*XXII[nd] WORLD ROAD CONGRESS*
*DURBAN-SOUTH AFRICA – 19-25 OCTOBER 2003*

***C 6 TECHNICAL COMMITTEE ON ROAD MANAGEMENT***

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*Title:* **DESCRIPTION AND IMPLEMENTATION OF A PAVEMENT MANAGEMENT SYSTEM (PMS) DEVELOPED FOR THE STATE OF QATAR**

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# 1 INTRODUCTION

In the last few years the State of Qatar has experienced continuous strong economic growth. Consequently, a huge increase in heavy traffic has been observed in many areas of the country, and particularly in Doha City.

The **Roads Department (RD) of the Ministry of Municipal Affairs and Agriculture,** in cooperation with **TECHNITAL** and **RoDeCo, has** developed and implemented a new **Pavement Management System (PMS**) to improve the effectiveness of the management of maintenance plans for urban roads and the highway network.

The scope of the PMS is to acquire updated methodologies such as the adoption of non-destructive high performance survey systems in the pavement evaluation (PE) phase, and to implement an effective road pavement management system.

The PMS has been implemented as a first entry-level system to be further developed and extended in the future. For this first phase of the PMS a network of around 350 km of roads has been considered: 160 km located in the Doha Industrial Area which has very high volumes of heavy traffic, and 190 km of other main roads in Doha.

The implementation of the PMS involved the following phases:

- Procurement of equipment;
- Field surveys;
- Analysis of survey data;
- Identification of maintenance rehabilitation strategies and priorities for the whole road network subject of the PMS;
- Installation of PMS software on RD facilities;
- Training of RD personnel.

The following equipment has been procured:

- A **IRI2 Class1+ Laser Profilometer** designed to detect every 10 mm of road section, the true longitudinal profile, the IRI *(International Roughness Index)*, with short (from 1 to 3.3 m) and medium (from 3.3 to 13 m) wave length irregularities filtered from the true profile
- A **FWD (Falling Weight Deflectometer)** to determine the pavement bearing capacity
- A **Distress Survey Car** to detect up to 7 types of surface distress at 3 different severity levels;
- *A* **WIM (Weigh In Motion) System** to determine the weight of a single axle, vehicle types and traffic volumes.

The following PMS Software has been developed by RoDeCo (Italy) and tailored for this project:

- RO.M.E.®: Road Moduli Evaluation
- ISO®: Identification of Homogeneous Sections
- RO.MA.®: Road Pavement Management System

The analysis of the raw survey data was performed using the RO.M.E. software *(*to estimate layer moduli and pavement residual life) and ISO software for identification of the road homogeneous sections.

All structural and surface parameters were analysed by RO.MA. software to evaluate the Pavement Quality Index (PQI).

The PMS was able to identify the main shortcomings of the existing pavements, and to identify the most suitable maintenance rehabilitation strategies and priorities over a period of 10 years for the road network analysed by the project.

Different maintenance strategies were considered to:

- assure the requested pavement quality levels;
- select the optimal costs/benefits ratio of any alternative maintenance measure at project and network level; and
- optimise the maintenance budget of RD.

The main characteristics of the PMS that has been procured by TECHNITAL and RoDeCo within this project are its simplicity and modularity, and its capability to be easily operated and further implemented in the future with limited costs.

In the course of the project a number of RD engineers were trained in the use of the equipment and in the use of the PMS software.

The software procured under the project has been installed on two computers (one desktop and one laptop) in a special office dedicated to the PMS within the premises of the RD.

RD staff are now in position to execute additional surveys, investigate additional roads and carry out all analysis and simulation for the definition of the best maintenance options in accordance with their requirements.

The PMS system procured under the project is conceived as a modular system, and can be upgraded and integrated in the future as required.


Fig. 1: General Map of Doha City and Industrial Area site

## 2 PAVEMENT EVALUATION PHASE

All roads subjected to this study (see Map in Fig.1) were tested using the equipment procured under the project, namely:

- FWD;
- IRI2;
- Distress Survey Car;
- WiM.

IRI2 measurements were carried out in the slow lane where more severe distress has been noted due to heavy traffic. Based on the profilometer speed, IRI2 was able to detect, every 5 to 50 mm of pavement section, the true longitudinal pavement profile.

Distress survey measurements were made using a 25-metre interval of road section. The following types of surface distress were detected:

- Alligator cracking;
- Longitudinal and transverse cracking;
- Rutting;
- Settlement;
- Potholes;
- Ravelling;
- Patching.

FWD surveys were carried on the slow lanes using a sample interval of 50-100 m of road section.

Several cores of existing pavements were collected and studied to estimate AC layer thickness.

The traffic used to estimate the pavement residual life was computed on the basis of the results of WIM measurements and on other conventional traffic counts. Axle loads were then converted in terms of 8.1 tons ESAL (Equivalent Standard Axle Loads), and future traffic volumes over 10 years were estimated on the basis of a yearly increment from 2 to 5%.

## 3 EVALUATION OF ROAD MODULI

Road Moduli have been evaluated making use of the RO.M.E. software.

RO.M.E. was designed to evaluate the moduli of pavement layers from FWD deflection bowls data, and to provide estimates of residual pavement life (fatigue) and of the overlay thickness to sustain the expected traffic loads.

The software needs the following basic input:

- Layer thickness;
- Traffic data (ESAL);
- FWD data;
- Temperature conditions measured during the field test.

Flexible pavement is normally modelled as a 3-layer structure with asphalt material combined into one top layer, sub-base as the second layer, and the subgrade as the third layer with an infinite thickness.

The AC layer is designated as layer 1, with thickness H1 and modulus E1. The granular subbase layer is designated as layer 2, with thickness H2 and modulus E2. The modulus of subgrade is then designated as E3.

The critical conditions in the flexible pavement are the horizontal tensile strains at the bottom of the top layer, and the vertical strains at the top of the subbase layer and of the top of the subgrade.

## 3.1 Back calculation of Pavement Layer Moduli

RO.M.E. includes a back calculation program for the processing of deflection data.

RO.M.E. software uses the Boussinesq equations to evaluate the strains, stresses and deflections of an homogeneous isotropic linear elastic semi-infinite space, and the Odemark-Kirk modifications known as the “Method of Equivalent Thickness-MET”.

