

**PRESENT PAVEMENT MAINTENANCE PRACTICE: A CASE STUDY FOR INDIAN  
CONDITIONS USING HDM-4**

by

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**ABSTRACT**

Highway agencies around the world have changed their attention from design and construction of new pavements to maintenance of already existing ones. Pavements must be selected for maintenance when they are still effective, before the need is apparent to the casual observers in order to avoid the rapid deterioration after a certain limit. The objectives of this study are to highlight the present pavement maintenance practice around the world with a particular attention to the maintenance trend in India and use Highway Development and Management (HDM-4) for the maintenance of a test section in Mumbai Metropolitan Region (MMR). This region has a humid, warm, and wet climate prevalent in the west coast of India. The test section has seven layers and is a six lane divided highway. Condition responsive maintenance has been carried out. Only cracking and roughness have been found out to be critical out of eight deterioration models in HDM-4 for the analysis period of 15 years. The condition of the pavement has become equivalent to new one after maintenance.

## INTRODUCTION

The focus of roadway activity in the early to mid 20<sup>th</sup> Century was on the construction of new pavements. In the latter part of the 20<sup>th</sup> Century continuing into the 21<sup>st</sup> Century, this focus has shifted to the maintenance and rehabilitation (M & R) of pavement infrastructures. Maintenance includes actions that retard or correct the deterioration of infrastructure facilities. These actions include crack sealing as well as resurfacing etc (1). Pavements must be selected for maintenance when they are still effective. In most cases, the proper time to apply maintenance is before the need is apparent to the casual observer. This is because once pavements start to deteriorate; they deteriorate rapidly beyond the point where maintenance is effective. With the increasing use and awareness of pavement management systems and the growing emphasis on asset management of pavement infrastructure, it is important to strengthen the maintenance components of these systems and particularly the preventive maintenance component (2). The most recent definition of preventive maintenance by AASHTO Standing Committee on Highway states that preventive maintenance is “a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional conditions of the system (without increasing structural capacity)” (3). Agencies have found that applying a series of low-cost preventive treatments can effectively extend the service lives of their pavements.

Preventive maintenance techniques should be scheduled to maximize safety, maintainability, and the cost-effectiveness of pavement preservation efforts. However, it is difficult for most users to establish the level of distress at which a particular maintenance treatment should be applied. Selection of the most appropriate maintenance treatment for a given distress type should consider several factors including type and extent of distress, climate, existing pavement type, cost of treatment, traffic type and volume, expected life, availability of qualified contractors, availability of quality materials, time of year, pavement noise, facility downtime (user delays), surface friction, anticipated level of service, and other project-specific condition.

Several types of treatments are used as preventive maintenance of flexible pavements. All of them, if placed in a timely fashion, will extend the life of the pavement. The most common are crack treatment, patch repairs, fog seals, chip seals, thin-cold mix seals, thin hot mix overlays, Hot In-Place (HIP) Recycling, texturization etc. Most of these are widely used by highway agencies and they are treated separately in this study.

### **Crack Treatment**

It is an effective method to seal the surface of the pavement to treat any cracks in a timely and effective manner. It includes crack sealing and crack filling. Crack Sealing consists of an application of a sealing material directly into the cracks of the pavement surface. It is normally used to prevent water and incompressible materials from entering into the pavement (4).

### **Patch Repairs**

Patch repairs are typically used to address localized pavement distress and prevent moisture infiltration. If the distress is a result of a structural deficiency, it may be necessary to remove and

replace some or all of the granular base/subbase and subgrade to mitigate the distress from reoccurring.

### **Fog Seals/ Rejuvenators/Restorative**

The fog seals treatment consists of an application of material, usually a diluted asphalt emulsion, sprayed directly on the surface of the existing pavement. It is normally used to enrich the surface of the pavement, to address raveling of chip seals or open-graded mixes and to reduce the oxidation of the pavement and seal minor surface cracks. The life of the treatment depends on the condition of the treated pavement, but is not normally greater than 3 to 4 years.

