is specified as the percentage of these distresses which are repaired under the recurrent maintenance operations.

Because Highway Authorities generally do not address large areas of ravelling or large areas of cracking under recurrent maintenance, the percentage area of distresses repaired under recurrent maintenance is typically small. For the pilot study this figure was set initially at a nominal 3.5%. This figure can be further refined in the future, for example to reflect the predominant distress type(s).

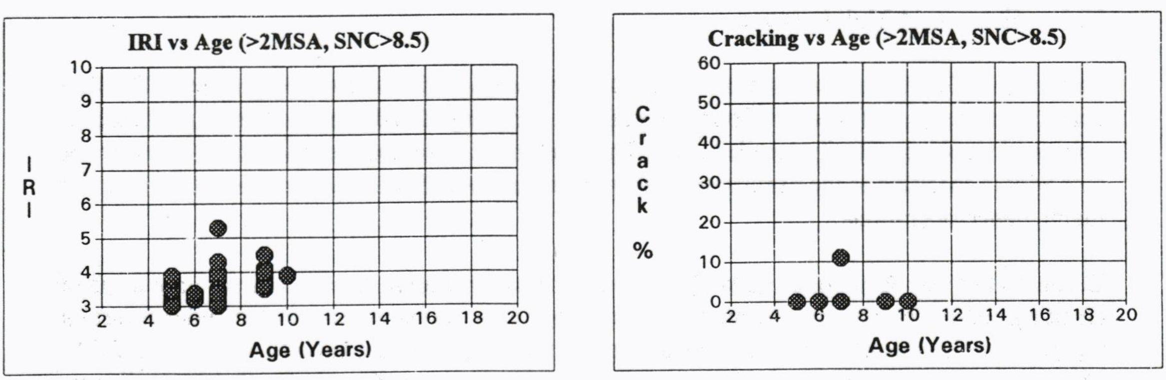
The other component of recurrent maintenance is a fixed annual cost which is not dependent on



Low Strength Pavement



Medium Strength Pavement



High Strength Pavement

Figure 1 Original Surfacings with Bituminous Bases - Heavy Traffic (>2MSA's per Year)

the amount of distress occurring in the pavement. It covers the costs of item such as lane marking, drain cleaning etc. The value for this item (which is not critical in terms of PMS analysis) has been set at a nominal HK$20,000/km/year which converts to approximately HK$2,800 per year for a typical MARCH section.

10.2 Whole Block Treatments

The system allows the user to define "whole block" maintenance treatments. The standard categories of whole block treatments are:

- preventative treatments;
- bituminous overlays;
- reconstructions.

For the Pilot Study, a number of treatments have been set up to reflect current maintenance practices. These treatments represent generic treatments for planning purposes. Detailed design and costing should be carried out prior to commencing any works. The treatments are essentially:

- overlays;
- inlays;
- reconstructions (flexible);
- reconstructions (rigid).

There are two overlay/inlay thicknesses of 45mm and 105mm which were adopted as an initial approach but may be modified with experience.

There are three classes of rigid and flexible reconstruction corresponding to "low", "medium" and "high" traffic loadings. These have appropriate varying strengths and costs assigned.

Because of the difficulties found with the HDM-3 calibration of lean concrete pavements with thick bituminous surfacing it was necessary to further sub-divide the pavements types. This was based on the requirement to use different calibration factors, and a further distinction as to whether the existing surfacing was either cracked or uncracked. Accordingly, the inlays and overlays above were sub-divided into:

- bituminous bases/granular bases (the calibration factors used were the same);
- lean concrete bases which are uncracked or slightly cracked only;
- lean concrete bases which are cracked.

In order to be able to accommodate the varying calibration factors, different surfacing codes and different treatment codes were set up so that the correct HDM-3 calibration factors could be applied at the appropriate locations.

For these reasons, each of the treatments applicable to lean concrete pavements were set up using three different treatment codes. The logic which automatically assigns the appropriate treatment codes to specific MARCH sections has been incorporated into a candidate treatment selection rule base.

Before the PMS system can select an optimised works program, the first step is to determine for each section, a list of all maintenance options that may be appropriate to improve the condition of the pavement. The process of compiling these lists of appropriate options is called 'Candidate/Treatment Selection'. The final decision as to which one of the list of treatments to adopt will be made during the optimisation process and will depend on the results of a complete life cycle costing of the road section under each of the different treatment options.

The life cycle costing includes on a year by year basis, analysis of pavement condition, vehicle operating costs and recurrent maintenance costs. The optimisation selects the treatments which provides maximum benefits to the entire network while not exceeding the budget constraints imposed in each of the three years of the planned programme.

