Application of Pavement Evaluation for Road Maintenance and Rehabilitation

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Abstract Timely maintenance and rehabilitation are required in order to maintain the road pavement in good condition. Proper evaluation of pavement is required prior to deciding the maintenance and rehabilitation strategies for the road. This paper discussed the process of pavement evaluation and the application of its results for use in the maintenance and rehabilitation of roads. The pavement life-cycle is first explained. The process of pavement evaluation is then explained and data collection for four major performance indicators, that is, visible distress, structural adequacy, surface friction and roughness are discussed, including the various equipment used for the evaluation. Finally, an explanation is made on how the results are analysed and decisions to determine the maintenance and rehabilitation strategies for the road network. It can be concluded that the systematic evaluation of pavement will lead to the optimization of resources used for pavement maintenance and rehabilitation.

Keywords Pavement evaluation · Pavement distress · Surface condition survey · Structural evaluation · Road maintenance · Road rehabilitation

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1 Introduction

As Malaysia relies heavily on road-based transportation, it is very important to maintain its road network. In a road network, pavements represent the largest capital investment; it is vital that the pavements are maintained to ensure that their condition is in a desirable state. Maintaining and operating pavements on a large road network typically involves complex decisions about how and when to resurface or apply other treatments to keep the road network performing and operating costs at a reasonable level. A road network needs to be regularly evaluated and maintained to meet the needs of the road user as a safe and efficient means of travel. If maintenance is neglected, the road condition will further deteriorate, causing not only the loss of life, injuries and damage due to accidents but also an increase in the vehicle operating costs.

2 Pavement Life-Cycle

A road pavement must fulfil two basic functions, that is structural and functional requirements (JKR Malaysia 1994; Asphalt Institute 2000). In terms of structural performance, the pavement must be of sufficient thickness and be composed of materials of sufficient quality, to be able to withstand the various loads that are applied to it by heavy vehicles. In terms of functional performance, the pavement must have a good riding quality to ensure comfortable travel for the road user and a surface having adequate drainage, skid resistance, reflectivity and line markings to ensure safe travel.

A pavement starts to deteriorate at an increasing rate once a road is opened to traffic. Initially, few distresses are present, and the pavement stays in relatively good condition. Over time as more traffic passes through it and as it ages due to the environment, more distresses develop, making it easier for subsequent damage to occur.

The timing of maintenance and rehabilitation actions can greatly influence their effectiveness and cost as well as overall pavement life. Once a pavement needs treatment, the sooner maintenance or rehabilitation activity is undertaken, the more cost-effective it will be.

Figure 1 demonstrates this concept. For the first 75% of pavement life, the pavement condition drops by about 40%. However, it only takes another 17% of pavement life for the pavement condition to drop another 40%. Additionally, in order to restore pavement condition to a predetermined level, it will cost 4–5 times as much if the pavement is allowed to deteriorate for even 2–3 years beyond the optimum rehabilitation point (Federal Highway Administration 1998).

This increase in cost is because of the following:

(1) The pavement condition must be improved by a greater amount (e.g., “very poor “ to “very good” versus “fair” to “very good”).

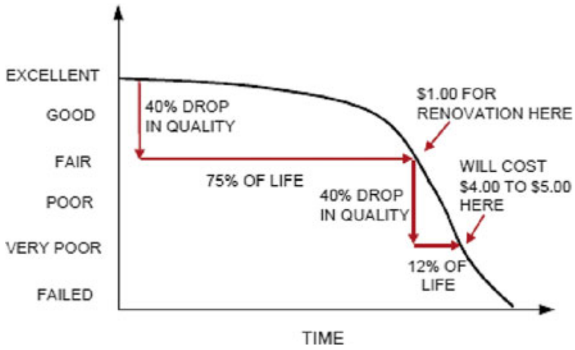


Fig. 1 Typical pavement condition life-cycle (Federal Highway Administration 1998)

(2) It costs more money per unit of pavement condition increase (e.g., it costs more to go from "very poor" to "poor" than it does from "fair" to "good").

Maintenance and rehabilitation can slow or reverse this deterioration.