### **Chip Seals**

Treatment by chip seals includes a spray application of binder immediately covered by a layer of one-sized or graded aggregate. Chip seals provide several benefits including waterproofing the surface, sealing small cracks, and improving the surface friction. They typically provide good performance on highways (<5000 ADT) for 3 to 7 years.

### **Thin Cold-Mix Seals**

Treatments by thin cold-mix seals consist of mixtures of emulsions, aggregates, Portland cement, and chemicals that are mixed in traveling plant and placed directly on the pavement. Slurry seals, microsurfacing, and cape seals are the broad subclasses of these treatments.

#### *Slurry Seal*

It is produced by mixing the aggregate and binder in a mobile mixing machine. The binder is usually asphalt emulsion, and the aggregate varies in size and type, depending on the application. Portland cement, hydrated lime, or aluminum sulfate is often added to aid in setting the slurry (5). It is used to correct superficial distresses such as raveling and coarse aggregate loss, seal slight cracks, and improve pavement friction. It is also used as a preventive maintenance treatment to seal pavement surfaces from intrusion of water and slow surface oxidation and raveling. The nominal life of slurry seal is 3 to 6 years on roads with light to moderate traffic.

#### *Micro-surfacing*

It is similar to slurry seal technology. It cures faster and may be applied in a thicker layer than slurry seal. It is an unheated mixture of polymer-modified asphalt emulsion, high-quality frictional aggregate, mineral filler, water, and other additives, mixed and spread over the pavement surface as a slurry. It is used to correct superficial distresses such as slight block cracking, raveling and segregation, flushing, and loss of pavement friction. Because micro-surfacing contains high-quality crushed aggregate, it is also used to fill-in ruts and surface deformation to the depth of up to 40 mm. When properly designed and constructed, and used on sound pavements, it performs well for 5 to 7 years.

### *Cape seal*

A chip seal followed by a slurry seal or microsurfacing, also fall into this category. This treatment is used to improve ride quality and reduce rock loss and noise associated with chip seals.

### **Thin Hot-Mix Overlays**

Treatments by thin hot-mix overlays are similar to conventional overlays, but the thickness is less than 37.5 mm. They are used to correct surface irregularities which cannot be addressed with the other maintenance treatments. They include dense-, open-, and gap-graded mixes and often contain modified binders such as polymers or crumb rubber. Dense- and gap-graded mixes seal the pavement surface, improve ride quality, and skid resistance. Open-graded mixes improve ride quality, surface friction, and enhance the ability of water to drain off the pavement. The performance of thin dense-graded overlays has been mixed, with lives of 2 to 10 years.

### **Hot In-Place (HIP) Recycling**

The recycled asphalt concrete is typically mixed with a recycling agent, and can be further supplemented with pre-heated aggregate. The resulting recycled layer can be used as a wearing surface or can be protected by a slurry seal, micro-surfacing, surface treatment or a hot-mix overlay. HIR is suitable for structurally sound pavements with surface defects such as raveling and segregation, cracking, and rutting that affect mainly the top pavement layer.

### **Texturization**

Texturization techniques include diamond grinding, micro-milling, precision milling, and other techniques that remove unevenness from the pavement surface or improve its texture and leave an abraded surface that is used as a driving surface. Texturization techniques can smooth out stepping at transverse cracks, wheel track rutting, and improve pavement friction.

## **PAVEMENT MAINTENANCE SCENARIO IN INDIA**

Due to the poor condition of roads, it is estimated that an annual loss of approximately over Rs. 6000 crores (\$1.33 Billion) is resulted in Vehicle Operating Cost (VOC) alone. The timely maintenance is missing due to many reasons, which otherwise could have minimized the losses to the exchequer. A rough estimate suggests that more than 50% of the primary road network is in bad shape needing immediate attention. It should be borne in mind that to achieve the desired economic growth, the foremost requirement is to ensure a good and an effective road network (6)

### **Types of Maintenance**

The maintenance activities have been divided into ordinary repairs (OR), periodical renewal (PR), special repairs (SR), and emergency repairs (ER) for the purpose of organization of maintenance budgeting in India. It is pertinent to note that organizational structure of maintenance activities related to OR has worked well in the past and it may be recommended that the same may be continued after updating to include all the new activities required to keep

pace with time and development till a scientific maintenance management system (MMS) is placed in position. In general, there are two types of maintenance; namely, routine maintenance (to cover OR) and major maintenance (to cover PR and rehabilitation)

#### *Routine maintenance (preventive)*

It is necessary to keep the road at minimum usable condition and covers crack sealing, pothole repair, reshaping, and shoulder make-up.

