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Integration Of Geographic Information Systems And Paver System To Award Efficient Pavement Maintenance Management System (Pmms) - Case Study-Irbid City-Jordan

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ABSTRACT

Information System (GIS), PAVER System for the purpose of flexible pavement distresses classifications and maintenance priorities. Classification process included distress type, distress severity level and options for repair. A system scheme that integrated the above-mentioned systems was developed. The system utilized the data collected by PAVER system in a GIS environment. GIS ArcGIS software was used for the purpose of data display, query, manipulation and Analyst.

The developed system was of great help in identifying, collecting and displaying pavement condition data. Pavement distresses were assigned based on pavement condition index values computed by: Pavement condition index (PCI). This technique was cost-effective and wise-based decision making for different maintenance activities and programs.Statistical models were developed to forecast pavement distresses quantities using Average Daily Traffic (ADT), climate conditions, socio-economical characteristics and pavement age. It was found that ADT and Pavement age variables played the most significant factors in the distresses quantification.

***KEY WORDS*:** GIS, PMMS, PCI, Pavement Distresses, Pavement Conditions, Distresses Classification, and Maintenance Priorities.

1. Introduction

The integration of GIS and PAVER systems open the door to fully automated technology application in distresses data collection and analysis. Such a new technology become widely popular due to its' effectiveness in carrying out different researches economically and safely. PMMS is a set of tools or methods that can assist decision makers in finding cost effective strategies for providing, evaluating and maintaining pavements in a serviceable condition. PMMS provides a systematic, consistent method for selecting maintenance, repair needs and determining the optimal time of repair by predicting future condition (Shahin and Kohn 2006). Literature shows that an objective repeatable rating system for identifying the pavement's condition was developed by the U.S Army Corps of Engineer (2004). This PMMS is called the PAVER system and over time it became a validated pavement maintenance management system for airports, cities and counties, designed to optimize funds allocated for pavement maintenance and rehabilitation (M&R) (ALSuleiman et al. 1992).

However, Paver system could have tedious data collection procedures for the implementation of pavement management system. Moreover, it requires professional expertise from end-users. It also doesn't have the capability of digital and spatial mapping as well as scheduling capabilities. Thus, the situation of pavement management system would be rather complicated especially for big cites of huge roads' networks (Al-kheder, 2002).

Therefore, it is anticipated that integrating GIS with the Paver system could be a viable tool in PMMS studies to overcome some of the previously mentioned deficiencies. The integration of this hybrid system could have numerous advantages, some of which may include practicality, capabilities of follow-up, ease-of-use digital capabilities and documentation possibility, planning and management of activities, access to various activities, archiving and updating (Shafik and Maher 2005). Thus, it would be an easy-to use hybrid system with complete data-base production through the development of digital and spatial maps (Abkowitz et al. 2008). Therefore, this research work will utilize and develop an integrated and hybrid system using both GIS and paver system as a viable tool for better PMMS and overcoming some of the problems rose before The processing system includes a: i) classifier that analyzes individual pavement cracks and categorizes them by type, severity, and extent, creating an inventory for repair planning; ii) database that catalogues all information into a GIS format for access by a Pavement Management System (PMS) which models the deterioration using trend analyses and environmental data.

Other studies that discussed field data acquisition technologies was developed. A system has been presented to facilitate the decision making process for Gaza city pavements. It is based mainly on the direct integration between Micro PAVER as a pavement software and GeoMedia Professional as GIS software in order to fully exploit the capabilities of each individual package. Also, a simple Graphical User Interface (GUI) has been developed in which it contains user-friendly menus that can help in presenting PMMS results and consequently, to justify the decisions made. A case study zone of about 20 km length of roads was inspected to analyze the proposed PMMS. Condition analysis and decisions were performed to determine maintenance needs, budgets, priorities (Shafik and Maher, 2005). Each one of Gaza PMMS software components provides functionalities for supporting the concrete tasks of the PMMS process. Gaza PMMS depends on the direct integration between Micro PAVER and GeoMedia Professional programs.