3 Pavement Performance and Evaluation

Pavement performance can be defined as the measurable adequacy of a pavement's structural and functional service over a specified design period. A pavement provides functional service by giving road users a safe and comfortable ride for a specified design speed. Functional service comprised factors such as acceptable ride quality, adequate surface friction for safety, appropriate geometry for safety, the appearance of geometric adequacy and appearance of the condition.

A pavement provides structural service by supporting traffic loadings and withstanding environmental influences. The type and thickness of materials used to construct the pavement layers dictate how the pavement performs structurally.

Structural and functional adequacy is closely related but is not entirely interdependent. Structural deterioration of pavement is manifested to some extent in diminished functional adequacy, in the form of increased roughness, noise, and even hazard to vehicles and their occupants. However, some types of structural deterioration can occur and progress to fairly advanced stages without being noticeable to users. It is also possible for a pavement's functional adequacy to decrease without any significant change in structural adequacy (e.g., loss of skid resistance).

The evaluation of pavement condition is carried out at the network and project level (Transport Research Laboratory 1999). Pavement evaluation is carried out at the network level to determine the status of an entire pavement network as part of a pavement management system. The overall goal of the network-level pavement evaluation is to predict the current condition level of all the pavements within the road system. This will facilitate the prediction of the overall road network pavement performance and allow future budget forecasting (Ismail et al. 2013). This can be then used to help prioritize and select projects for pavement rehabilitation. Data obtained

Table 1 Test intervals for network and project level

Pavement test	Network level	Project level
Surface condition survey	100 m (Road scanner)	50 m (Manual survey)
Falling weight deflectometer	500 m	100 m
Coring and DCP	2000 m	250 m

from the network-level pavement evaluation is not sufficient for developing a proper rehabilitation alternative for a specific project. At the project level, a more detailed pavement evaluation is required to provide the information required for properly selecting a rehabilitation alternative and designing the project. The overall goal of the project level data collection is to obtain sufficient information to analyse and design rehabilitation options for specific pavement sections within the system (Austroads, 2018). This will facilitate the selection of the most desirable rehabilitation option, preparation of cost estimates, plans and specifications for the rehabilitation of the pavement section. Table 1 shows the intervals for the pavement evaluation tests carried out at both network and project levels. Table 2 shows the type of tests carried out for both network and project-level evaluation.

Pavement evaluation at the project level is a process in which systematic assessment of pavement condition is carried out to determine its modes of distress/deterioration before the appropriate treatment/rehabilitation design is proposed. The components of pavement evaluation include data collection, data analysis and rehabilitation design. Data collection involved surface condition survey, structural assessment and laboratory evaluation of pavement materials (Bennet et al. 2007). Data collected are then analysed and primary modes of distress for the pavement evaluated are identified. A further comprehensive analysis of data is carried out to identify the most suitable and evaluate the most economical rehabilitation technique before the implementation of the selected rehabilitation works for the pavement section. The process of project-level pavement evaluation and rehabilitation is shown in Fig. 2.

4 Performance Indicator

There are characteristics of pavements that can be measured quantitatively and can be correlated to the users' subjective assessments of performance. The four major performance indicators are visible distress, structural adequacy, surface friction and roughness (Garber and Hoel 2009). The following sections describe how these indicators are related to performance and how they can be measured.

Table 2 Type of tests for network and project level

Test	Purpose	Equipment and method
Falling Weight Deflectometer (FWD)	To determine pavement structural condition	Applying a load of 700 kPa and measuring the deflection bowl
Coring	To determine asphalt layer thickness and crack depth	Extract core samples using a rotary coring machine
Dynamic cone penetromete	To determine the thickness of the pavement layer	Releasing a standard weight onto the anvil and measures the rod penetration into the ground and then plot graph Penetration versus cumulative blows
Ground-penetrating radar	To determine the thickness of the pavement layer, change in construction and defects within the pavement	Sending electro-magnetic pulses down and registering the reflection time and dielectric discontinuities
Trial pit	To closely inspect pavement condition and to collect samples	Cutting and removing materials layer by layer
Road scanner	To capture pavement condition data, road geometry, survey mapping information and roadside assets	Using multi-laser profiler together with GPS and digital imaging system
Manual surface condition survey	To determine the category and extent of crack, surface defects, drainage condition, etc	Walking along the road and recording at 50 m block interval
Walking profiler	To determine road profiles and also the roughness index, IRI	Using measuring beam and sensor to measure distance and profile
Traffic count and axle load survey	To determine the damaging effect of commercial vehicles	Weigh vehicles using portable weigh-in-motion systems
Surface friction tester	To determine surface friction or skid resistance of the road surface	Measuring the friction force on a test wheel operated at a constant load and longitudinal reference slip
Grip tester	To measure surface friction or skid resistance	Directly measure the horizontal (drag) and vertical (load) force Friction = Load/Drag
Mini texture meter	To determine the macrotexture of the road surface	Using pulsing laser light projected onto the road surface and measuring surface displacement