#### *Major Maintenance (Corrective)*

It is necessary to keep the pavement structurally and functionally sound to serve the intended purpose. This category of maintenance involves good investment in terms of material and manpower costs. The main strategies are surface treatment/renewal and overlaying/strengthening. Surface treatment is generally provided to meet the functional requirement of the carriageway for the riding comfort and safety of the user. Strengthening/riding quality improvement is provided to meet both functional and structural requirement of the road.

### **Optimization and prioritization of Maintenance Strategies**

When planning investments in pavement sector, it is necessary to evaluate all the costs associated with the proposed project. These include construction costs, M & R costs, road user costs (RUC), and all other external or exogenous costs or benefits that can directly attribute to the pavement project. These three costs constitute what is commonly referred to as the total transport cost or the life cycle cost (LCC). Flow chart for prioritization of maintenance is given in Figure 1.

### **Intervention Criteria**

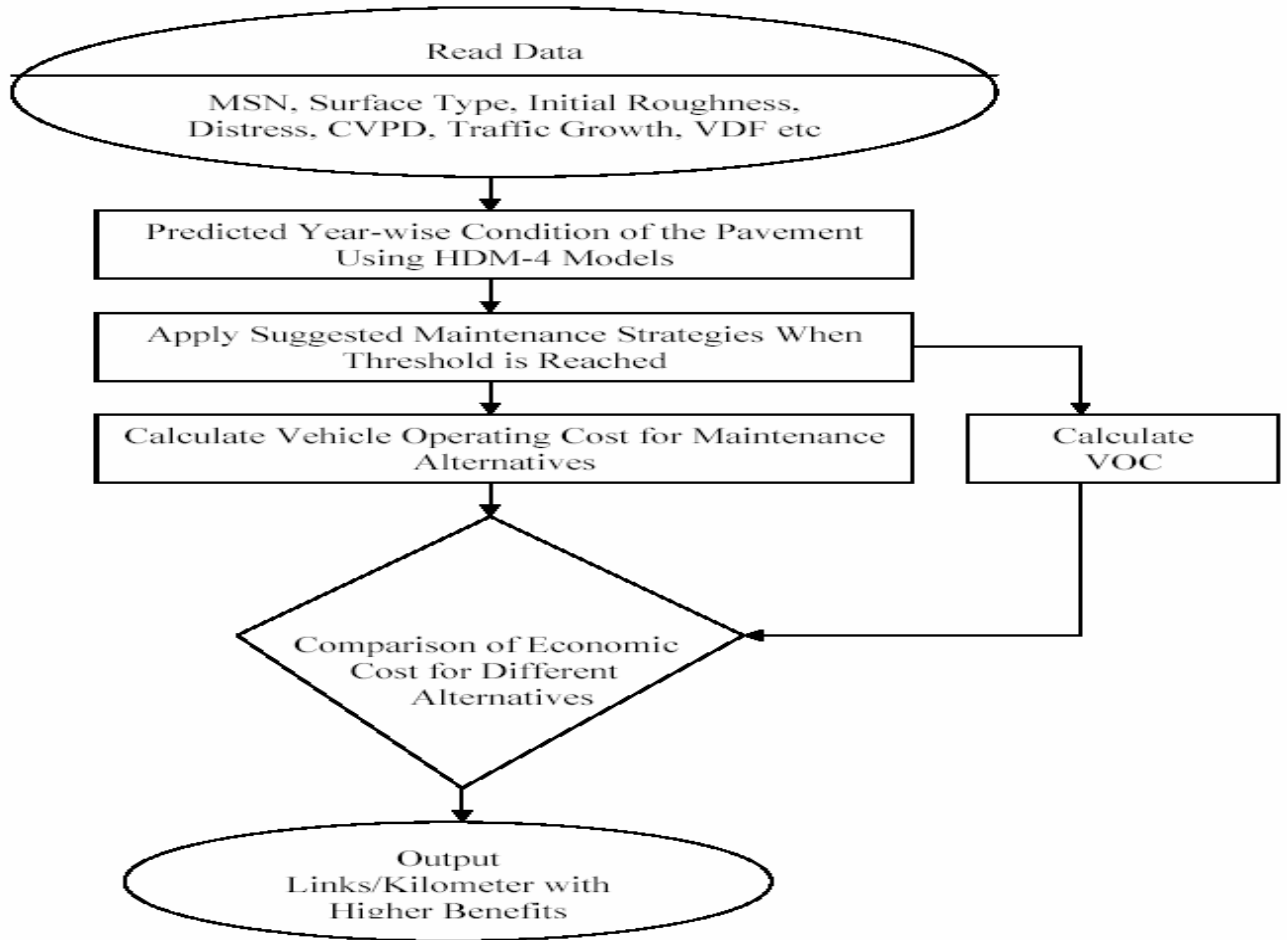
There are two types of maintenance inputs in practice, viz.; time bound (scheduled) maintenance, and pavement condition responsive maintenance.