For standard 3-layer pavement structures, RO.M.E. estimates a starting calibration value of the subgrade modulus using some external FWD deflections, since these deflections, far from the centre of the plate, are approximately a function of the subgrade modulus only. The subgrade modulus is then adjusted during the surveys, taking into account the subgrade non-linear behaviour.

## 3.2 Calculations of Moduli Layers and Pavement Residual Life

Using the radius of curvature of deflection bowls, ROME. is able to estimate the moduli of top layers and of subbase layers.

The subgrade moduli under the centre of the load are adjusted to the same values estimated from calibration deflections. The iteration process is completed when the calculated deflection bowl fits the real deflection bowl (convergence criteria).

RO.M.E. can provide for the calculation of strains and stresses over the different seasonal conditions. The change of AC layer moduli with temperature is taken into account using a logarithmic equation.

Finally, applying Fatigue Law and Miner's Law, the pavement residual life can be estimated.

After the estimate of pavement residual life, RO.M.E. calculates the theoretical overlay to allow the structure to sustain the expected design traffic.

# 4 ROADS HOMOGENEOUS SECTIONS

Normally roads are not maintained in lengths less than 200-300 metres. In consideration of the above, the PMS cannot suggest a change of the maintenance measures every 100-200 meters, i.e. the maintenance measures suggested have to be homogeneous within the appropriate range.

It is therefore necessary to compress the data as much as possible into homogeneous road sections. This is achieved using ISO software.

The object of ISO is to identify, using statistical methods, the road homogeneous sections. The main steps of ISO are the following:

1. Split surface and structural parameters in terms of ranges and assumption of the minimum homogeneous section (HS) length;
2. Compute (HS) for each variable, independently from the others;
   a) assumption of the first $HS^{(1)}$ based on step 2;
   b) computation (Mean and Standard Deviation) of the actual HS(n;
   c) apply *t-test* on actual HS to evaluate if it belongs to HS(n;
   d) if *t-test* failed, a new *t-test* population is made;
   e) if *t-test* is satisfied, the whole population is assigned to $HS^{(n).}$
   $$HS^{(n)} = HS^{(n)} + \Sigma \text{ elements};$$
   f) if *t-test* mentioned in e) is failed and the sum of the elements is greater than the minimum HS length, a new $HS^{(n+1)}$ is defined: $HS^{(n+1)} = \Sigma$ elements. Then the software restarts from point c).
3. Subdivision of each HS in terms of classes.
4. S link section
5. The average value of each parameter is corrected with S.D.
6. The user can accept the final results or change their minimum HS length

# 5. ELABORATION OF RAW DATA

## 5.1 Data from Profilometer IRI2

From the measured profiles, the following parameters were estimated (averaged every 25 m):

- IRI values;
- Short wave irregularities;
- Medium wave irregularities.

To interpret the above parameters, the following reference values were assumed:

- IRI (mm/m) ≤ 2.5 fair;
- 2.5 < IRI < 3.5 inadequate;
- IRI ≥ 3.5 critical;
- Short waves > 2 and <=3 mm/m inadequate;
- Medium waves > 4 and <=6 mm/m inadequate;

The results of the analysis have shown that most of the surveyed roads have inadequate or critical evenness of the pavement longitudinal profile.

## 5.2 Surface Distress Survey

Each type of surface distress, detected every 25 metres of road section, was evaluated at 3 different levels of severity:

- Severity 0 no distress
- Severity 1 low distress
- Severity 2 medium distress
- Severity 3 high distress

The severity level of each type of distress was based on the extent of distress in the inspected area and on the severity of distress detected (i.e. the dimensions of cracks or holes is the parameter used to establish the severity of distress).

The sum of the severity level of each type of distress for 1 km of road section defines the Distress Index.

| **Distress Index (DS/km)** | |
|---|---|
| 0 | No distress |
| 0 - 30 | Low distress |
| 30 - 60 | Medium distress |
| > 60 | High distress |

The most frequent types of surface distress detected were rutting, alligator cracking, longitudinal and transverse cracking.

For many roads in the Industrial Area the following has been also observed:

- the almost complete loss of the bitumen on the pavement surface;
- frequent cases of polished aggregate that can cause skid hazard.

## 5.3 FWD Surveys

For each FWD test, the following were evaluated using RO.ME:

- Moduli values of AC (E1), subbase (E2) and subgrade (E3), at field test conditions;
- Moduli values of AC, subbase and subgrade adjusted at different seasons of the year and for AC layer, also at the reference temperature of 20°C (E1 20°C);
- Pavement Residual Life (fatigue) in years;
- Theoretical reinforcement (mm) needed to sustain the design traffic for 10 years (*assumed Design Pavement Life*).

The following average moduli were observed:

| Average moduli (Mpa) | **AC Layer at 20°C** | **Subbase Layer** | **Subgrade** |
|---|---|---|---|
| Industrial Area | 3,357 | 482 | 419 |
| Other roads | 2,770 | 304 | 225 |

The above values can be considered as adequate. Particularly high moduli values were detected for subbase layer and subgrade.

Referring to RO.M.E. detailed results, most of roads under study showed medium-high moduli values, particularly those constructed recently. However, low moduli were estimated for a not negligible amount of (old) roads.

Most of roads of the Industrial Area are affected by very large traffic volumes and exceptional loads. The actual thickness of the AC pavement layers is only 1/4$^{th}$ or 1/5$^{th}$ of the thickness that would be normally needed for such traffic volumes.

In consideration of the above, despite some of the surveyed roads show low-medium distress or adequate IRI or/and AC layer moduli, the replacement of both subbase and AC layers is the only long-term maintenance strategy that can be suggested.

Fig.2 and Fig. 3 report an example of graphic representation of surface and structural parameters obtained from survey data.