Inspection data is entered and processed by Micro PAVER to assess pavement network. Results are saved in the PAVER database and then connected into GeoMedia through the Warehouse Connection Wizard. Join of PAVER and GeoMedia databases is established based on the similar section ID in both. This will enable data and condition results after each periodic inspection to be updated into the GeoMedia database. A simple GUI, named PMMS, has been developed to help in presenting the PMMS results and to justify the decisions made. This GUI contains user-friendly menus that can call Micro PAVER and GeoMedia files. It also has capabilities to execute rapid queries and perform different types of reporting. In addition, reports can be exported in different types of document format (PDF, Excel, Word, etc). With this tool, the GUI can provide answers to questions related to each one of the following:

a. Pavement Type: Which sections are paved, unpaved or closed?
b. Pavement Condition: Which sections or branches are with failed, poor, excellent conditions, etc?
c. Pavement Maintenance: Which sections require routine maintenance, overlaying or reconstruction?
d. Treatment Cost: What are the treatment cost of each section, each branch or overall?

The PMMS interface inputs data from both GeoMedia and Micro PAVER. Its basic principle of analysis is based on knowing the PCI value, area, functional classification and other information for each section of Gaza pavement network. The condition class and treatment type required can then be determined. PMMS also allows unit cost of each treatment type to be entered and this will be helpful in determining maintenance cost for each section (Shafik and Maher, 2005).

Other studies that discussed field data acquisition a technology was developed (Jaselskia, 2009). This study describes the results of the research project investigating the use of advanced field data acquisition technologies. The objectives of the research project were to (1) research and evaluate current data acquisition technologies for field data collection, manipulation, and reporting; (2) identify the current field data collection approach and the interest level in applying current technologies within Iow transportation agencies; and (3) summarize findings, prioritize technology needs, and provide recommendations regarding suitable applications for future development. The literature review in this research revealed that many of these technologies could have useful applications in the transportation industry.

A survey was developed to explain current data collection methods and identify the interest in using advanced field data collection technologies. Surveys were sent out to county and city engineers and state representatives responsible for certain programs (e.g., maintenance management and construction management). Results showed that almost all field data are collected using manual approaches and are hand-carried to the office where they are either entered into a computer or manually stored. A lack of standardization was apparent for the type of software applications used by each agency--even the types of forms used to manually collect data differed by agency. Furthermore, interest in using advanced field data collection technologies depended upon the technology, program (e.g., pavement or sign management), and agency type (e.g., state, city, or county).

The state and larger cities and counties seemed to be interested in using several of the technologies, whereas smaller agencies appeared to have very little interest in using advanced techniques to capture data. A more thorough analysis of the survey results is provided in the report. Recommendations are made to enhance the use of advanced field data acquisition technologies: (1) Appoint a statewide task group to coordinate the effort to automate field data collection and reporting. Subgroups representing the cities, counties, and state should be formed with oversight provided by the statewide task group. (2) Educate employees so that they become familiar with the various field data acquisition technologies (Al-kheder, 2002).

Further, researchers will be capable to perform real-time operations, extract highly accurate data, present spatially inventory data, introduce numerous analytical techniques and develop highly technological system. Maintenance and operation engineers were also anticipated to use the findings and guidelines of this research work to automate most of their routine decision making activities (Al-Mestarehi 2009).

The main objective of this paper was to present the feasibility to integrate GIS, PAVER system in order to build digital distress maps linked to locations, useful surface information, and pavement conditions databases. Maps showing distribution of maintenance activities over roadway network sections based on pavement condition index values were also developed. Using the developed system, distresses classification and rehabilitation actions for roads network were investigated. Figure 1 shows a flowchart for the general frame work of this research.