#### *Time Bound (Scheduled) Maintenance*

The present policy of maintenance of pavements is based on providing routine maintenance whenever required and renewal/strengthening after every five years without analyzing its economic implications. The main drawback of this policy is that some pavements, though good, are resurfaced as per time specific renewal cycle, while some other pavements deteriorate quickly, even though needing renewal but not covered by the maintenance cycle.

#### *Pavement Condition Responsive Maintenance*

It is very useful for judicious disbursement of maintenance funds. Most recently developed tools/software packages such as HDM-4, though have provision for time bound maintenance intervention criteria, but prefer for condition responsive maintenance intervention.



**FIGURE 1** Flow chart for prioritization of maintenance (6).

For Indian conditions, it is suggested that condition responsive maintenance intervention criteria may be adopted. To formulate condition responsive maintenance criteria, some basic minimum desired serviceability level need to be fixed. The suggested criteria are based on the widely accepted performance indicators such as roughness, cracks, rutting, skid, potholes, etc. Based on these performance indicators, the suggested intervention criteria for primary, secondary and urban roads are given in (6). The intervention criteria for primary roads are given in Table 1.

**TABLE 1** Intervention Criteria for Primary Roads

Sr. No.	Serviceability Indicator	Level 1 (Good)	Level 2 (Average)	Level 3 (Acceptable)
1	Roughness by Bump Integrator (max. permissible in mm/km)	2000	3000	4000
2	Potholes per km (max. numbers)	Nil	2-3	4-8
3	Cracking and patching area (max. permissible in percent)	5	10	10-15
4	Rutting (mm)	5	5-10	10-20
5	Skid resistance (skid number minimum desirable)	50	40	35

## **PAVEMENT MAINTENANCE IN HDM-4**

In HDM-4, maintenance standards are used to represent the targets or levels of condition and response that are aimed to be achieved. Maintenance standards define the maintenance works required to maintain the road network at the target level. Each maintenance standard consists of a set of one or more works items. Each works item is defined in terms of the road surface class to which it applies, an intervention level, an operation type, and the resultant effect on the pavement (7). Routine and periodic maintenance are the two kinds of maintenance treated in HDM-4. All maintenances can be carried out based on scheduled and condition-responsive except inlays, in which it is always defined in terms of condition-responsive works.

### **Routine maintenance**

The routine maintenance works on bituminous roads, whose effects on pavement performance are modelled, comprises patching, crack sealing, edge-repair, and drainage works (8). Drainage maintenance is an important works activity that prevents accelerated pavement deterioration. Edge-repair is not critical for multi-lane highways. Other routine maintenance works include vegetation control, and repairs to road appurtenances. Their effects on pavement performance are not modeled endogenously, and therefore, only their costs are considered in an analysis. Patching and cracking are critical ones and discussed below.