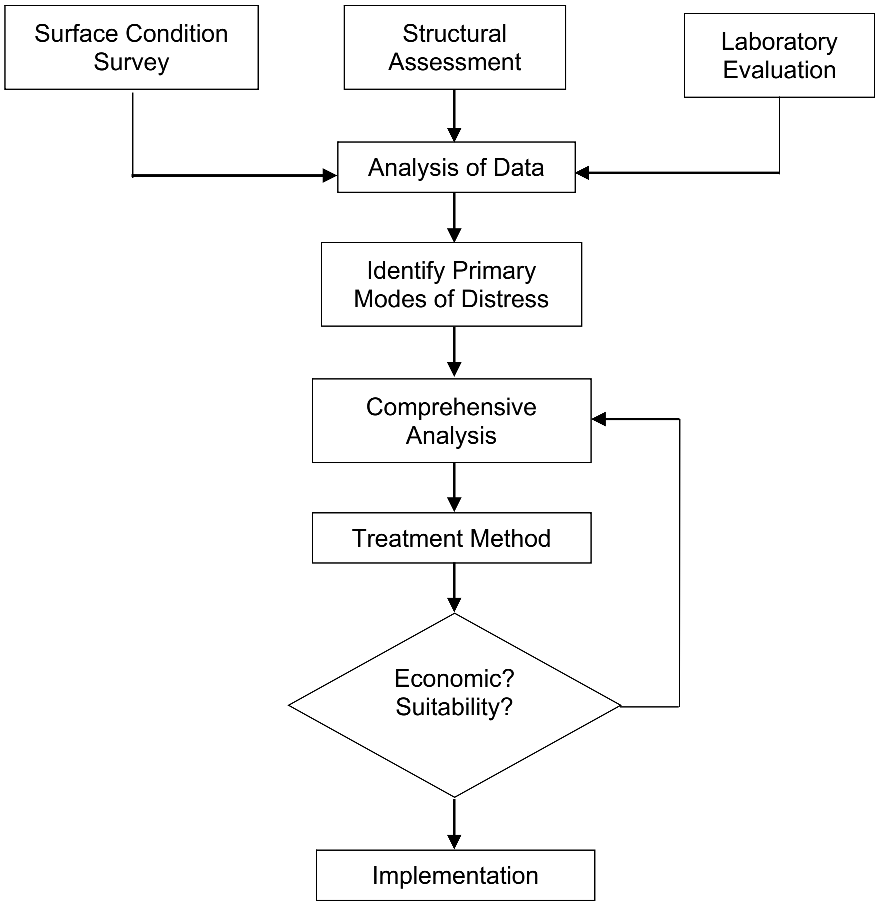


Fig. 2 Flowchart of pavement evaluation and rehabilitation process

4.1 Visible Distress

Surface condition survey is carried out to determine visible distress of the pavement surface. Distress occurs in pavements as a result of complex interactions of design, construction, materials, traffic, environment and maintenance procedures. Visible distress is quantified with respect to type, severity and quantity. Distress types, severities and quantities are determined during a distress survey of the pavement. The information can be manually observed (Fig. 3) or using high-speed survey equipment such as the road scanner (Fig. 4).