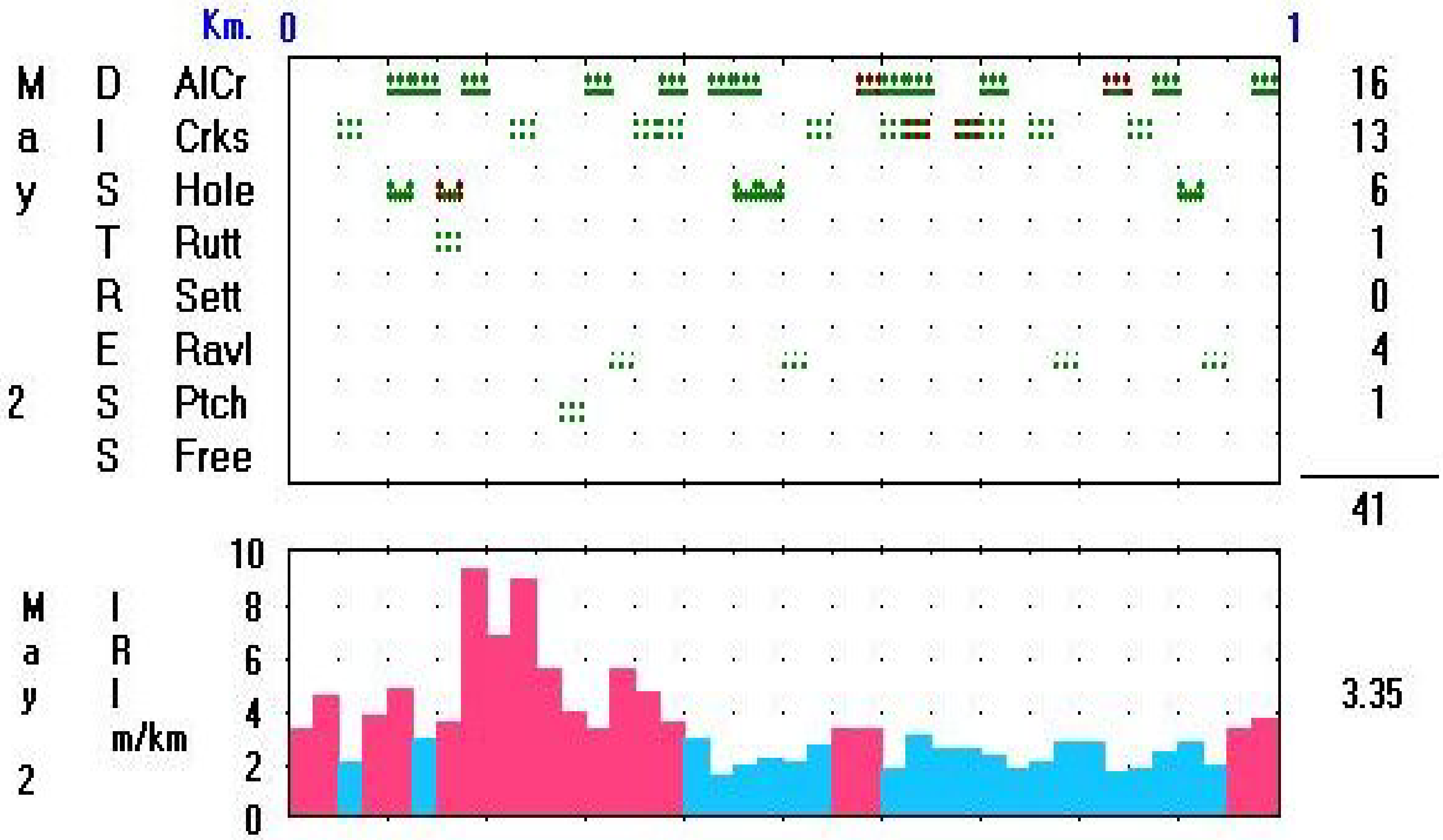


Fig. 2: Example of representation of Distress and IRI for East Industrial Area Road