#### *Patching*

It is used to repair potholing, wide structural cracking, and raveling. The user may specify patching to repair the individual surface distresses, or a combination of all the three distresses. If more than one kind of patching works is applicable in any analysis year, then patching works specified to treat the three distresses will override those specified to treat the individual distresses. It is assumed that potholing, wide structural cracking, and ravelling have priorities in that order, and no patching is performed to fix these individual distress-areas until those of higher priorities are completely repaired

#### *Crack Sealing*

It treats transverse thermal cracking and wide structural cracking. However, it is assumed that crack sealing is not applied to treat wide structural cracking if the area of wide structural cracking exceeds 20 %. When crack sealing is performed, it is assumed that the treatment of transverse thermal cracking takes priority over that of wide structural cracking, and no crack sealing is performed to fix wide structural cracking until transverse thermal cracking is completely repaired.

### **Periodic Maintenance**

The periodic maintenance works on bituminous roads comprises of preventive treatment, resealing, overlay, mill and replace, inlays, and reconstruction.

### *Preventive Treatment*

It includes fog sealing and rejuvenation. When preventive treatment is performed, any surface distress and preventive treatment age are reset to zero. It has effects of delaying the initiation of cracking and raveling, but the pavement structure and strength remains unaltered.

### *Resealing Works*

Resealing without shape correction can repair surface distress but cause little change to roughness or structural strength of the pavement. However, resealing with shape correction can achieve some reduction in roughness through the filling of depressions and repair of damaged areas. Resealing works resets surface distresses, surfacing age, and preventive treatment ages to zero, and thereafter the pavement condition is considered to be new. Single surface dressing without shape correction, double surface dressing without shape correction, cape seal without shape correction, and slurry seal operations have no effect on rutting.

### *Overlay*

It is specified using new surfacing thickness, layer strength coefficient, surface material, and construction defect indicator for bituminous surfacing. Overlay work resets surface distresses to zero, and thereafter the pavement condition is considered to be new.

### *Mill and Replace*

It involves the removal of all or part of the existing bituminous surfacing and replacing it with a new bituminous surfacing. It is usually performed to correct defects that have occurred mainly due to poor construction quality and the bituminous material being too rich or brittle, or where the road surface levels need to comply with some requirements related to drainage facilities, bridge underpasses, and other such structures. Information on new surfacing thickness, layer strength coefficient, surface material, and depth of milling are required to specify mill and replace works.

### *Inlays*

It is a special works activity considered under rehabilitation that is normally applied to treat rutting along wheel paths. To define an inlay works, the percentage of total carriageway area to be repaired and the construction quality factors should be specified

### *Reconstruction*

It refers to all works that require the re-specification of the surfacing and road base types. It may be specified either as a maintenance standard or as an improvement standard if the works involve the minor widening of the carriageway.

## OBJECTIVE

The main objectives of the study are: to review overall present maintenance practice, maintenance trend in India, maintenance strategies in HDM-4 and finally, to see the effect of maintenance on pavement deterioration using HDM-4.

## METHODOLOGY

Effect of maintenance on pavement deterioration has been carried out using HDM-4. There are eight deterioration models in HDM-4; four of them have been calibrated for Indian Conditions.

### HDM-4

The International Study of Highway Development and Management (ISOHDM) has been carried out to extend the scope of the HDM-III model and provide a harmonised systems approach to road management, with adaptable and user-friendly software tools. This has produced HDM-4. The scope of HDM-4 has been broadened considerably beyond traditional project appraisals to provide a powerful system for the analysis of road management and investment alternatives.

HDM-4 is a powerful system for the analysis of road management alternatives. With different application tools, HDM-4 can be applied in project analysis, program analysis, strategy analysis, research and policy studies. The project analysis tool has been used for carrying out maintenance in this study.

