EVALUATION OF PAVEMENT CONDITIONS AND MAINTENANCE WORKS FOR ROAD NETWORK IN SAUDI ARABIA

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Abstract

An effective pavement management system depends on reliable, accurate, and complete information. Having quality pavement management data is directly linked to the ability of the pavement management system to contribute to the development of reasonable and reliable recommendations and decisions regarding an agency's pavement network. In this study, historical data of pavement distresses and pavement conditions on the main and secondary road network of Saudi Arabia were collected. These data were categorized, processed, and analyzed. These data have been employed to generate prediction of pavement distresses and conditions evaluation for the Saudi Arabia Urban Road Network. Throughout the study, the most common types of pavement distresses on road network of KSA have been identified. Also, the maintenance programs and priorities have been analyzed. The current computer software for pavement management system in KSA were studied and evaluated.

Keywords: Pavement Management, Road distresses, Road Maintenance

Introduction:

The Kingdom of Saudi Arabia has a huge road network (86000 km) connecting its major cities and neighboring countries. It also has a large municipal and urban road network. Pavements in these roads were designed to a high standard to serve for long periods before any major rehabilitation is required and to ensure safety for road users (Herber, 2015). A pavement network is a capital investment for the nation; funds available for maintaining this infrastructure are ever decreasing while maintenance needs are ever increasing. Moreover, many of these roads have experienced an early deterioration in the form of fatigue cracking and rutting that requires enormous funds for maintenance and repair (Al Mubaraki, 2010).

The harsh environment in Saudi Arabia affects almost the whole country. Saudi Arabia has a desert climate. Temperature is one of the most important factors affecting performance of the pavement. Temperature variations within the pavement structure contribute in many different ways to distresses and possible failure of that structure. Under-loading conditions, the pavement temperature is major factors affecting the deformation response of bituminous structures (Al-Abdual Wahhab et al. 2001). The harsh environment with high traffic load operating on the Saudi road network makes the pavement more susceptible to a wide range of distress types.

Objectives:

The main objectives of this paper can be summarized as follows:

1. Identify the most prevalent pavement distresses in the different regions of KSA and their effect on the performance of road networks.
2. Study and evaluate treatment methods and materials and suggest the most effective.
3. Analyze the maintenance programs and priorities
4. Study and evaluate the current computer software systems for pavement management.

Methodology

The methodology consists of 3 main steps:

1. Data collection and analyses
2. Assessment of road networks in the different regions of KSA
3. Evaluation of the pavement management system in KSA

Data Collection

The main source of data is the survey done by the survey conducted by General Directorate for Operations and Maintenance, Deputy Ministry for Technical Affairs, The Ministry of Municipal and Rural Affairs, Saudi Arabia (General Directorate for Opeations and Maintenance, 2011). The Kingdom is divided into 5 regions according to climate conditions and 14 Emirates (Amana), and 160 municipalities, see Figure 1. 1260 samples of road sections were tested (90 per Amana).

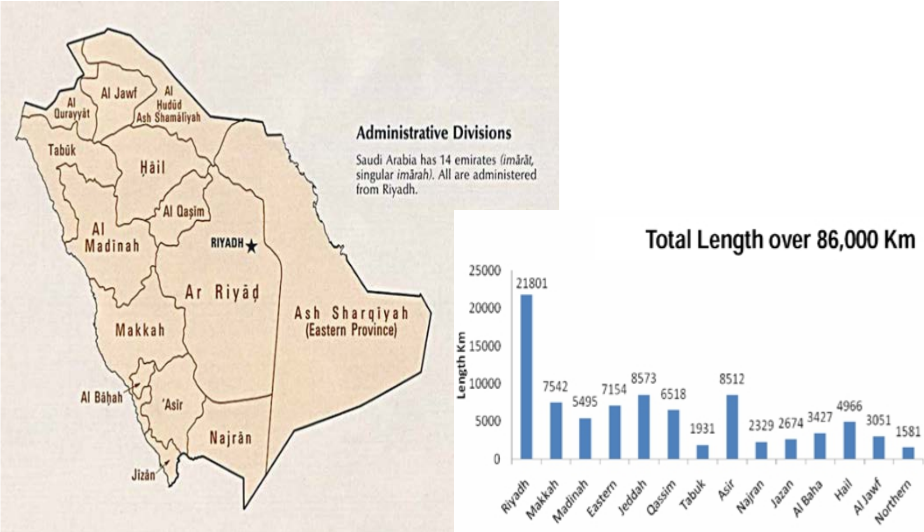

Figure 1 Administrative Divisions of KSA

Assessment of Road Networks in the different Regions of KSA

KSA has a large road network connecting its regions, cities, provinces, towns, villages. Also the network connects neighboring countries. It also has large urban and rural roads. Today, there are over 86000 km of asphalt paved roads and around 112000 km of agricultural roads. The total costs of constructing the kingdom's roads network is more than $50,000 billion. The MOMRA manages the Urban Roads Network (URN) and the MOT manages the Rural Roads Network (RRN). Figure 2 shows that the SANRN is divided into two main networks, the urban network and rural network. Road network data (Figure 3) were collected from Amanas and municipalities. The data coding for the different Amanas is presented in Table 1.