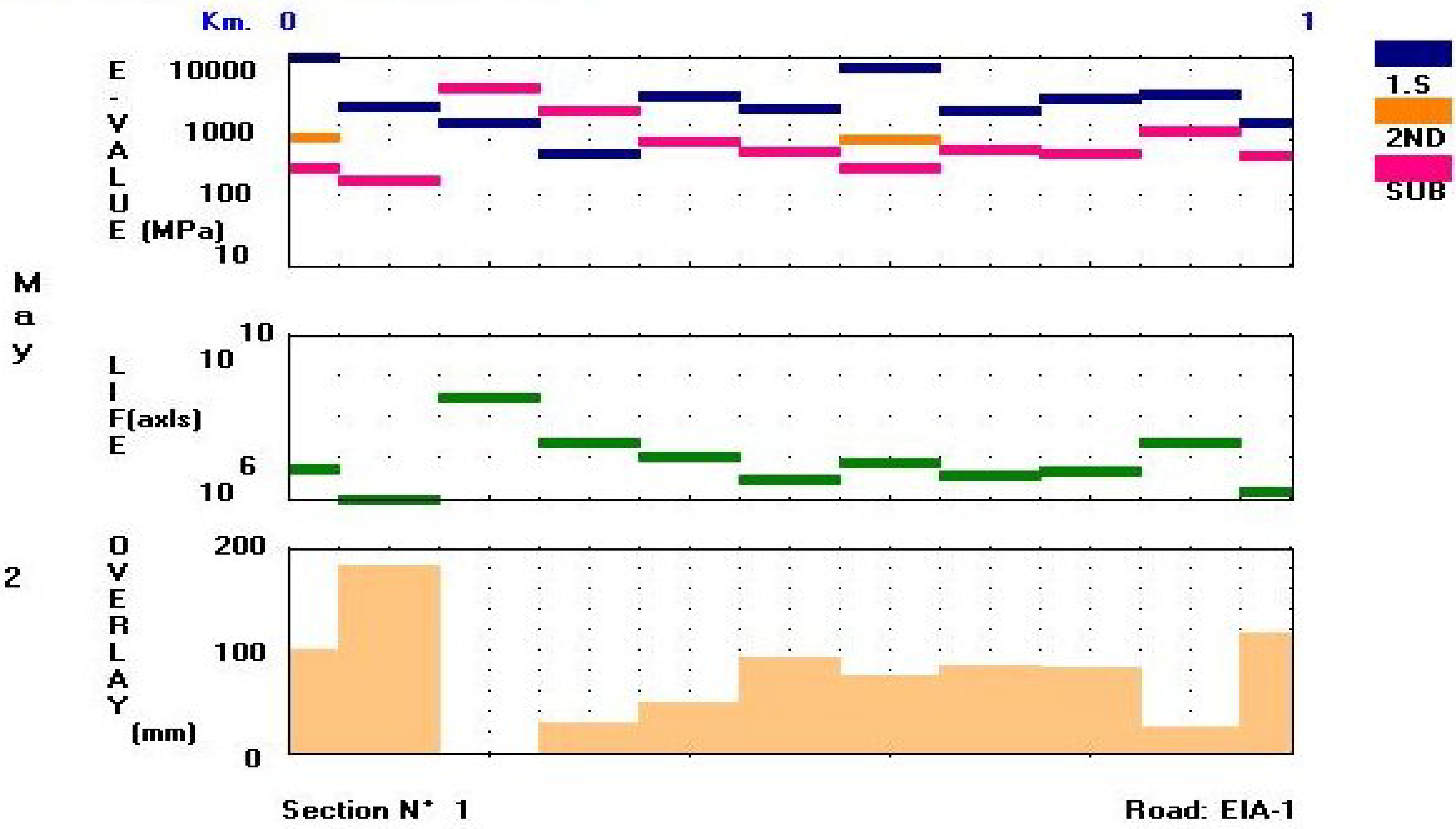


Fig.3: Example of representation of moduli values and pavement residual life

# 6 PAVEMENT MANAGEMENT SYSTEM

The proposed PMS is designed to provide the following information:

- Pavement condition rating (PCR);
- Pavement quality index (PQI);
- Budget costs of maintenance works;
- Comparison between different pavement management strategies.

## 6.1 Pavement Condition Rating and Pavement Quality Index

The pavement quality level is defined by the RO.MA. software using the following surface and structural parameters:

- IRI (mm/m);
- Distress Index/km;
- Pavement Residual Life (fatigue) (years);
- Side Force Coefficient (skid resistance coefficient) (not used in this case).

For each of the above parameters the related Pavement Condition Rating (PCR) is computed and expressed, for each homogeneous road section, by means of an appraisal scale from 0 to 100 (zero is the lowest and 100 is the highest PCR).

The following set of values for $PCR_i$=0 and $PCR_i$=100 are used in the RO.MA.:

| $PCR_i$ | Pavement parameter | PCR=0 | PCR=100 |
|---|---|---|---|
| 1 | IRI | 4 | 0.7 |
| 2 | DISTRESS INDEX/KM | 120 | 0 |
| 3 | SFC (Side Force Coefficient) | 30 | 70 |
| 4 | PAV. FATIG.RES. LIFE (years) | 2 | 15 |

Pavement Quality Index (PQI) is then computed according to the following weighted average value of $PCR_i$:

$$PQI = \Sigma \; PCR_i * w_i \qquad (i=1 \text{ to } 4)$$

where $w_i$ is the weight of $PCR_i$ used to compute PQI.

The PQI values computed by RO.MA. are:

- Initial Value;
- Subsequent Values: every year of the study period of PMS (10 years in our case) and every time after a maintenance work;
- Averaged PQI values over the study period (10 years in our case).

PQI scale is defined as the following:

| PQI (0-100) | Quality Level |
|---|---|
| 0-30 | *Very low* |
| 30-50 | *Low* |
| 50-60 | *Fair* |
| 60-80 | *Good* |
| > 80 | *Very good* |

## 6.2 Maintenance Strategies

The object of the PMS is to select, among different maintenance measures, the maintenance strategy that minimises the sum of maintenance and user costs (optimal maintenance design) and maximises the user benefits, as shown in Fig.4

User costs and user benefits, estimated over the period of 10 years, are based of the following factors:

- The time delay and related costs suffered by user during road maintenance works;
- User costs connected to the actual and future pavement conditions.

Maintenance costs as defined by the PMS are estimated for the whole period of evaluation of the PMS (10 years) on the basis of detailed maintenance costs introduced by the operator.