Pavement distress refers to the condition of a pavement surface in terms of its general surface appearance. Distress manifestations can be categorized according to the mechanism of distress, fractured, distorted or disintegrated (Brown et al. 2009). Fracture is the state of a pavement that is breaking. Example of fractures includes

Fig. 3 Manual measurement of rutting using a straight edge

Fig. 4 High-speed road scanner

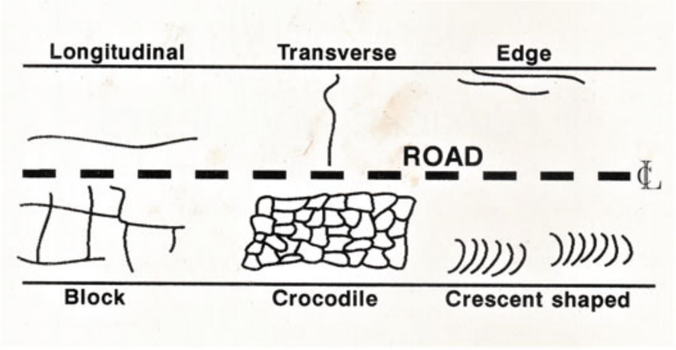


Fig. 5 Types of cracks (JKR Malaysia 1992)

cracks and spalling. Distortion is a permanent change in the shape of the pavement or pavement component. It can be manifested by ruts and corrugation of the surface. Disintegration is the decomposition or abrading of a pavement into its constitutive elements. Disintegration of the pavement includes ravelling, stripping and surface polishing.

Most road authorities, however, use the guidelines produced by FHWA for visual assessment of their pavements (Miller and Bellinger 2003). For example, Malaysia used a modified version of the guidelines to assess the surface condition of its flexible pavements (JKR Malaysia 1992). The distresses are categorized according to the following types: (a) cracks; (b) surface deformations; (c) surface defects; (d) patching defects; (e) potholes; and (f) edge defects. These distresses are shown in Figs. 5, 6, 7, 8 and 9.

4.2 Structural Adequacy

Structural performance is related to the ability of the pavement to sustain traffic loading. Deflection testing is usually performed to predict future structural performance. Nondestructive testing (NDT) devices, such as the falling weight deflectometer (FWD), are used to evaluate the structural capacity of the pavement (Khin Onn 2001). The FWD works by applying a load to the pavement that is similar in magnitude and duration to the load applied by a moving wheel of a vehicle (Fig. 10). The response of the pavement to that load is then measured by transducers placed at varying distances from that load, and the results can be analysed for both individual layers and the overall pavement structure (Lay 2009).

For the structural evaluation of pavements, the thickness of each pavement layer must be determined before the analysis can be carried out. For network evaluation, the ground-penetrating radar together with the dynamic cone penetrometer (Fig. 11)

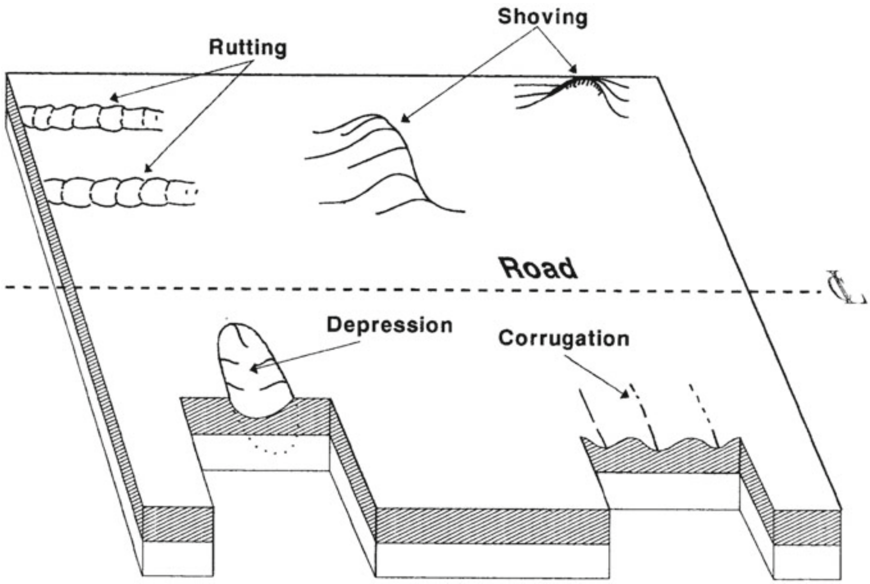
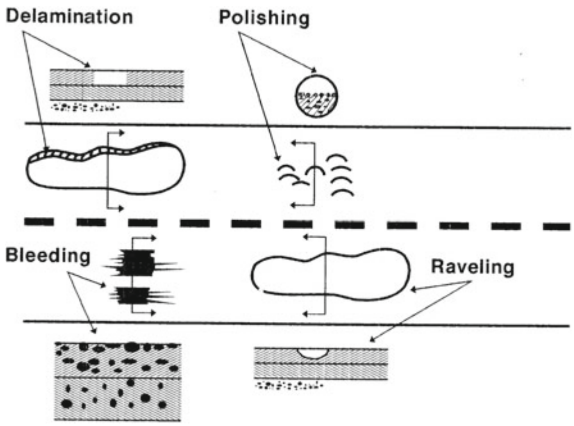