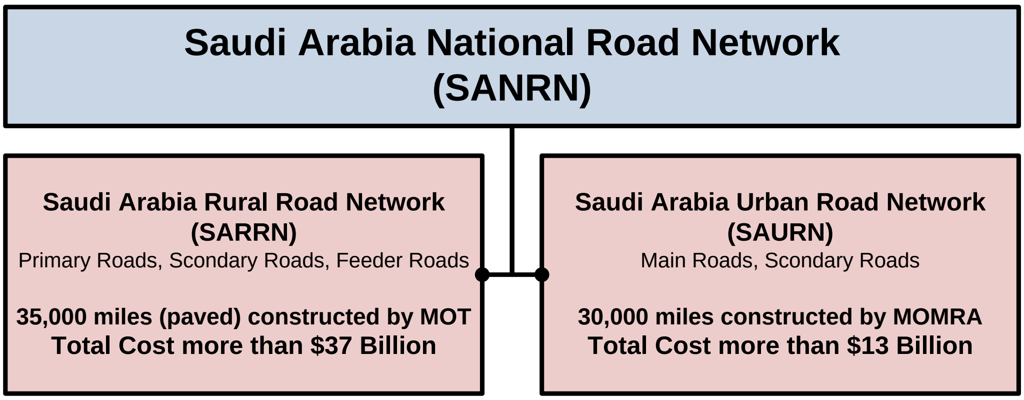

Figure 2 SANRN Classification

Figure 3 Intercity Main Road Network in KSA

Table 1 Network Definition and Coding System

Municipality	City		Region		Area		Road			Section	Sector		Lane		Feature	
Riyadh	0	2	0	9	1	2	0	1	0	N						
Makkah	0	2	0	9	1	2	0	1	0	N			M	1		
Madina	0	2	0	9	1	2	0	1	0	N			M	1		
Qaseem	0	2	0	9	1	2	0	1	0	N			M	1		
Dammam	0	2	0	9			0	1	0		1	3	M	1	8	
Others	No System															

Methods of Pavement Condition Assessment

The method of pavement condition assessment differs among authorities. Some authorities depends only on the experience of the supervising engineer, some other authorities depend on pavement surface observations, while some other authorities take into account road surface and measuring the structural and functional capacity of pavement. In Riyadh Amana, the assessment depends on the estimation of Urban Distress Index (UDI), where the road network is divided into intersections and sections. The intersection extends to 50 m from all directions and the remaining segments are divided into sections (100 m each). The value of UDI varies from 0 to 100 as in Table 2.

Table 2 Pavement Condition Rating in Urban Distress Index Method

UDI	Pavement Condition (Rating)
90-100	Excellent
70-89	Good
40-69	Fair
0-39	Poor

The UDI is based on the classification of pavement distresses into categories according to its shape and its effect on vehicular traffic and its causes and the rate of its development. This results in reducing the number of distresses groups to 15. The Amana of the Holy Capital and Madina depends on the same method of pavement condition prediction, which depends on UDI.

In Riyadh, the pavement condition prediction on the International Roughness Index (IRI) using Automatic Road Analyzer-ARAN. This scale evaluates the pavement surface condition based on its IRI as in Table 3. The skid resistance is measured by K.J. Law device. The coefficient of friction and the structural capacity are measured by using the Dynatest Falling Weight Deflectometer (FWD).

Table 3 Pavement Condition Rating in International Roughness Index Method

IRI (m/km)	Rating
<1.5	Excellent
1.5-2.0	Good
2.0—3.0	Fair
3.0-	Poor

The Pavement Condition Index – PCI according to ASTM-D-6433 predicts the pavement performance according to the PCI value. Roughness coefficient, skid resistance and structural capacity may be used if the devices are available.

In Amanas which haven't a pavement management system, the pavement conditions are evaluated by visual inspection and riding quality without calculating any pavement condition indices. The most frequent distresses are identified according to density and severity. The maintenance priorities are determined and arranged according to the budget. This is done in Amanas of Tabouk, Al Hudud Ashamaliah, Algof, Hael, Asir, Jazan, Nagran, and Al Baha.

Saudi Aramco Company uses the method of Performance Index (PI) based on the effect of some distresses on pavement performance such as segregation, alligator cracking, rutting, bleeding, patching, and block cracking, in addition to measuring the structural capacity of pavement layers and measuring surface roughness (IRI).

The Royal Authority of Al Jbeil depends on the classification of pavement distresses and the change in pavement surface in evaluating the overall pavement performance by deducting points according to each distress and summing up the distress deducted points (DDP) and predicting the pavement surface condition by calculating Pavement Distress-Based Rating – Urban Distress Index (UDI) and evaluating the pavement according to

Table 4. This method is not applied due to the lack to technical facilities. The Urban Distress Index (UDI) is calculated as follows:

$$\mathrm{UDI} = 100 - 20\sum\left(\frac{T_{ij} \times D_i}{100}\right)$$

Where T_{ij} = Deduct points

D_i = Distress density

Table 4 Pavement Condition Rating in Urban Distress Index Method

UDI	Rating
76-100	Good
56-75	Fair
0-55	Poor

The Ministry of Transportation uses the ARRB equipment (Figure 4) and RST equipment in evaluating pavement performance. This equipment measures the IRI, rutting, stripping, cracks in pavement. According to these measurements, the PCR is calculated. In addition, the skid resistance is measured by K.J. Law device and the structural capacity is measured by using the Dynatest Falling Weight Deflectometer (FWD), in addition to measuring pavement layers thicknesses, moisture, voids ratio with the help of Georadar technology (Ground Penetration Radar).