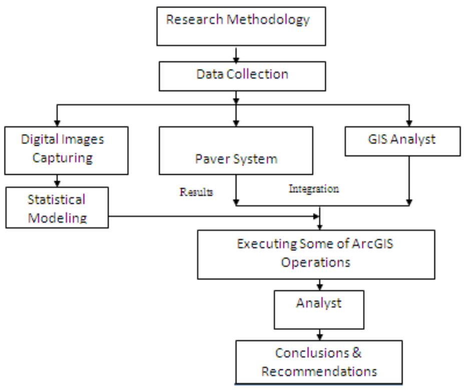

Figure 1: Flowchart of general frame work of research

2. Data-Base Development

To achieve the objectives of this study, an integrated database related to 35 arterials, 24 collectors, 31 locals of Irbid-Jordan city were developed. The selection criterion was dependent on covering variables having different pavement and traffic conditions.

The collected data included the following elements:

a. Pavement Condition Data: this data-base for each road section included: distress type, distress severity, distress density, Present Serviceability Rating (PSR) and other related information that included: section identification, section type, section location, and section dimensions.

b. Other Variables: this data-base included: a) Roadway Geometry Inventory (arterial, or collector or local name, arterial, or collector, or local length (m), arterial, or collector, or local width (m), arterial, or collector, or local type (divided or non divided), and arterial, or collector, or local directions (one or two-way);b) Traffic Data (Average annual daily traffic volumes);c) Climate Condition (Rainful, Snow, Max Air Temperature, Min Air Temperature, Max Humidity, Min Humidity) and d) Socio- economical characteristics (Density of population, Ratio of number of vehicles to number of houses in every section zone).

3. Software

The following equipment were used to measure pavement condition quantities, and presenting collected data (Al-Mestarehi, 2009):

a. Micro- PAVER Software: Micro-PAVER software was utilized for selecting maintenance and repair (M&R) needs and priorities and determining the optimal time of repair by predicating future pavement condition.

b. GIS Map Software: ArcGIS software brought geographic information to the desktop to visualize, explore, query and analyze data spatially. ArcGIS was made by Environmental Systems Research Institute (ESRI 2008).

4. Pavement Condition Measurement

The methodology of automatic distresses measurement could be summarized in the following steps:

a. Select roads in Irbid city that were divided into branches which are defined as any identifiable part of the pavement network which are a single entity and have a distinct function. The selected branches that are divided into smaller component called sections.

The following factors were considered when dividing branches into sections:

- Pavement structure: the structural composition (thickness and materials).
- Traffic: the volume and intensity of traffic.
- Construction history: the pavement sections should have the same construction history.
- Pavement Rank: the functional classification (arterial, collector, or local).
- Drainage facilities: the drainage facilities and shoulders should be consistent throughout the pavement section.

b. Divide pavement sections into sample units with an area of 232 ± (10) m^2.

c. Use Hand odometer was used to measure distress length and area. A straight edge and ruler were used to measure the depth of ruts or depression. The distresses inspection was conducted by walking over the sample unit, measuring the distress type and severity.

The resulted pavement condition database was used as a data source for PAVER system.

5. Calculation of the PCI Using Paver System

The following steps were used to compute PCI and pavement condition rating:

a. Defining the pavement inventory (network, branches, or sections).
b. Entering the dates and samples information.

The inspection component of PAVER can be launched from the PAVER Button Bar via PCI using the following steps:

- Click on the (edit inspection) to enter inspection dates.
- Click on the (edit sample unit) to enter the survey information.
- Entering information on distress (Type, Severity, or Quantity).
- PCI Computation.

6. GIS Layers

Desktop GIS combines the capabilities of display, thematic, and street-based mapping systems along with the ability to analyze geographic locations and the information linked to those locations. Moreover, information could be accessed from vector or raster maps, or maps could be accessed from information; i.e. it is a dynamic and on-line data acquisition system. Thematic mapping systems enable us to create graphic displays using information stored in a spreadsheet or database. Each map produced is based on Layer (coverage).

Layers of pavement condition data, climate condition data, socio-economical characteristic data and road inventory data were presented and incorporated into ArcGIS GIS desktop. Presented Layers included:

a. Layers of pavement condition at arterials, collectors, and locals: In this Layer detailed description for all elements related to pavement conditions at the studied arterials, collectors, and locals were presented. Polylines features were used to draw arterials', collectors, and locals sections. A comprehensive data-base of all types of distresses associated with their severity levels, pavement condition index, options for repair and maintenance were incorporated into the data-base. However, Figure 2 shows a view of the city arterials, collectors, and locals' pavement conditions according to PCI values.