Fig. 6 Types of surface deformation (JKR Malaysia 1992)

Fig. 7 Types of surface defects (JKR Malaysia 1992)



is used to determine the thickness of the pavement layers and the CBR value of the subgrade.

Traffic count and axle load study is carried out to determine the damaging effect of commercial vehicles on the existing pavement using portable weigh-in-motion systems such as the weighing pads (Transport Research Laboratory 2004). Data from the tests are then used to determine the existing pavement residual life and the required overlay thickness based on the projected future traffic.

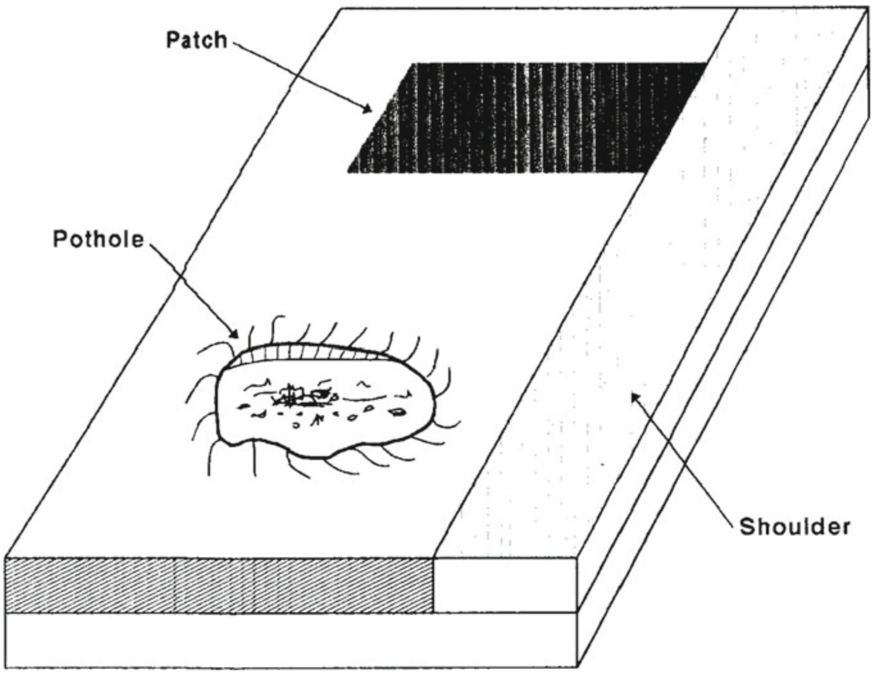


Fig. 8 Potholes and patching defects (JKR Malaysia 1992)

4.3 Surface Friction

Surface friction refers to the surface pavement characteristic that prevents the skidding of vehicles' tyres. The microtexture, macrotexture and transverse slope of the pavement influence a pavement's surface friction (Transport Research Laboratory 2004). Microtexture refers to the roughness of the aggregate particle surfaces. Microtexture contributes to the friction by adhesion with vehicles' tyres, contributing largely to skidding resistance at low speed (Shahid 2018). Macrotexture refers to the overall texture of the pavement, providing the surface texture needed to provide channels for water trapped between the road surface and the tyre to drain quickly, reinstating the contact between the tyres and the road surface (Shahid 2018). Adequate macrotexture is critical for vehicles' operations under wet condition. Transverse slope contributes to surface friction by removing water from the pavement surface. In Malaysia, a 2.5% transverse slope is provided for surface drainage. Aquaplaning is likely to occur if water is not removed immediately from the pavement's surface, particularly during rain.