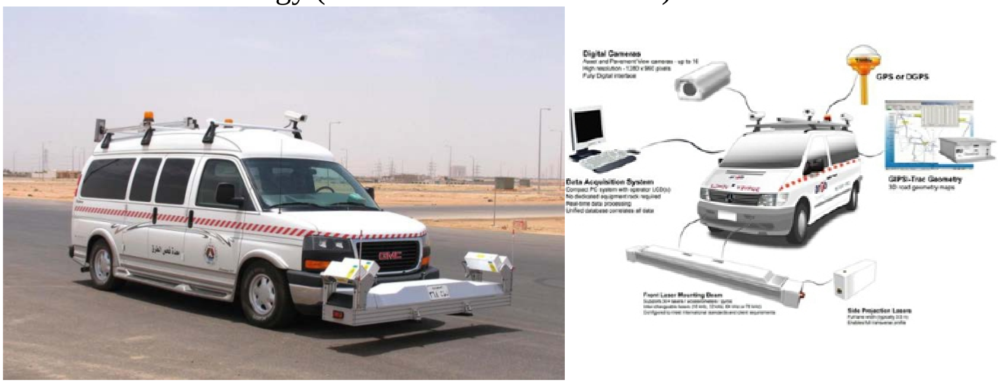

Figure 4 ARRB Equipment used by Ministry of Transportation in KSA

The estimation of future pavement performance is considered a main factor that affects directly the effective scheduling for maintenance programs and setting the priorities of implementation. Pavement performance models for estimating the future UDI in Riyadh depends on four factors: pavement age, traffic volume, surface drainage, and the type of treatment. These models (Table 5) are currently under development.

Table 5 Future Pavement Performance Estimation Models used in Riyadh Amana

Amana	Maintenance Type	Pavement Performance Models
Riyadh	No Maintenance	$UDI = 80.6 - 0.37\ Age^2$
	Routine	$UDI = 88.6 - 0.20\ Age^2 - 5.0\ ADT + 6.26\ DR$
	Overlay	$UDI = 98.8 - 0.107\ Age^2 - 2.15\ ADT + 0.83\ DR$
	Routine	$PSI = 3.87 - 0.00459\ Age^2 - 0.383\ ADT + 0.155\ DR$
	Overlay	$PSI = 3.67 - 0.00134\ Age^2 - 0.161\ ADT + 0.153\ DR$

Where UDI = Urban Distress Index
Age = Pavement Age
DR = Surface Drainage
ADT = Average Daily Traffic
PSI = Pavement Serviceability Index.

The East Province (Ash Sharqiyah) uses the same performance models of the ARAMCO Company that takes into consideration the pavement age in estimating future PCI. The rest of Amanas has no pavement performance estimation models.

ARAMCO Company studied the relation between Performance Index PI and the pavement age for three types of roads, as well as the relationship between PCI and pavement age. Table 6 shows the relationship between PI and pavement age, where correlation coefficients of 0.77 for parking areas, 0.44 for local streets, 0.93 for main streets were found. The table also presents the relationship between PCI and pavement age where correlation coefficients of 0.95 for parking areas, 0.82 for local streets, 0.95 for main streets were found. Thus, a relationship between PI and PCI was developed with 0.74 correlation coefficient.

Table 6 Performance Models Used by ARAMCO

Authority	Road Type	Pavement Performance Models
ARAMCO	Parking	$PI = 0.0198\ Age^2 - 2.972\ Age + 100$
	Local	$PI = -0.0119\ Age^3 + 0.2895\ Age^2 - 4.0947\ Age + 100$
	Main	$PI = 0.0080\ Age^3 - 0.3728\ Age^2 + 0.6282\ Age + 100$
	Parking	$PI = -0.0291\ Age^3 + 0.8683\ Age^2 - 8.5300\ Age + 100$
	Local	$PI = -0.0211\ Age^3 + 0.5185\ Age^2 - 5.5968\ Age + 100$
	main	$PI = 0.0006\ Age^3 - 0.0878\ Age^2 - 2.3379\ Age + 100$
$PCI = 0.9209\ PI$		

Where
PI = Performance Index
Age = Pavement age
PCI = Pavement condition index.

Maintenance Methods and Materials

The economic analysis of maintenance methods and materials and its efficiency was conducted by investigating types of pavement maintenance and rehabilitation. Amanas use most type of pavement maintenance works such as routine, preventive, rehabilitation and reconstruction. Municipalities use limited methods in their pavement maintenance. Ministry of Transport uses all types of maintenance works, but it uses some preventive methods that are not used in Amanas such as the skid-resistant layer, open-grade mix from scrapping waste.

Maintenance Decision Trees

Pavement management systems employ different decision-trees according to the field data available for each system. For example, in Riyadh, the maintenance decisions depend on the Urban Distress Index (UDI). One or more treatment (Table 7) is selected based on the decision trees. Figures (5, 6, 7) illustrate decision-trees at section, intersection, and area levels. Table 8 presents the treatment decision for each type of distresses in Riyadh Amana.