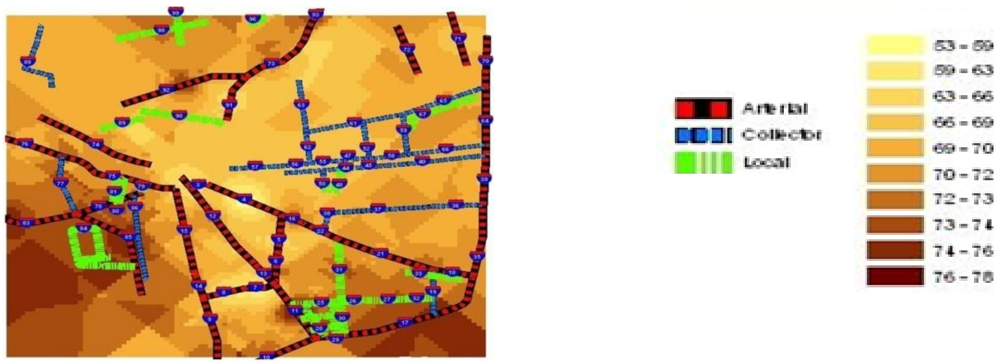

Figure 2: Irbid arterials, collectors, and locals associated with PCI values.

b. Other Layers: These Layers included: Layers of traffic volumes at arterials, collectors, and locals (polylines shapes including: average annual daily traffic volumes), socio-economical characteristic Layer (polyline shapes), and climate condition Layer (polyline shapes). However, Tables 1-3 summarize the data-base elements used for each traffic volumes Layer, climate condition, and socio-economical characteristics.

Table 1: Traffic Volumes for different Streets Types

PCI	Street Type	Year	AADT	PCI	Street Type	Year	AADT
71	Arterial	2008	31004	68	Collector	2008	8487
72	Arterial	2008	32335	65	Collector	2008	11654
78	Arterial	2008	34876	67	Collector	2008	10672
73	Arterial	2008	33518	70	Collector	2008	9520
72	Arterial	2008	36450	64	Collector	2008	8543
71	Arterial	2008	23657	65	Collector	2008	7105
72	Arterial	2008	21756	72	Collector	2008	9634
74	Arterial	2008	20650	71	Collector	2008	8460

74	Arterial	2008	23657	74	Collector	2008	8543
71	Arterial	2008	21543	71	Collector	2008	9590
73	Arterial	2008	24825	74	Collector	2008	7166
70	Arterial	2008	39432	74	Collector	2008	8973
68	Arterial	2008	37985	75	Collector	2008	7533
71	Arterial	2008	35820	66	Local	2008	500
68	Arterial	2008	26414	50	Local	2008	467
71	Arterial	2008	24610	55	Local	2008	765
69	Arterial	2008	22963	40	Local	2008	485
66	Arterial	2008	34521	66	Local	2008	399
70	Arterial	2008	31870	62	Local	2008	862
73	Arterial	2008	31245	55	Local	2008	800
72	Arterial	2008	29743	56	Local	2008	830
70	Arterial	2008	30851	41	Local	2008	380
67	Arterial	2008	34678	54	Local	2008	233
74	Arterial	2008	32741	52	Local	2008	615
77	Arterial	2008	31965	53	Local	2008	579
76	Arterial	2008	29510	54	Local	2008	544
65	Arterial	2008	35423	60	Local	2008	644
63	Arterial	2008	32467	64	Local	2008	837
74	Arterial	2008	37865	45	Local	2008	755
71	Collector	2008	10423	56	Local	2008	627
70	Collector	2008	9520				