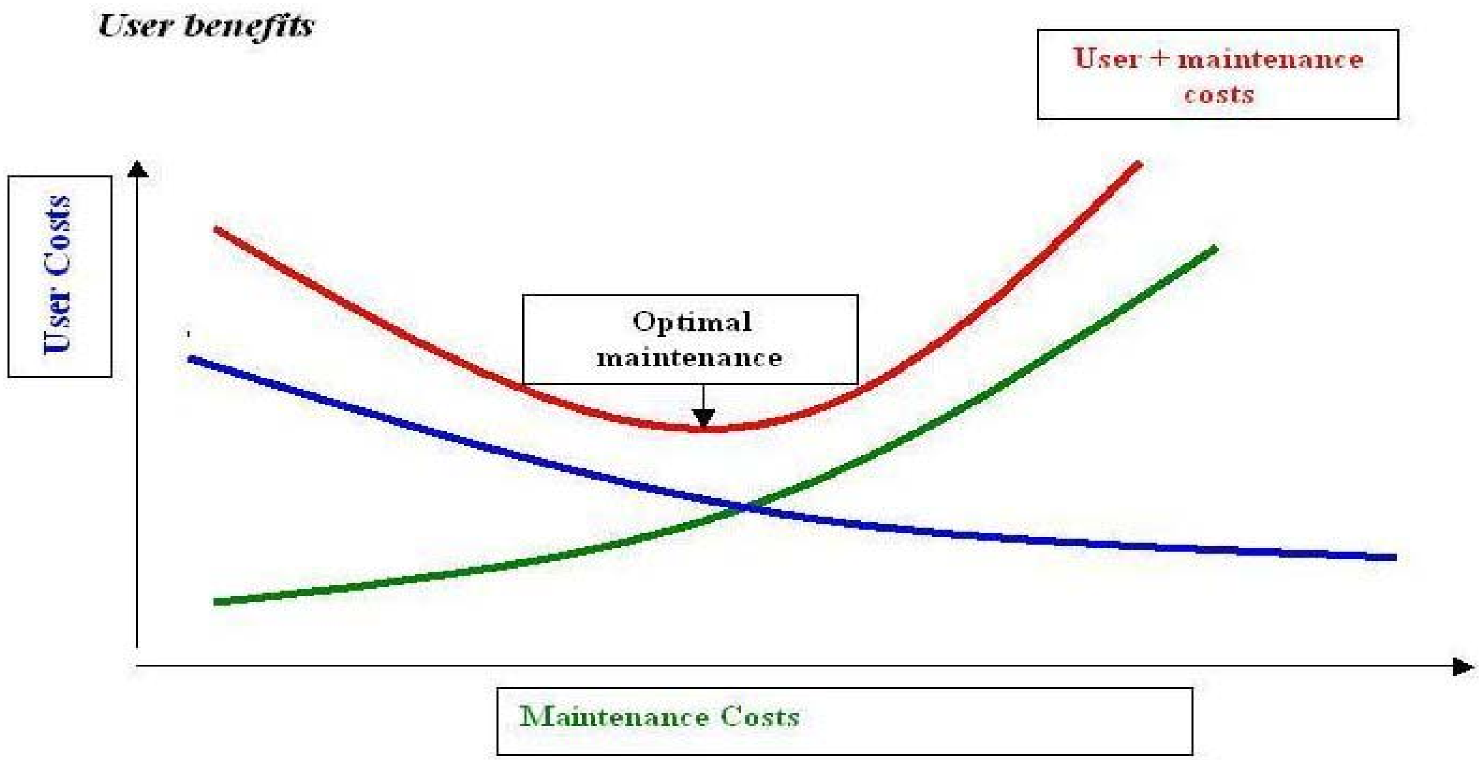


Fig. 4: Optimal maintenance design

Because exceptionally heavy traffic was detected in the Doha Industrial Area and in some of the other main roads included in the study, it was considered that the pavement design standards adopted by the Qatar Highway Design Manual should be optimised and adapted to cater for these particular load conditions.

Two maintenance strategies have therefore been evaluated, one adopting the standards suggested by the QHDM (basic strategy) and one introducing a new pavement material, namely a cement bound subbase course (alternative strategy).

**Basic Strategy**

Pavement materials to be as suggested by the QHDM (Qatar Highway Design Manual). This solution has to be adopted even if the AC-layer thickness recommended by the PMS exceeds the maximum thickness reported in QHDM. Subbase material is water bound granular material.

**Alternative Strategy**

Subbase to be constructed using cement bound granular material when the AC layer thickness recommended by PMS exceeds the maximum value reported in QHDM.

The whole road network was analysed in terms of road homogeneous sections, using RO.MA. to select the best technical and economic maintenance measures over a period of 10 years, according to the above strategies.

## 6.3 Unit Prices of Maintenance Measures

The RO.MA. software allows the operator to enter maintenance works unit prices suitable for the period and the country. For a first calibration of the PMS, the following unit prices were adopted:

| Maintenance items | unit | Costs (QR) |
|---|---|---|
| AC Wearing Course | $m^2$/40mm thickness | 16.00 |
| AC Base Course | $m^2$/10mm thickness | 2.00 |
| Bituminous Prime Coat | $m^2$ | 1.43 |
| Bituminous Tack Coat | $m^2$ | 0.77 |
| Granular Subbase | $m^2$/10mm thickness | 0.49 |
| Granular Subbase (cement bound) | $m^2$/10mm thickness | 0.78 |
| Scarification of AC layer | $m^2$/10mm thickness | 1.32 |
| Subbase layer and subgrade scarification | $m^2$/10mm thickness | 0.16 |

## 6.4 Results of the PMS first evaluation

The RO.MA software has studied and analysed all the roads considered in this first phase of the PMS and, for each homogeneous section, has indicated the recommended maintenance measures.

An example of the maintenance measures indicated in the RO.MA outputs is as follows:

**Reinf. Wear. course mm 40**: Reinforcement with AC-Wearing Course of 40 mm laid directly on top of the existing pavement.

**Scar. mm 400 + Sba mm 150 + Reinf. AC mm 250-T5S2**: Scarification of 400 mm of the existing pavement, laying of 150 mm of subbase layer (granular material) and of 250 mm of AC-layer (Base Course + Wearing Course) as recommended by QHDM pavement type T5S2.

**Scar. mm 300+Cemt-Sba mm 200+Reinf. AC mm 100**: Scarification of 300 mm of the existing pavement, laying of 200 mm of cement bound subbase layer and 100 mm of AC- layer (Base Course + Wearing Course).

The following other information is also shown in RO.MA. outputs:

- Total maintenance costs;
- User costs related to the delay due to maintenance works;
- Financial costs;
- User benefits related to the improvement of PQI;
- Cost/benefits ratio;
- Priorities (1 means maximum priority). For this project 5 levels of priority were used.

An extract of the results of RO.MA. is reported on Tables 1,2,3.