Table 7 Main and Secondary Treatments for Flexible Pavement (Riyadh)

Maintenance Type	Treatment Decision No	Treatment Decision Name
Main	1	Do Nothing
	4	Crack Filling
	5	Surface Patching
	5	Surface Leveling and Covering
	6	Deep Patching
	8	Cement Mortar
Secondary	10	Base Repair and Reconstruction
	11	Thin Asphalt Layer
	12	Thick Asphalt Layer

Maintenance Priorities

Maintenance priorities vary at local, regional and international pavement systems. All Amanas depend on pavement surface conditions in arranging priorities, which gives high priority to the pavements that have worst conditions. Also, all Amanas take into account type and importance of the roads along with pavement condition in setting maintenance plans within the budget allowed. Some Amanas consider type and amount of traffic, date of latest maintenance, along with pavement conditions and road importance in arranging priorities. It is noted from Figure 8, that 36% of Amanas employ these priorities.

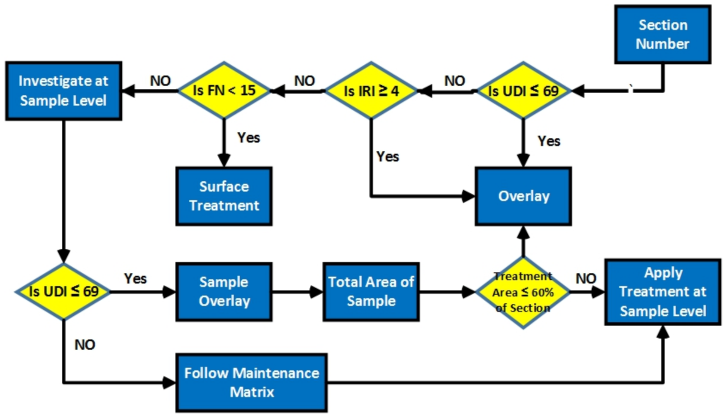

Figure 5 Decision Tree for Branch Streets in Riyadh

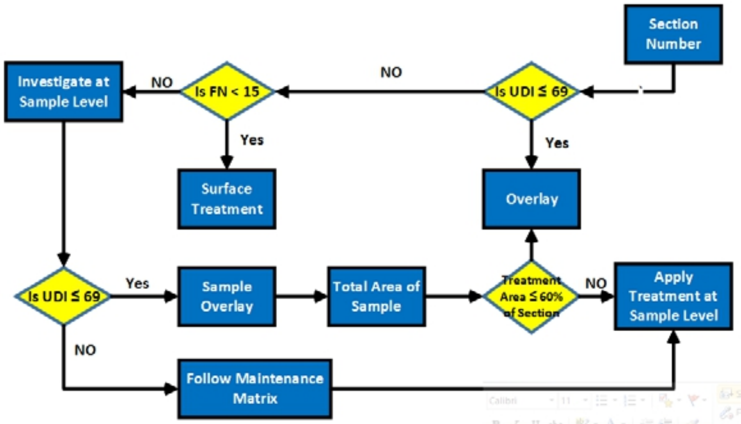

Figure 6 Decision Tree for Intersections of Main Streets in Riyadh

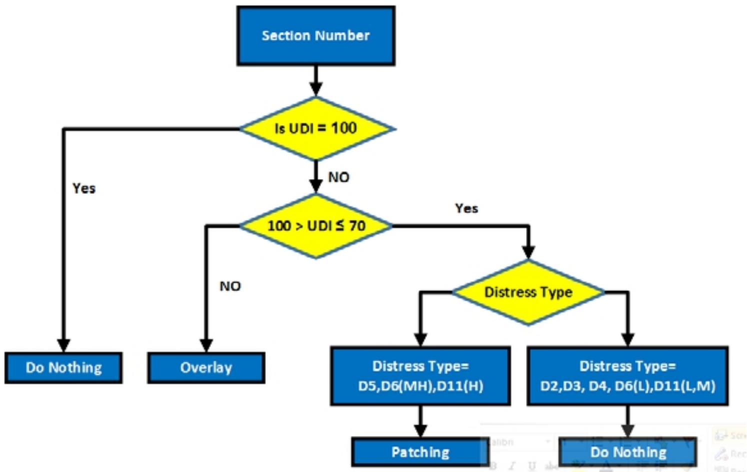

Figure 7 Decision Tree for Areas of Branch Streets in Riyadh

Table 8 Treatment Decisions for different Common Distresses in Riyadh

Distress	Intensity	Density < 10	Density 10-50	Density > 50	Distress	Intensity	Density < 10	Density 10 - 50	Density > 50
Fatigue Cracking	Low	1	4	4	Bleeding	Low	1	1	1
	Medium	6	6	10		Medium	1	5	5
	Severe	6	6	10		Severe	1	5	8
Shrinkage Cracking	Low	1	4	8	Polished Aggregate	Low	1	1	1
	Medium	4	4	8		Medium	1	1	1
	Severe	8	8	8		Severe	1	1	8
Long. & Transverse Cracks	Low	4	4	4	Stripping	Low	1	1	1
	Medium	4	4	4		Medium	8	8	8
	Severe	4	4	8		Severe	8	8	8
Patching	Low	1	1	1	Slippage Cracking	Low	1	4	4
	Medium	1	1	1		Medium	4	4	5
	Severe	1	1	1		Severe	6	6	6
Potholes	Low	5	5	5	Slippage Depression	Low	1	1	1
	Medium	6	6	6		Medium	5	5	5
	Severe	6	6	6		Severe	6	6	6
Depression	Low	1	1	1	Slippage Potholes	Low	5	5	5
	Medium	5	5	5		Medium	6	6	6
	Severe	6	6	6		Severe	6	6	6
Rutting	Low	1	5	5	Raveling	Low	5	5	5
	Medium	5	5	5		Medium	8	8	8
	Severe	6	6	6		Severe	8	8	8
Creep	Low	1	1	1					
	Medium	6	6	6					
	Severe	6	6	6					