10.3 Rule Bases

To effectively operate the system it is necessary to use engineering knowledge to construct a set of rules which select feasible treatments based on existing condition, structure and traffic levels. The rules are stored in an SQL macro which is then referred to in the PMS manual as a rule base. If required, a number of different rule bases can be constructed and then the appropriate one selected at the time of candidate selection.

It is possible to add to or change these rules to include different selection criteria. Once the rule base has been run, it is possible to view, on the screen, the selections for any given road section. The screen form also shows a summary of the road condition and traffic level. At this stage it is possible to manually alter any of the selections or to require a particular treatment to occur in a given year.

The rules incorporated in the rule base developed under the pilot PMS have been kept to a minimum to allow the system as much flexibility as possible in the selection as works programmes.

The rules are therefore used for 3 purposes:

- to select the appropriate overlay/inlay code which can vary if lean concrete is present;
- to rule out treatments that are known from experience to be not practicable;
- to assign the appropriate treatment code corresponding to the reconstruction option.

10.4 Optimised Works Programme

Once the candidate road sections and lists of treatments have been selected, the next step is to run the life cycle costing option which models each road section under each of the treatment options for a total of twenty-four years into the future. The costs and benefits of doing each of the treatments (as compared to no treatment being done) are calculated and future cost streams are discounted back to Net Present Value (NPV) for comparison purposes. The discount rate to be used is user definable. For the pilot study a discount rate of 8% was used.

During optimisation, not only is each treatment considered, the costs and benefits are also calculated if the treatment is deferred for either one or two years. In this way the system is able to determine an optimised three years works program in one pass.

Once the life cycle analysis has been completed, then many optimisation scenarios can be run in a comparatively short time.

10.5 Optimisation Parameters

The system provides a number of options which allow the user to select different objective functions on which to base the optimisation. These options include:

- Optimise based on maximising the pavement condition (in terms of 'Pavement Condition Index' or PCI).
- Optimise based on minimising the vehicle operating costs (VOC), for road users.
- Optimised based on minimising the total cost which includes both vehicle operating costs and future recurrent maintenance costs.

10.6 Points to Consider When Selecting the Optimisation Criteria

The following points need considering in association with optimisation:

- VOC associated with a road are heavily affected by traffic volumes and road roughness. Surface cracking does not affect VOC until such time that the cracking progresses to the point where it manifests itself as roughness. An optimisation based on VOC will tend to favour treatments which reduce road roughness, and the roads with heavy traffic will receive more attention. The optimisation will place less emphasis on treating cracking unless appropriate "must do" standards are applied.
- Recurrent maintenance costs are largely associated with the patching of potholes and reinstatement of small areas of badly cracked pavement. Optimisation based on recurrent maintenance tends to choose treatments which keep the pavement sealed. Because recurrent maintenance does not address roughness, then the rougher roads will not attract attention if they are uncracked and a cheaper resurfacing treatment will be favoured over a reconstruction. Again appropriate maximum roughness standards as a function of road hierarchy or AADT should be applied.
- Because VOC are much larger in magnitude than recurrent maintenance costs, an optimisation based on a combined VOC and recurrent maintenance cost will tend to be

largely influenced by the VOC.

- The Pavement Condition Index is a subjectively based index which weights and combines all of the major pavement distresses into one or more indices, typically on a scale of 0 to 100. Because the importance of a road is a function of how much traffic it carries, the AADT value for the road is usually also made a parameter in the calculation of Condition Index. The Pilot Scheme has incorporated the AUSTROADS Condition Index in the PMS economic analysis. The Index comprises two component indices relating to the "health" or condition of the surfacing (alone) and for the whole pavement.

11. CONCLUSIONS

The Pilot Study demonstrated that low cost, automated data collection systems can be introduced into a medium-sized network such as the 1500 km, prodominantly urban Hong Kong network. Ongoing operation of such systems can be undertaken by in-house staff.

Automated processing and uploading of data to the Pilot PMS database and mapbase has been implemented which greatly reduces the inputs required to operate and manage the PMS.

Pavement performance prediction using the HDM-3 model has been shown to correlate broadly with the historical performance of the Shatin Pilot Study network for which reasonable construction and maintenance records were available. The model algorithms, however, are not perfect and, as has been experienced on other studies, there is generally a relatively high degree of scatter when comparing predicted and actual condition. The current HDM-4 development programme in Kuala Lumpur is expected to improve upon the original algorithims which were developed prior to 1985 - largely before the widespread use and application of PC's and database management systems in Road Management Research.

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