#### *Input Parameters in HDM-4*

HDM-4 application has been designed to work with a wide range of data type and quality. HDM-4 supplies default data that are user definable. Users can choose the prevailing values in the environment under study. The flexibility in data requirement not only reduces the data entry work but also permits all potential users with a variety of data to integrate HDM-4 into road management systems. Some of the main input data required are divided into four groups and discussed below.

**Road Network Data:** is used by all of HDM-4 applications. Data is structured into two main groups:

- ❖ Road network data including specification and labeling, network information, speed-flow patterns, climate zones, and intersection types.
- ❖ Network element data including description and identification, road class, traffic geometry, pavement condition, history, and miscellaneous.

**Vehicle Fleet Data:** contains the characteristics of the vehicle fleet that will be operating on the road network being analyzed. A vehicle fleet comprises a mix of several vehicle types that use a road network. It uses a set of representative vehicles for which a number of physical and performance characteristics are defined. The vehicles can be grouped using three levels of classification:

- ❖ Categories: includes motorized and non-motorized vehicles.
- ❖ Classes: Motorized vehicles are divided into several classes including motorcycles, cars, utilities, trucks, buses; non-motorized vehicles are divided into 4 classes including animal carts, bicycles, pedestrians, and rickshaw.
- ❖ Types: A vehicle type represents a set of vehicles within a class, which has different characteristics. There are 16 motorized vehicle types and 4 non-motorized vehicle types provided as standard default representative vehicles within HDM-4.

**Traffic Data:** are not input in one folder. They are incorporated in several modules. Traffic includes the following:

- ❖ Traffic categories including normal, diverted, and generated,
- ❖ Traffic composition including volume and growth rates,
- ❖ Axle loading,
- ❖ Road capacity and speed flow relationships, and
- ❖ Traffic- flow pattern.

**Road Works Standards:** refer to the targets or levels of conditions that a road agency wants to achieve. Usually, road agencies set up different standards to meet specific objective in practice.

#### *Output Parameters of HDM-4*

HDM-4 supports flexible options for data and analysis results. Users can make printed or electronic reports. They can also export data and results to standard database for other users. The file formats are not limited to text, word document, MS excel, and lotus 1-2-3 spread sheet. In addition, users have direct access to the result database files (DBF). HDM-4 can produce the following three types of output, which can assist road managers to make informed decisions:

- ❖ Strategic road maintenance and development plans, produced from long-term predictions of road network performance,
- ❖ Economic efficiency indicators, produced from analysis of individual road projects, and
- ❖ Multi-year work programmes, produced from prioritization of several road projects.

## **CASE STUDY**

The case study for this study is the test section in Mumbai Metropolitan Region (MMR) in India, which was built by City and Industrial Development Corporation (CIDCO) of Maharashtra Ltd. in 1990. It is located at the southern most tip of MMR and was planned over a total area of 2592Ha. comprising of 64 sectors. The complete area of the test section is divided into four categories; namely, residential, port based industrial area, office complex and ware housing complex. The area is covered by two major deposits of marine and fluvial deposits connecting steep hill slopes. The underlying soil consists of a thick layer of soft marine clay deposits which is very soft and highly compressible. CIDCO has implemented ground improvement scheme before going a head with developmental activities in the area (9).

MMR has a humid, warm and wet climate prevalent in the west coast of India. Annual rainfalls of 1800-2800mm, maximum wind velocity of 150kmph, mean humidity of 85% from June to September and 55% from November to March, mean daily maximum temperature of

33°C in May and June and 30.6°C in January, mean daily minimum temperature of 26.2°C in May and June and 16.3°C in January.