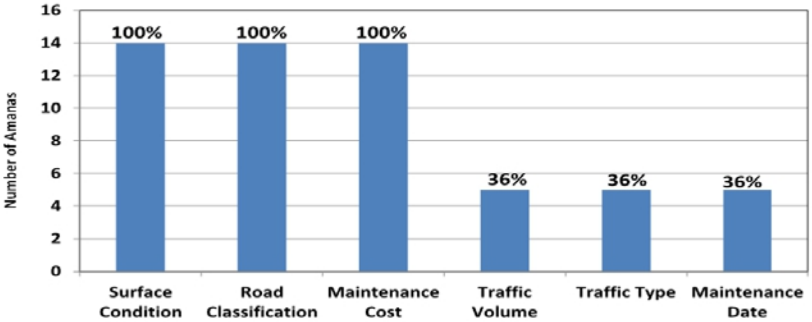

Figure 8 Priorities used by Amanas

In Riyadh only, the Maintenance Effectiveness (ME) is calculated according to the following equation:

$$ME = \left(\frac{t}{C}\right) \times \Delta UDI$$

Where:

ΔUDI = difference in pavement condition before and after treatment

T = treatment life cycle

C = treatment cost.

Data Classification

Road Network Classification

The evaluation of road networks and pavement distresses identification and their effects on the performance should take into consideration the climate conditions, geographic location, and materials types, in addition to road age, traffic volumes, and surface drainage. The samples for analysis were selected according to different stages as follows:

Classification According to Temperature and Materials Quality

Referring to the Performance Grade (PG) for road network in KSA, the road networks can be classified into 4 categories:

First Category: Road networks of the Eastern and North-eastern regions which includes Ash Sharqiah Amana that have high temperatures and low quality materials.

Second Category: Road networks of the Middle and Northern regions which include Amanas of Riyadh, Kosseim, Al Hudud Ash Shamalieh, Al Gof, and Hael that have moderate temperatures and moderate quality materials

Third Category: Road networks of the Western-Middle which include Amanas of the Holy Capital, Madina, and Jedda that have moderate temperatures and high quality materials.

Fourth Category: Road networks of the Western south and North which include Amanas of Tabouk, Al Baha, Assir, Jazan, and Nagran, that have low temperatures and high quality materials.

Distribution of Samples sections

Samples were selected according to statistical methods as follows: 90 road sections were selected for each Amana for visual inspection according to road type (main, collective, local), drainage facility (yes, no), and potholes (yes, no).

Data Analysis

The decision for type and cost of maintenance depends on the most common pavement distresses in sample or in section according to distress type, severity, and intensity. The results for Amanas and Municipalities are presented as follows.

The visual inspection of samples from Riyadh Amana and municipalities of Kharj and Oneiza (Middle and Northern Region) showed that –as in Figure 9- the most common pavement distresses are patch, raveling, and all types of cracks (shrinkage, fatigue, longitudinal and transverse). The greater percent is for raveling.

Similarly, the Dammam city, Hofouf Governorate, and Hafr El Baten Governorate were selected as representative samples for the Eastern and North-Eastern Region. The visual inspection showed that the most common pavement distresses are fatigue, shrinkage, longitudinal and transverse cracking and patching. The greater percent is for raveling with higher density than the Middle region.

The Western-Middle Region includes the Amanas of the Holy Capital, Madina, Jedda. The Holy Capital, Madina, Jedda, in addition to Yanboa and Taef Municipalities were selected to represent the region. The visual inspection showed that the most common pavement distresses are raveling, patching, fatigue, longitudinal and transverse cracking.

The Western-North and Western-South Region includes the Amanas of Tabouk, Baha, Assir, Garan, and Nagran. Abha City, Sabiaa Municipality, and Tarrif Municipality were selected to represent the region. The visual inspection showed that the most common pavement distresses are shrinkage cracking raveling, and patching. Table 9 shows the most common distresses and the less prevalent distresses in each Amana. Table 10 summarizes the values of PCI, distress density (D), deduct points (DP) For the most common pavement distresses in different regions of KSA