| N | Road File Name | From km | To km | Area sqm | IRI mm/m | IRRmw mm/m | IRRsw mm/m | Y IRI | Axles ESAL/y/direct. | DS/km | Y DS | H1 mm | E1 MPa | H2 mm | E2 MPa | E3 MPa | Resid.Life ESAL | Reinf. mm | Y FWD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ALBINA-1 | 0.000 | 1.650 | 12045 | 3.96 | 3.12 | 0.85 | 2 | 320,000 | 48 | 2 | 70 | 1504 | 250 | 353 | 357 | 3.700E+05 | 68 | 2 |
| 2 | ALBINA-1 | 1.650 | 3.250 | 11680 | 4.02 | 2.42 | 0.92 | 2 | 320,000 | 70 | 2 | 70 | 3919 | 250 | 289 | 287 | 3.700E+05 | 88 | 2 |
| 3 | ALBINB-1 | 0.000 | 0.500 | 3650 | 2.90 | 2.55 | 0.64 | 2 | 920,000 | 22 | 2 | 70 | 4517 | 250 | 346 | 324 | 1.000E+06 | 152 | 2 |
| 4 | ALBINB-1 | 0.500 | 1.725 | 8943 | 3.19 | 2.99 | 0.69 | 2 | 1,970,000 | 47 | 2 | 70 | 2504 | 250 | 745 | 510 | 1.300E+06 | 92 | 2 |
| 5 | ALBINB-1 | 1.725 | 2.350 | 4562 | 2.71 | 1.96 | 0.59 | 2 | 320,000 | 53 | 2 | 70 | 1024 | 250 | 779 | 707 | 3.800E+06 | 34 | 2 |
| 6 | ALIM-1 | 0.000 | 1.000 | 7300 | 4.98 | 3.69 | 1.20 | 2 | 520,000 | 103 | 2 | 70 | 3635 | 250 | 387 | 365 | 5.600E+05 | 101 | 2 |
| 7 | ALIM-1 | 1.000 | 1.750 | 5475 | 5.33 | 3.83 | 1.25 | 2 | 520,000 | 59 | 2 | 70 | 1373 | 250 | 530 | 514 | 8.000E+05 | 70 | 2 |
| 8 | ALIN-1 | 0.000 | 0.150 | 1095 | 5.69 | 4.46 | 1.32 | 2 | 650,000 | 80 | 2 | 70 | 3007 | 250 | 419 | 327 | 6.600E+05 | 107 | 2 |
| 9 | ALINSA-1 | 0.000 | 0.500 | 3650 | 4.21 | 3.30 | 0.89 | 2 | 650,000 | 44 | 2 | 70 | 2790 | 250 | 358 | 358 | 6.600E+05 | 113 | 2 |
| 10 | ALINSA-1 | 0.500 | 1.225 | 5293 | 3.52 | 2.96 | 0.80 | 2 | 650,000 | 36 | 2 | 70 | 791 | 250 | 705 | 705 | 1.100E+06 | 47 | 2 |
| 11 | ALINSA-1 | 1.225 | 1.750 | 3833 | 2.77 | 2.65 | 0.60 | 2 | 650,000 | 23 | 2 | 70 | 2107 | 250 | 505 | 505 | 1.100E+06 | 93 | 2 |
| 12 | ALINSB-1 | 0.000 | 0.750 | 5475 | 1.89 | 1.82 | 0.40 | 2 | 260,000 | 11 | 2 | 70 | 1552 | 250 | 1002 | 882 | 2.400E+06 | 23 | 2 |
| 13 | ALKAR-1 | 0.000 | 3.350 | 24455 | 4.88 | 3.20 | 1.14 | 2 | 320,000 | 87 | 2 | 70 | 5027 | 250 | 388 | 317 | 3.600E+05 | 85 | 2 |
| 14 | ALKARB-1 | 0.000 | 0.575 | 4198 | 3.10 | 2.94 | 0.70 | 2 | 320,000 | 17 | 2 | 70 | 2177 | 250 | 703 | 703 | 1.400E+06 | 24 | 2 |
| 15 | ALKARB-1 | 0.575 | 1.725 | 8395 | 3.89 | 3.64 | 0.85 | 2 | 320,000 | 43 | 2 | 70 | 1448 | 250 | 509 | 499 | 6.100E+05 | 52 | 2 |
| 16 | ALKARB-1 | 1.725 | 2.300 | 4197 | 3.02 | 2.64 | 0.69 | 2 | 320,000 | 42 | 2 | 70 | 323 | 250 | 929 | 929 | 2.300E+06 | 18 | 2 |
| 17 | ALKAS-1 | 0.000 | 2.125 | 6375 | 4.42 | 2.59 | 0.98 | 2 | 3,940,000 | 32 | 2 | 72 | 6846 | 250 | 672 | 461 | 4.300E+06 | 146 | 2 |
| 18 | ALKAS-1 | 2.125 | 4.025 | 5700 | 4.11 | 2.74 | 0.92 | 2 | 3,940,000 | 25 | 2 | 72 | 10197 | 250 | 638 | 468 | 3.900E+06 | 195 | 2 |
| 19 | ALKAS-1 | 4.025 | 5.800 | 5325 | 4.59 | 3.14 | 1.07 | 2 | 3,940,000 | 40 | 2 | 72 | 7297 | 250 | 702 | 415 | 3.900E+06 | 159 | 2 |
| 20 | ALKAS-1 | 5.800 | 6.300 | 1500 | 5.12 | 4.26 | 1.14 | 2 | 3,940,000 | 26 | 2 | 72 | 12352 | 250 | 1173 | 214 | 6.000E+06 | 138 | 2 |
| 21 | ALKAS-1 fast lane | 0.000 | 6.300 | 18900 | | | | | | | | | | | | | | | |
| 22 | ALKAS-4 | 0.000 | 0.925 | 2775 | 3.85 | 2.20 | 0.86 | 2 | 3,940,000 | 38 | 2 | 72 | 4107 | 250 | 793 | 793 | 3.900E+06 | 116 | 2 |
| 23 | ALKAS-4 | 0.925 | 5.825 | 14700 | 4.85 | 3.06 | 1.15 | 2 | 3,940,000 | 43 | 2 | 72 | 7421 | 250 | 575 | 372 | 4.000E+06 | 174 | 2 |
| 24 | ALKAS-4 | 5.825 | 6.350 | 1575 | 4.50 | 2.98 | 1.07 | 2 | 3,940,000 | 44 | 2 | 72 | 12811 | 250 | 594 | 436 | 3.900E+06 | 215 | 2 |
| 25 | ALKAS-4 fast lane | 0.000 | 6.350 | 19050 | | | | | | | | | | | | | | | |