### Alignment and Geometry

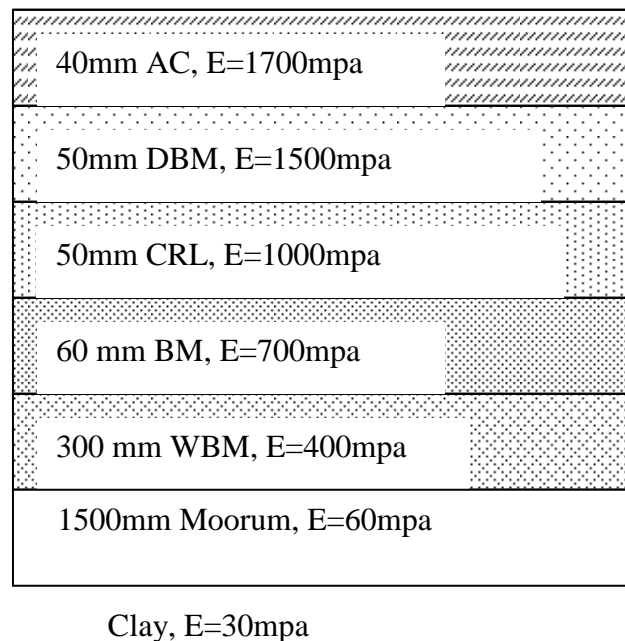
Terrain Classification of the area is made by the general scope of the area across the road alignment. The road network of the test section is in the filled up areas and hence it is plain terrain. However, the percent cross slope for plain and rolling terrain is given as in Table 2.

**TABLE 2** Terrain Classification of Test Section

Sr.No.	Terrain Classification	Percent Cross Slope of the Area
1	Plain	0-10
2	Rolling	10-15

Rolling design speed (80km/hr and 65km/hr in plain and rolling terrain respectively) should normally be the guiding criteria for correlating the various design features. Minimum design speed (65km/hr in plain terrain and 50km/hr in rolling terrain) can be adopted in sections where site conditions or economics do not permit a design based on the rolling design speed.

The major roads in the area are having a six lane divided carriageway. However, there are different cross-sections provided for the design requirements and site restrictions. Test section with six lanes has been considered for this study. The cross slope of the carriageway has been proposed as 2.5%. The cross-section of the test section is shown in Figure 2.



**Figure 2** Cross-section of test section for the analysis.

### Traffic Data

Traffic data has been collected and provided by CIDCO. Traffic data at Punjab Conware has been used and the same is shown in Table 3. Assumptions made are: standard axle load is 100 kN, annual increase of load repetitions is 5%, direction and lane distribution factors are 0.5 and 0.6 respectively, and construction time is 1 year.

**TABLE 3** Traffic Data for the Study

<b>Date</b>			<b>2/3- Wheeler</b>	<b>Car/Jeep/ Tempo</b>	<b>Truck 2- axle</b>	<b>Trailor 3-axle</b>	<b>Trailor 4-axle</b>	<b>Trailor 5-axle</b>	<b>Trail 6-axl</b>	<b>Total (4+5+6+7+8)</b>
<b>From</b>	<b>To</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>
30-09-03	01-10-03	Up	821	925	1672	1154	1575	157	5	<b>4563</b>
		Down	969	914	1814	1227	1601	168	10	<b>4820</b>
01-10-03	02-10-03	Up	779	695	1127	831	1388	58	2	<b>3406</b>
		Down	1299	1048	1856	931	1613	81	3	<b>4484</b>
02-10-03	03-10-03	Up	345	235	584	810	1332	68	0	<b>2794</b>
		Down	367	240	671	811	1453	67	0	<b>3002</b>
03-10-03	04-10-03	Up	596	679	1460	1036	1570	127	0	<b>4193</b>
		Down	1017	890	1664	918	1588	173	0	<b>4343</b>
04-10-03	05-10-03	Up	413	302	723	916	1470	155	0	<b>3264</b>
		Down	439	375	747	873	1304	106	0	<b>3030</b>
05-10-03	06-10-03	Up	494	355	701	824	1185	65	8	<b>2783</b>
		Down	355	296	720	768	1056	56	18	<b>2618</b>
06-10-03	07-10-03	Up	670	608	1055	828	561	164	50	<b>2658</b>
		Down	688	552	976	864	816	149	58	<b>2863</b>
		<b>Total</b>	<b>9252</b>	<b>8114</b>	<b>15770</b>	<b>12791</b>	<b>18512</b>	<b>1594</b>	<b>154</b>	<b>48821</b>