Table 9 Pavement Condition Index (PCI) for Different Regions of KSA

Geographic Region	Amana	PCI Range, %	PCI Avge %	Most/less Common Distress	DP, %
Middle and Northern Region	Riyadh	21-99	80	Raveling/Fatigue cracks	25/20
	Kharj	23-99	74	Raveling/Fatigue cracks	30/23
	Aniza	13-100	64	Raveling/Fatigue cracks	25/23
Eastern and North-Eastern Region	Dammam	56-98	82	Raveling/Fatigue cracks	25/29
	Hafr El Baten	23-100	76	Raveling/Fatigue cracks	42/18
	Al Hofouf	61-100	80	Raveling/Fatigue cracks	40/18
Western-Middle Region	Holy Capital	38-100	78	Raveling/Fatigue cracks	26/21
	Madina	21-100	85	Raveling/Shrinkage cracks	55/22
	Jedda	11-100	73	Raveling/Fatigue cracks	14/0.7
	Taef	38-100	80	Raveling/Fatigue cracks	31/15
	Yanboa	20-100	73	Raveling/Shrinkage cracks	25/2
Western-North and Western-South Region	Abha	56-100	80	Patching/ Fatigue cracks	40/29
	Tarrif	21-99	61	Raveling/Fatigue cracks	33/15
	Sabiaa	30-100	78	Raveling/Fatigue cracks	34/15

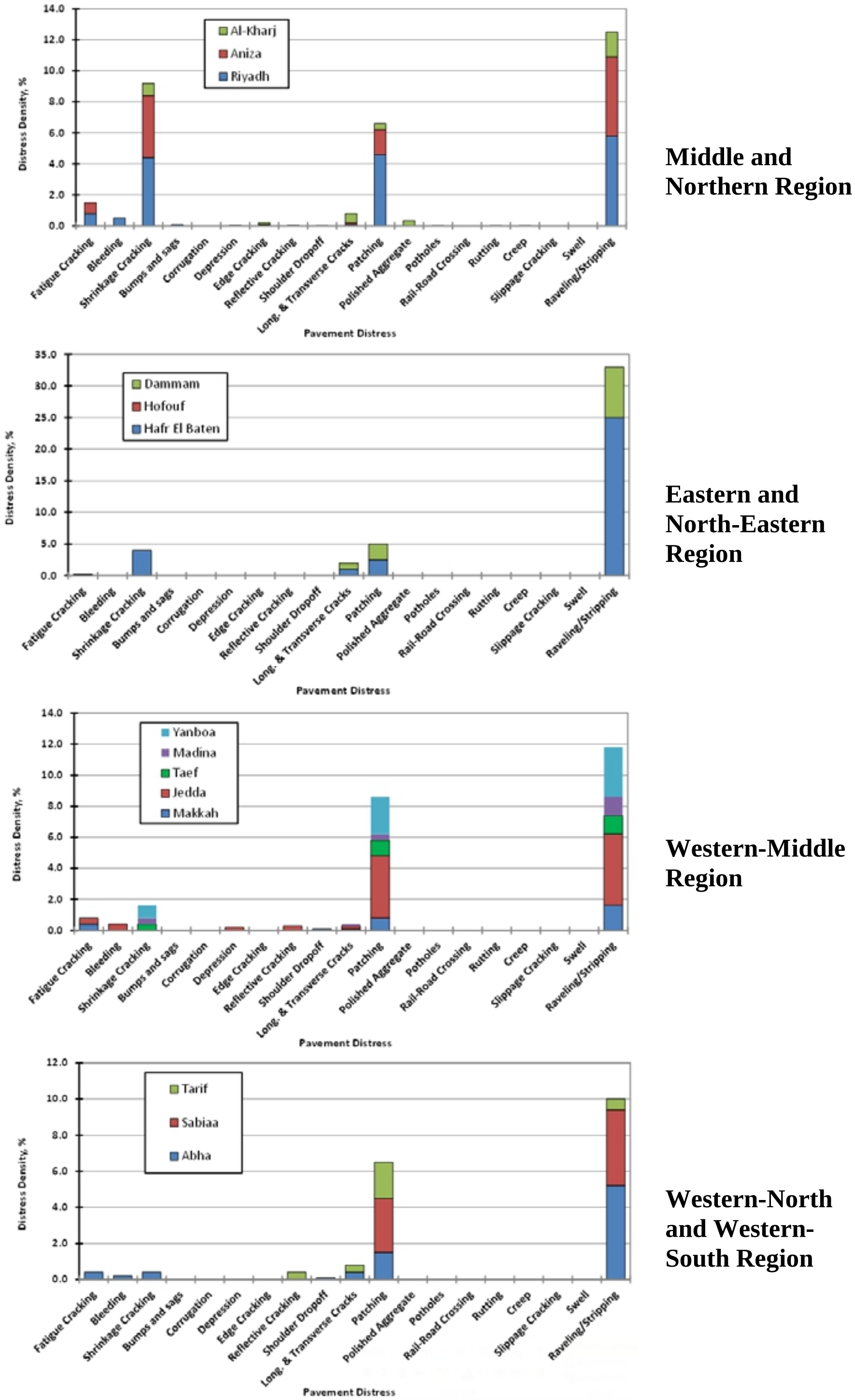

Figure 9 The Most Common Pavement Distresses in the different geographic Regions

Table 10 Densities (D) and Deduct Points (DP)
For Most Common Pavement Distresses in Different Regions of KSA