Figure 12 shows the mini texture meter which is used to determine the macrotexture of the road surface. Using pulsing laser light projected onto the road surface and measuring surface displacement, the macrotexture of the road can be determined. Figure 13 shows the surface friction tester which is used to determine surface friction

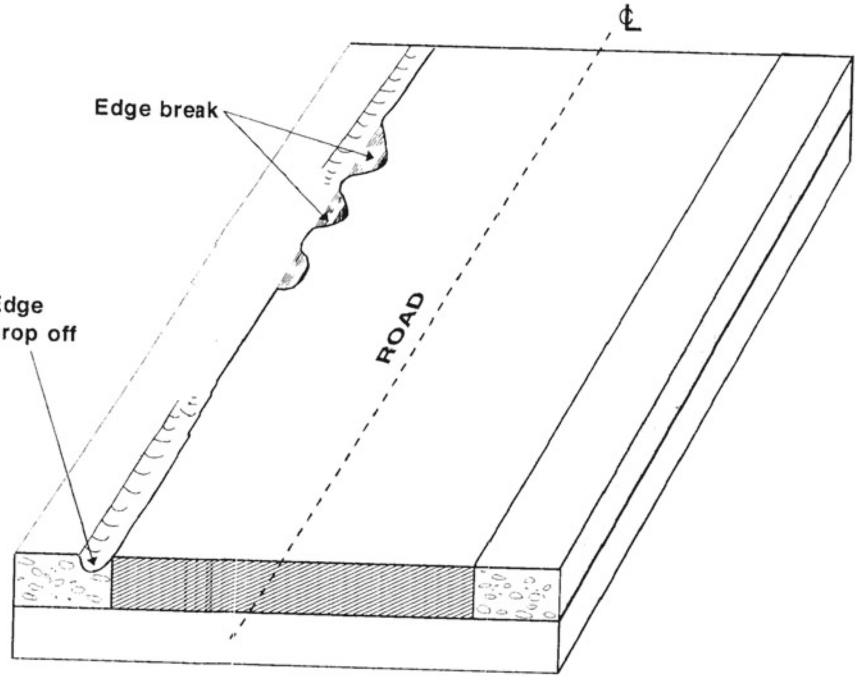


Fig. 9 Types of edge defects (JKR Malaysia 1992)

Fig. 10 Falling weight deflectometer

Fig. 11 Dynamic cone penetrometer

or skid resistance of the road surface. The skid resistance is determined by measuring the friction force on a test wheel operated at a constant load and longitudinal reference slip.

4.4 Roughness/Serviceability

Pavement roughness refers to the irregularities in the pavement surface that affect the smoothness of a ride. A road user assesses the condition of a pavement largely in terms of ride quality. Data collected by the high-speed road scanner with the attached multi-laser profiler (Fig. 14) is used to determine the ride quality in terms of international roughness index (IRI) (Shahid 2018). Figure 15 shows the walking profiler used to determine project-level road profile and also the international roughness index (IRI).

Fig.12 Mini texture meter

Fig. 13 Surface friction tester

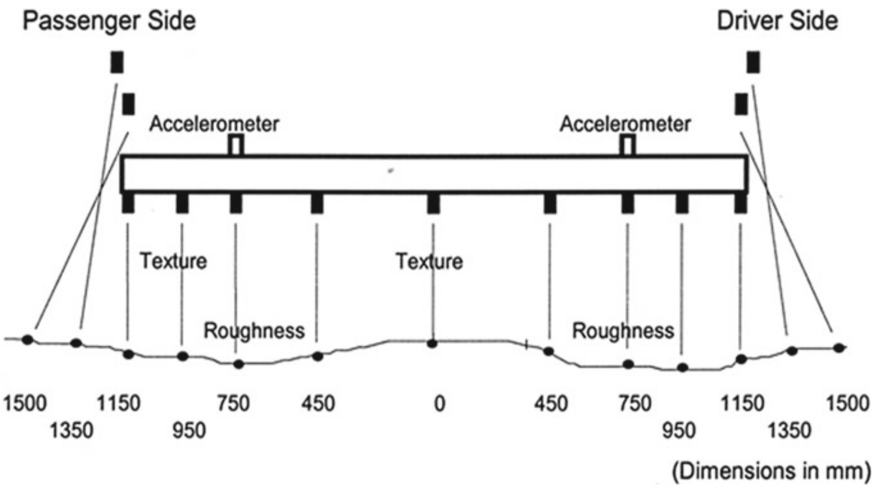


Fig. 14 Multi-laser profiler sensor configuration

Fig. 15 Walking profiler

5 Data Analysis and Determination of the Suitable Type of Rehabilitation

Generally, the road pavements will show some forms of distress and appropriate treatment was required to improve the functional and structural integrity of the roads. Various rehabilitation methods to accommodate the existing pavement condition are considered as shown in Table 3.