Table 1: Homogeneous road sections

| N | Road File Name | From km | To km | PQI INIT. | Maintenance measures | Maint. code | Maint.Costs QR | Maint. year | Priority | PQI After maint | PQI 10 ys averaged | Tot.Maint.Costs QR*1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ALBINA-1 | 0.000 | 1.650 | 19 | Reinf.wear course mm 40 | 2 | 209,944.4 | 3 | 3 | 57 | 67 | 645.5 |
| 2 | ALBINA-1 | 1.650 | 3.250 | 13 | Reinf.wear course mm 40 | 2 | 203,582.4 | 3 | 3 | 52 | 64 | 625.9 |
| 3 | ALBINB-1 | 0.000 | 0.500 | 32 | Scar.mm 310+Sba mm 100+Reinf.AC mm 250-T5S3 | 15 | 288,149.2 | 2 | 2 | 99 | 84 | 581.0 |
| 4 | ALBINB-1 | 0.500 | 1.725 | 24 | Reinf.wear course mm 40 | 2 | 155,876.5 | 2 | 2 | 58 | 68 | 867.6 |
| 5 | ALBINB-1 | 1.725 | 2.350 | 32 | Reinf.wear course mm 40 | 2 | 79,515.7 | 2 | 2 | 83 | 77 | 442.6 |
| 6 | ALIM-1 | 0.000 | 1.000 | 6 | Reinf.wear course mm 40 | 2 | 127,239.0 | 2 | 2 | 38 | 64 | 672.0 |
| 7 | ALIM-1 | 1.000 | 1.750 | 16 | Reinf.wear course mm 40 | 2 | 95,429.3 | 2 | 2 | 52 | 67 | 504.0 |
| 8 | ALIN-1 | 0.000 | 0.150 | 11 | Reinf.wear course mm 40 | 2 | 19,085.9 | 2 | 2 | 41 | 64 | 100.8 |
| 9 | ALINSA-1 | 0.000 | 0.500 | 20 | Reinf.wear course mm 40 | 2 | 63,619.5 | 2 | 2 | 48 | 65 | 336.0 |
| 10 | ALINSA-1 | 0.500 | 1.225 | 25 | Reinf.wear course mm 40 | 2 | 92,257.0 | 2 | 2 | 69 | 72 | 487.2 |
| 11 | ALINSA-1 | 1.225 | 1.750 | 33 | Reinf.wear course mm 40 | 2 | 66,809.2 | 2 | 2 | 61 | 66 | 352.8 |
| 12 | ALINSB-1 | 0.000 | 0.750 | 66 | Reinf.wear course mm 40 | 2 | 95,429.3 | 5 | 5 | 68 | 47 | 95.4 |
| 13 | ALKAR-1 | 0.000 | 3.350 | 9 | Reinf.wear course mm 40 | 2 | 426,250.7 | 3 | 3 | 44 | 65 | 2,092.7 |
| 14 | ALKARB-1 | 0.000 | 0.575 | 39 | Reinf.wear course mm 40 | 2 | 73,171.1 | 3 | 3 | 88 | 82 | 361.9 |
| 15 | ALKARB-1 | 0.575 | 1.725 | 21 | Reinf.wear course mm 40 | 2 | 146,324.9 | 3 | 3 | 64 | 71 | 723.8 |
| 16 | ALKARB-1 | 1.725 | 2.300 | 44 | Reinf.wear course mm 40 | 2 | 73,153.7 | 3 | 3 | 89 | 82 | 361.8 |
| 17 | ALKAS-1 | 0.000 | 2.125 | 23 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 683,859.0 | 1 | 1 | 99 | 89 | 2,751.8 |
| 18 | ALKAS-1 | 2.125 | 4.025 | 24 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 611,450.4 | 1 | 1 | 99 | 89 | 2,460.4 |
| 19 | ALKAS-1 | 4.025 | 5.800 | 21 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 571,223.4 | 1 | 1 | 99 | 89 | 2,298.5 |
| 20 | ALKAS-1 | 5.800 | 6.300 | 24 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 160,908.0 | 1 | 1 | 99 | 89 | 647.5 |
| 21 | ALKAS-1 fast lane | 0.000 | 6.300 | | Reinf.wear course mm 40 | 2 | 329,427.0 | 1 | 1 | | | |
| 22 | ALKAS-4 | 0.000 | 0.925 | 22 | Reinf.wear course mm 40 | 2 | 48,368.3 | 1 | 1 | 50 | 70 | 658.0 |
| 23 | ALKAS-4 | 0.925 | 5.825 | 20 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 1,576,898.4 | 1 | 1 | 99 | 89 | 6,345.2 |
| 24 | ALKAS-4 | 5.825 | 6.350 | 20 | Scar.mm 510+Sba mm 200+Reinf.AC mm 350 | 23 | 168,953.4 | 1 | 1 | 99 | 89 | 679.8 |
| 25 | ALKAS-4 fast lane | 0.000 | 6.350 | | Reinf.wear course mm 40 | 2 | 332,041.5 | 1 | 1 | | | |
| 26 | ALMANA-1 | 0.000 | 0.650 | 16 | Reinf.wear course mm 40 | 2 | 82,705.4 | 3 | 3 | 55 | 68 | 409.1 |
| 27 | ALMANA-1 | 0.650 | 1.150 | 19 | Reinf.wear course mm 40 | 2 | 63,619.5 | 3 | 3 | 50 | 66 | 314.7 |
| 28 | ALMANA-1 | 1.150 | 1.725 | 17 | Reinf.wear course mm 40 | 2 | 73,171.1 | 3 | 3 | 67 | 72 | 361.9 |
| 29 | ALMANA-1 | 1.725 | 2.450 | 16 | Reinf.wear course mm 40 | 2 | 92,257.0 | 3 | 3 | 49 | 66 | 456.3 |
| 30 | ALMANA-1 | 2.450 | 3.300 | 19 | Reinf.wear course mm 40 | 2 | 108,153.2 | 3 | 3 | 77 | 76 | 535.0 |