Distress Type		Middle and Northern Region			Eastern and North-Eastern Region			Western-Middle Region					Western-North and Western-South Region		
		Riyadh	Kharj	Aniza	Dammam	Hafr El Baten	Al Hofouf	Holy Capital	Madina	Jedda	Taef	Yanboa	Abha	Tarrif	Sabiaa
Fatigue Cracking	D	0.486	0.690	1.280	2.55	0.38		0.23		0.676	0.10	3.10	0.123	0.31	0.178
	DP	2.89	3.32	5.39	3.81	2.9		2.44		3.38	1.33	7.53	1.06	4.32	2.13
Shrinkage Cracking	D	0.864	3.440	21.83		6.07		6.18	1.74		1.83	0.61	0.678	7.95	
	DP	2.34	1.48	5.4		2.62		0.61	0.29		0.85	0.30	0.14	5.07	
Long. & Transverse Cracks	D		1.180		2.55										
	DP		0.53		0.21										
Patching	D	7.620	5.390	9.44	7.9	3.12		6.93	2.386	10.88	4.83	13.96	2.827	7.06	9.252
	DP	5.45	4.35	6.92	3.11	3.95		2.94	1.74	6.52	3.96	8.18	1.45	9.7	7.17
Raveling/ Stripping	D	9.175	17.45	23.74	25.2	34.85		13.28	6.688	13.19	6.05	18.41	0.93	20.87	11.55
	DP	3.64	4.37	6.06	3.39	6.85		3.09	2.53	4.49	2.7	5.45	0.98	9.21	4.72

Visual inspection and calculations of PCI were made for the streets of the different Amanas of the geographic zones of KSA. Some selected results are summarized in Figure 10.

Computer Systems used in Pavement Management

Amanas are using different systems that vary in components, databases, system development environment, and integration with geographic information systems (GIS). Riyadh Amana employs ORACLE 10G database which is developed by Oracle Developer 2000 Forms 6i programming language. Figure 11 illustrates the pop-up menus that can be used in inputting data related to areas, sections and intersections. The system contains a number of forms to enter pavement deficiencies (Figure 11). Geographic data are entered to the system via Geomedia 5.5 Software. All date are saved in the database ORACLE 10G.

Eastern Zone Amana employs ORACLE 10G database which is developed by Visual Basic 6.0 programming language. Road network and sections data are entered to the system via input forms that were specially developed for the system. The system employs the geographic information systems ArcGIS, the standard database ORACLE 9i and the MS-ACESS programming language as a working environment. Some screenshots are presented in Figure 12).