The collected data are analysed using suitable rehabilitation software to determine the condition of the existing road pavements. The pavements can be categorized as good, fair, bad or very bad based on the crack index (CI) and mean rut depth (RD) as summarized in Table 3.

The pavements are classified as good if there was no crack (C0) or RD less than 5 mm. The pavements are considered to be in fair condition if they exhibited single crack (C1) or multiple cracks but not interconnected (C2) or RD was between 5 and 15 mm. The pavements are categorized as bad when they exhibit interconnected cracks (C3) or crocodile cracks (C4) or when the RD is between 16 and 25 mm. Very bad condition is reached when severe crocodile cracks with spalling or block cracks (C5) are observed or when RD exceeds 25 mm. The overall pavement condition is determined by combining and weighting both CI and RD accordingly.

For structural evaluation of the pavement, the collected data is used in the analysis as shown in Fig. 16. First, the FWD data and the DCP results are analysed to determine the elastic moduli of the pavement layers and subgrade. The required overlay thickness is then determined, taking into account the elastic moduli, expected traffic loads, residual life and the recommended sectioning (Institute 1996). Together with the surface condition survey results, the proposed maintenance or rehabilitation method is then determined. The maintenance and rehabilitation strategies are discussed in the following section.

Table 3 Treatment matrix

Crack index		Rut depth (mm)			
		Good	Fair	Bad	Very bad
		<5	*5–15*	*16–25*	*>25*
Good	C0	T0	T1	T2	T3
Fair	C1 and C2	T1	T2	T3	T4
Bad	C3 and C4	T2	T3	T4	T5
Very bad	C5	T3	T4	T5	T5

Notes
Crack index: C0: No crack; C1: Single crack; C2: Multiple cracks, not connected; C3: Interconnected cracks; C4: Crocodile cracks; C5: Crocodile cracks and spalling or block cracks
Treatment types: T0: Do nothing; T1: Thin overlay; T2: Hot in-place recycling; T3: Structural overlay; T4: Cold in-place recycling; T5: Reconstruct