Table 2: Maintenance measures

| N | Road File | From | To | Tot.Maint.Costs | Interest Costs | User Costs (delay for maint. works) | Benefits | Costs/Benefits |
|---|---|---|---|---|---|---|---|---|
| | Name | km | km | QR*1000 | QR*1000 | QR*1000 | QR*1000 | Ratio |
| 1 | ALBINA-1 | 0.000 | 1.650 | 645.5 | 0.0 | 71.8 | 27.7 | 25.87 |
| 2 | ALBINA-1 | 1.650 | 3.250 | 625.9 | 0.0 | 70.7 | 27.0 | 25.76 |
| 3 | ALBINB-1 | 0.000 | 0.500 | 581.0 | 0.0 | 259.2 | 83.0 | 10.13 |
| 4 | ALBINB-1 | 0.500 | 1.725 | 867.6 | 0.0 | 236.7 | 46.1 | 23.96 |
| 5 | ALBINB-1 | 1.725 | 2.350 | 442.6 | 0.0 | 169.0 | 54.9 | 11.15 |
| 6 | ALIM-1 | 0.000 | 1.000 | 672.0 | 0.0 | 180.2 | 17.3 | 49.27 |
| 7 | ALIM-1 | 1.000 | 1.750 | 504.0 | 0.0 | 156.1 | 17.8 | 37.18 |
| 8 | ALIN-1 | 0.000 | 0.150 | 100.8 | 0.0 | 74.7 | 3.1 | 56.45 |
| 9 | ALINSA-1 | 0.000 | 0.500 | 336.0 | 0.0 | 136.3 | 15.3 | 30.86 |
| 10 | ALINSA-1 | 0.500 | 1.225 | 487.2 | 0.0 | 164.2 | 29.0 | 22.46 |
| 11 | ALINSA-1 | 1.225 | 1.750 | 352.8 | 0.0 | 139.7 | 17.8 | 27.73 |
| 12 | ALINSB-1 | 0.000 | 0.750 | 95.4 | 0.0 | 18.1 | 0.3 | 409.77 |
| 13 | ALKAR-1 | 0.000 | 3.350 | 2,092.7 | 0.0 | 286.5 | 45.9 | 51.89 |
| 14 | ALKARB-1 | 0.000 | 0.575 | 361.9 | 0.0 | 118.7 | 26.2 | 18.32 |
| 15 | ALKARB-1 | 0.575 | 1.725 | 723.8 | 0.0 | 167.8 | 25.9 | 34.43 |
| 16 | ALKARB-1 | 1.725 | 2.300 | 361.8 | 0.0 | 118.7 | 27.4 | 17.57 |
| 17 | ALKAS-1 | 0.000 | 2.125 | 2,751.8 | 0.0 | 989.7 | 1,763.5 | 2.12 |
| 18 | ALKAS-1 | 2.125 | 4.025 | 2,460.4 | 0.0 | 1,029.4 | 1,576.8 | 2.21 |
| 19 | ALKAS-1 | 4.025 | 5.800 | 2,298.5 | 0.0 | 995.0 | 1,473.1 | 2.24 |
| 20 | ALKAS-1 | 5.800 | 6.300 | 647.5 | 0.0 | 528.1 | 415.0 | 2.83 |
| 21 | ALKAS-1 fast lane | 0.000 | 6.300 | | | | | |
| 22 | ALKAS-4 | 0.000 | 0.925 | 658.0 | 0.0 | 370.5 | 164.5 | 6.25 |
| 23 | ALKAS-4 | 0.925 | 5.825 | 6,345.2 | 0.0 | 1,653.1 | 4,066.5 | 1.97 |
| 24 | ALKAS-4 | 5.825 | 6.350 | 679.8 | 0.0 | 541.1 | 435.7 | 2.80 |
| 25 | ALKAS-4 fast lane | 0.000 | 6.350 | | | | | |
| 26 | ALMANA-1 | 0.000 | 0.650 | 409.1 | 0.0 | 126.2 | 12.2 | 44.00 |
| 27 | ALMANA-1 | 0.650 | 1.150 | 314.7 | 0.0 | 110.7 | 7.9 | 53.97 |
| 28 | ALMANA-1 | 1.150 | 1.725 | 361.9 | 0.0 | 118.7 | 14.0 | 34.39 |
| 29 | ALMANA-1 | 1.725 | 2.450 | 456.3 | 0.0 | 133.3 | 10.7 | 55.16 |
| 30 | ALMANA-1 | 2.450 | 3.300 | 535.0 | 0.0 | 144.3 | 26.4 | 25.74 |
| 31 | ALMANB-1 | 0.000 | 1.075 | 620.7 | 0.0 | 151.7 | 32.2 | 23.98 |

Table 3:Optimization: total maintenances costs, user and benefit and costs/benefits ratios

The following table summarises the total maintenance budget costs estimated for the first 3 years, for both maintenance strategies:

| | Costs (QR million) | | Total costs (QR million) |
|---|---|---|---|
| **Maintenance Strategies** | **Industrial Area** | **Other Roads** | |
| Basic Strategy | 37,000 | 39,000 | 76,000 |
| Alternative Strategy (use of cement bound material for subbase layer) | 30,000 | 26,000 | 56,000 |

The lower cost of the alternative strategy is explained by the fact that with the rigid subbase obtained with cement bound granular material, pavement thicknesses are reduced.

In accordance with the assumptions made, the alternative maintenance strategy yields savings of 20 and 32% of the costs estimated for the basic strategy for the Industrial Area and for the Other Roads in Doha respectively.

The PMS can now be upgraded and updated by the RD operators to better suit RD requirements, and to reflect rapidly changing construction market indicators.

# 7 SUMMARY AND CONCLUSIONS

A PMS was successfully implemented in the State of Qatar, providing the Roads Department with a powerful but easily manageable tool to assist in the analysis of existing road pavements, and in defining future maintenance and rehabilitation programmes.

The PMS has been implemented as a first entry-level system to be further developed and extended in the future. For this first phase of the PMS a network of around 350 km of roads has been evaluated: 160 km located in the Doha Industrial Area, suffering from very high volumes of heavy traffic, and 190 km of other main roads in Doha.

The road network of Doha City subjected to this first phase of the PMS was split into homogeneous sections on the basis of the analysis of the results of the pavement evaluation phase. This was carried out using non-destructive high performance survey systems that had been procured as part of the project.

Detailed results of analysis of the implementation of the PMS for the State of Qatar are presented and discussed.

Surface and structural pavement parameters were evaluated from survey field data on more than 350 km of roads of Doha city, and homogeneous road sections were identified to be analysed by the PMS.

From the analysis of the survey data the following conclusions can be drawn:

- The main roads in the Industrial Area and some of the main roads in Doha are affected by very heavy traffic loads.
- Most of roads in the Industrial Area have uneven longitudinal profiles and medium surface distress.
- Most of the main roads in Doha have adequate longitudinal profiles and low surface distress.
- Subgrades of existing roads are usually very good with very good bearing capacity and moduli.
- With the exception of some newly constructed roads, the thickness of the existing AC pavements is very low and not adequate to sustain the high volumes of heavy traffic that has recently developed. Therefore most roads show very short pavement residual life.

The Qatar Highway Design Manual (QHDM) recommends different pavement structures for different volumes of traffic (number of ESALs), the most severe condition being for 50 million ESALs

Since in most of the roads included in this study higher loads were detected (up to 80 million ESALs), two different maintenance strategies have been studied:

- Conventional Strategy: Follow the recommendations of the QHDM but increasing the thickness of water bound subbase and AC layers to cope with the new loading conditions;
- Alternative Strategy: Substitute the water bound sub-base with a cement bound sub-base, reducing the thickness of AC layers accordingly.

The results of the PMS show that the use of cement bound material as the subbase can produce significant savings in the long term.

All equipment and software procured under the project has been handed over to the RD, and a special PMS Office has been established.

A number of technicians from the RD have been trained in the use and maintenance of the equipment and in the use of the PMS software. They are now able to further develop the PMS by updating the input data and by extending the analysis to a greater number of roads in Qatar.

Further development of the system is now being considered.