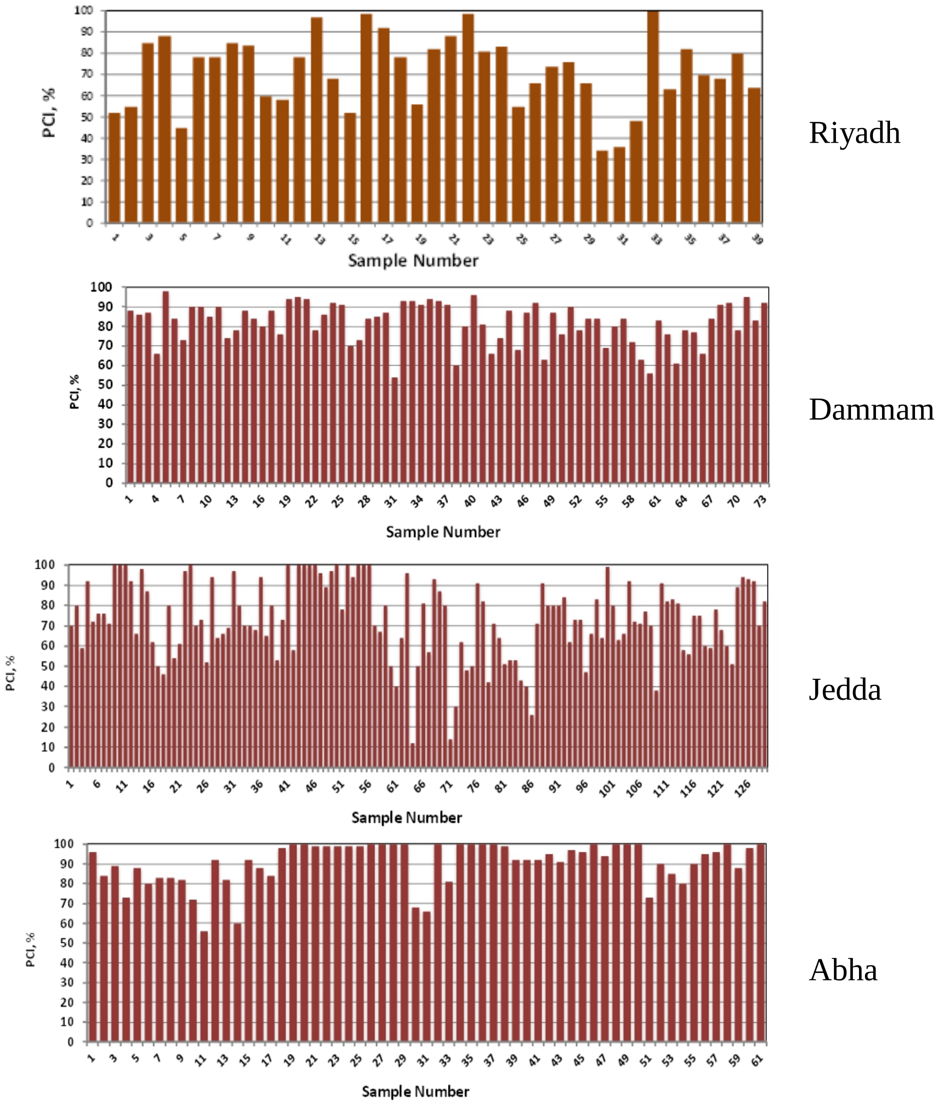

Figure 10 PCI of Streets in different Geographic Zones

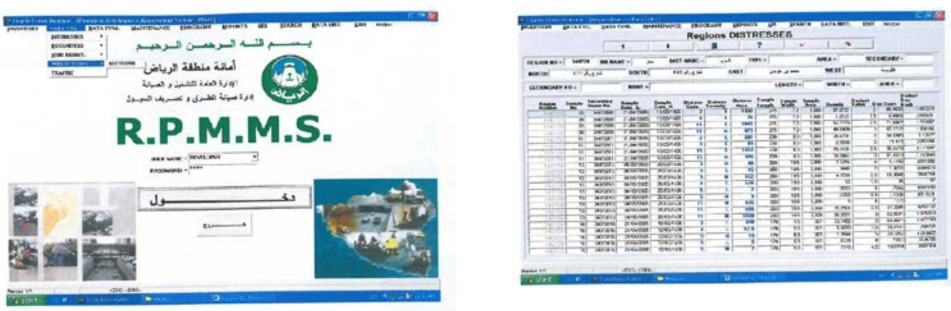

Figure 11 Pavement Management System in Riyadh Amana & Input Screens

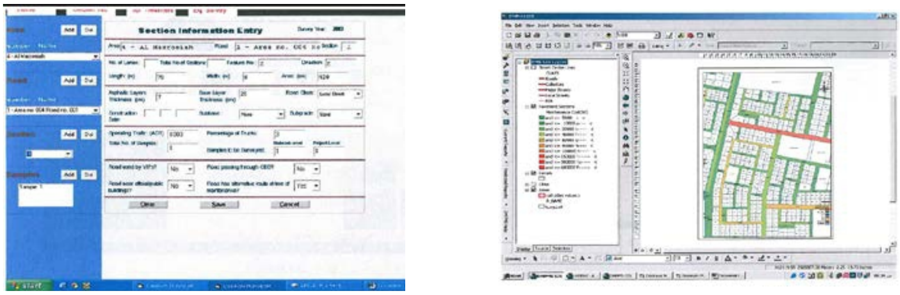

Figure 12 Input Screens and GIS Screen in Eastern Zone Amana

The holy Capital and Madina Amanas employ ORACLE 9i database. Forms for inputting data are developed by Visual Basic 6.0 programming language. Figure 13 shows the pop-up menus by which all data could be updated. The system contains a number of forms for entering pavement distresses data. Geographic data are entered to the system via Geomedia 5.2 Software. All date are saved in the database ORACLE 9i. All other Amanas have no pavement management system.

Figure 13 Pavement Management System in Holy Capital Amana and Input Screens

From 1996, ARAMCO Company employs a pavement management system that was developed by Texas Research and Development Inc.). The system is upgraded according to the actual operation by the same incorporation. The system works by “Web-enabled” technique to allow users to input data without the need to send paper forms. The system contains an application that can present pavement conditions on digital maps via GIS in the company. The system employs ORACLE 9i database and form are developed using Visual Basic 6.0. The system integrates with Geographic database (GIS) by ArcGIS working environment.

Conclusion:

Historical data of pavement distresses and pavement conditions on the main and secondary road network of Saudi Arabia were collected. These data were categorized, processed, and analyzed. These data have been employed to generate prediction of pavement distresses and conditions evaluation for the Saudi Arabia Urban Road Network. The most common types of pavement distresses on road network of KSA have been identified.

Based on the analysis of the previous data, the pavement conditions of the road networks of KSA regions can be estimated and the most common pavement distresses can be concluded. Figure 14 shows the most common pavement distresses for the four regions namely; cracking, patching, and raveling. The figure shows that raveling is widely common in the Eastern region due to the nature of the pavement construction materials. The most common distress in the Western-Middle region is patching due to many infrastructure installations and maintenance. The figure shows also that the shrinkage cracking is more common in Middle region due to the significant difference in temperature among seasons and between day and night.

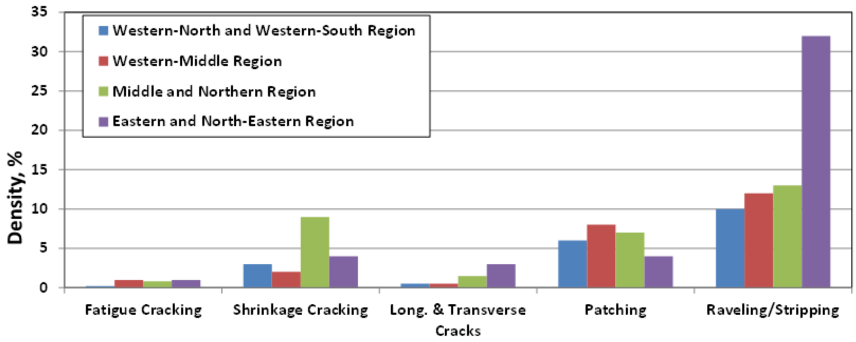

Figure 14 The most common Pavement Distresses in KSA Regions

To ensure databases integration between different Amanas, it is recommended to use the segment-section coding method in coding the road network data in pavement management system.

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