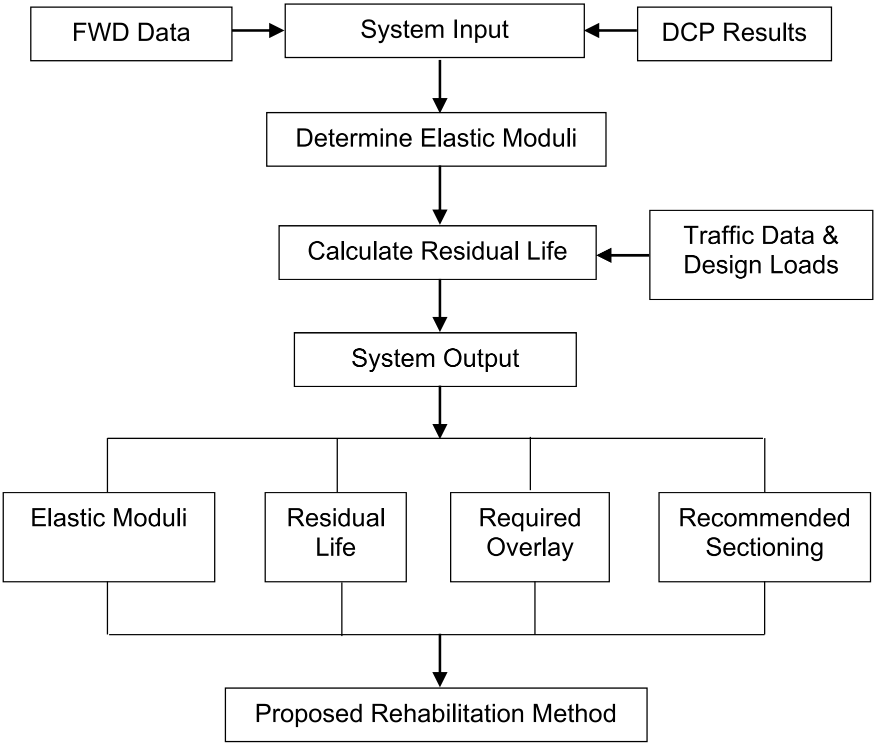


Fig. 16 Structural evaluation analysis

6 Maintenance and Rehabilitation Strategies

Maintenance and rehabilitation are the two principal treatments used to extend pavement life. In general, maintenance can slow the rate of deterioration by correcting small pavement defects before they worsen and contribute to further defects. Beyond a certain point, however, defects become too large for correction by maintenance. At this point, rehabilitation can be used to correct a large number of relatively severe defects, thus improving the pavement's condition.

In general, there are several levels of treatment to correct pavement deterioration as follows:

- Routine and periodic maintenance
- Rehabilitation
- Reconstruction.

Maintenance actions help slow down the rate of deterioration by identifying and addressing specific pavement deficiencies that contribute to overall deterioration. Rehabilitation is the act of repairing portions of an existing pavement to reset the deterioration process, while reconstruction is the total replacement of the deteriorated pavement.

6.1 Maintenance

Pavement maintenance describes all the methods and techniques used to prolong pavement life by slowing the deterioration rate. Thus, the performance of a pavement is directly tied to the timing, type and quality of the maintenance it receives. The following pavement maintenance operations are also known as preservation methods (Asphalt Institute 1996; Khin Onn 2003):

- Crack sealing
- Patching
- Fog seals
- Rejuvenation
- Sand seal
- Chip seal
- Slurry seal
- Cape seal
- Micro-surfacing
- Thin-lift overlay, and
- Ultrathin overlay.

6.2 Rehabilitation

While pavement maintenance can slow the rate of deterioration, it cannot stop the damage from occurring. Therefore, the effects of deterioration eventually need to be reversed by adding or replacing material in the existing pavement structure. This process is rehabilitation.

Rehabilitation options depend upon local conditions and pavement distress types but typically include (Asphalt Recycling and Reclaiming Association 2001; Kandhal and Mallick 1997):

- Hot mix asphalt (HMA) structural overlay
- Cold in-place recycling (CIPR)
- Hot in-place recycling (HIPR)
- Full-depth reclamation (FDR).

Rehabilitation essentially reverses the effects of deterioration by adding, replacing or recycling material in an existing pavement structure. The inclusion of recycling techniques may be appealing on many levels. First, it reuses in-place materials that are commonly some of the best materials available. Second, it is often a very cost-competitive option compared to reconstruction. Third, the disruption to the public tends to be less as the road can typically be used during the rehabilitation work. Especially in urban settings, this can greatly reduce user costs associated with a project.

Both recycling and reconstructing correct a myriad of distresses in a single effort. However, with recycling, the agency may choose to stage the construction steps into appropriate phases over an extended time. Staging improvements can reduce the funds needed to address a road today, while still correcting problems in the short term. Subsequent stages provide for a long-term solution, with the completion of all the planned stages.

6.3 Reconstruction

Reconstruction involves the removal and rebuilding of all or part of the road pavement using fresh material and new construction specifications (Nicholls 2017). Reconstruction can be either full or partial depending on which layer the new pavement is to be rebuilt. Full reconstruction is necessary when the subgrade layers, as well as the pavement layers, have deteriorated beyond repair. In this case the rebuilding will include the subgrade. However, partial reconstruction is required when the road base has been contaminated and has lost its inherent stability.

7 Conclusion

A road network needs to be regularly evaluated and maintained to meet the needs of the road user as a safe and efficient means of travel. The various methods of testing to evaluate the functional and structural performance of the pavement are discussed so that the condition of the pavement can be assessed. Data collected from the pavement evaluation process is used in the analysis of pavement condition, to determine the functional and structural condition of the pavement. From this, suitable maintenance or rehabilitation method can be applied to ensure that the structural and functional performance of the pavement is adequate. In conclusion, the evaluation of pavement is a systematic process that will lead to the optimization of resources used for pavement maintenance and rehabilitation, and for the longer use of the pavement.

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