## RESULTS AND DISCUSSIONS

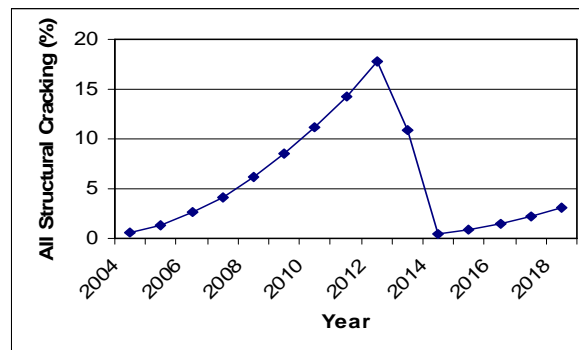
Eight deterioration models in HDM-4 with their respective maximum limits as per HDM-4 and for Indian Conditions are indicated in Table 4. Maximum limit for Indian Conditions have been used for maintenance intervention, but limits as per HMD-4 have been used for which there are no standards in India. Pavement condition responsive maintenance has been carried out using HDM-4 for analysis period of 15 years. Only cracking and roughness have been found to be critical and have needed maintenance. The effect of maintenance on both is discussed below separately.

**TABLE 4** Allowable Limits for Pavement Deterioration as per HDM-4 and Indian Conditions

Sr.No.	Deterioration Model	Maximum Limit	
		HDM-4	Indian Conditions
1	Cracking (%)	15	20
2	Raveling (%)	20	30
3	Potholing (No/km)	5	8
4	Edge-break (m <sup>2</sup> /km)	100	-
5	Rutting (mm)	15	20
6	Roughness IRI (m/km)	6	-
7	Texture Depth (mm)	0.3	-
8	Skid Resistance SCRIM at 50km/hr	0.3	35SN

### Effect of Maintenance on Cracking

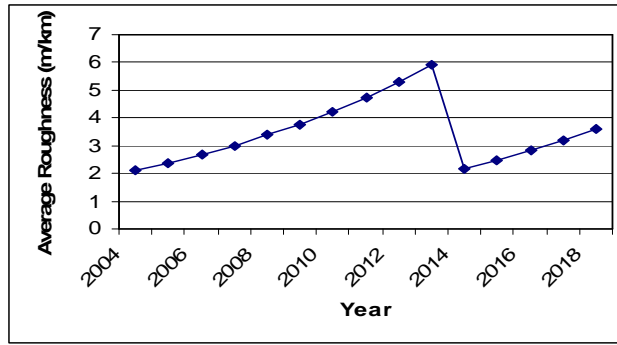
Condition responsive maintenance has been carried out after 9 years as can be seen from Figure 3. After maintenance intervention, the condition of the pavement has been improved and became equivalent to new pavement. Pavement deterioration is not linear. The slope becomes steeper if intervention is not done. Using condition responsive maintenance based on pre-determined criteria is very important.



**FIGURE 3** Effect of maintenance on cracking.

### Effect of Maintenance on Roughness

Condition responsive maintenance has been done at the end of 10 years as indicated in Figure 4. The rate of deterioration is slower than cracking and as a result, the slope does not increase significantly. Due to the maintenance intervention, roughness of the pavement has become the same as the original pavement.



**FIGURE 4** Effect of maintenance on roughness.

### CONCLUSIONS

Based on this study, the following conclusions have been made:

- The attention of highway agencies has been changed from construction of new pavements to maintenance and rehabilitation of already existing ones.
- There are some differences in maintenance classification and definitions among highway agencies.
- Pavement maintenance should be carried out before its deterioration is apparent.
- Condition responsive maintenance is better than time bound (scheduled) maintenance.
- Out of eight deterioration models in HDM-4, only cracking and roughness have been found to be critical during the analysis period of 15 years.
- Rate of deterioration pavement in cracking is higher than that of roughness.
- The condition of the pavement has become equivalent to new pavement after condition responsive maintenance using HDM-4.
- HDM-4 is user friendly software and it can be used for maintenance of pavements.

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