Table 2: Raw Data of Number of Vehicles on each Zone in Irbid-city

	Number of Vehicles on each Zone				Number of Vehicles on each Zone		
Zone Name	**2006**	**2007**	**2008**	**Zone Name**	**2006**	**2007**	**2008**
AL-Gami	38	40	44	AL-Nusha	503	536	588
AL-Tal	57	61	67	AL-Hikma	711	757	831
AL-Hashimi	141	150	165	AL-Worod	700	745	818
AL-Malab	285	303	333	NO Name	39	41	45
AL-Midan	397	423	464	NO Name	211	224	246
AL-Salam	650	693	760	AL-Fraha	976	1040	1141
AL-Auda	667	710	779	AL-Taba	587	625	686
AL-Nasir	314	334	367	NO Name	757	806	885
AL-Karami	500	532	584	AL-Brar	901	960	1053
Hinana	560	597	655	AL-Nadif	233	248	273
AL-Herafeen-alsharqi	6	7	8	AL-Qasila	587	625	686
AL-Zahra	544	579	636	AL-Manara	648	690	758
AL-Ndalus	472	503	552	AL-Sawani	162	173	190
AL-Shal aladar	406	433	475	AL-seha	432	460	505
AL-Rawada	355	378	415	AL-Matla	558	594	652
AL-Eman	233	248	273	AL-Marg	59	63	69
AL-Cena	32	34	38	AL-Sada	227	242	265
AL-Bada	88	94	103	AL-Aserafi	119	127	139
AL-Baqa	172	183	201	AL-Basateen	264	282	309
AL-Gamaa	840	894	981				

Table 3: Climate Condition for different Streets Types

PCI	Street type	Year	Rainful (mm)	Snow (No.snow days)	max max Temp (Cº)	Min max Temp (Cº)	Max min Temp (Cº)	Min min Temp (Cº)	Max Humidity (%)	Min Humidity (%)
71	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
72	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
78	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
73	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
72	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
71	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
72	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
74	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
74	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
71	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
73	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
70	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
68	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
71	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
68	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
71	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
69	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
66	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
70	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
73	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
72	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
70	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
67	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
74	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
77	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
76	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
74	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
71	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
70	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
68	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
65	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
63	Arterial	2008	202.9	3	33	14	22	3.7	95.9	49
65	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
67	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
70	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
64	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
65	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
72	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
71	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
74	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
71	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
74	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
74	Collector	2008	202.9	3	33	14	22	3.7	95.9	49
75	Collector	2008	202.9	3	33	14	22	3.7	95.9	49

66	Local	2008	202.9	3	33	14	22	3.7	95.9	49
50	Local	2008	202.9	3	33	14	22	3.7	95.9	49
55	Local	2008	202.9	3	33	14	22	3.7	95.9	49
40	Local	2008	202.9	3	33	14	22	3.7	95.9	49
66	Local	2008	202.9	3	33	14	22	3.7	95.9	49
62	Local	2008	202.9	3	33	14	22	3.7	95.9	49
55	Local	2008	202.9	3	33	14	22	3.7	95.9	49
56	Local	2008	202.9	3	33	14	22	3.7	95.9	49
41	Local	2008	202.9	3	33	14	22	3.7	95.9	49
54	Local	2008	202.9	3	33	14	22	3.7	95.9	49
52	Local	2008	202.9	3	33	14	22	3.7	95.9	49
53	Local	2008	202.9	3	33	14	22	3.7	95.9	49
54	Local	2008	202.9	3	33	14	22	3.7	95.9	49
60	Local	2008	202.9	3	33	14	22	3.7	95.9	49
64	Local	2008	202.9	3	33	14	22	3.7	95.9	49
45	Local	2008	202.9	3	33	14	22	3.7	95.9	49
56	Local	2008	202.9	3	33	14	22	3.7	95.9	49

7. DATA ANALYST AND INTERPRETATION

Analyst scheme was divided into five parts:

a. GIS Geostatistical Analyst for the pavement condition database through histogram Analyst, Quantity Qualitative (QQ) Plot Analyst, and Geostatistical wizard to predication models Analyst.

b. Charts Analyst for arterial roadway inventory data-base, collector roadway inventory data-base, and local roadway inventory data-base.

c. Querying options for pavement condition index assignment, budget wise-based decisions and others.

d. GIS spatial Analyst for the pavement condition database, traffic volume data-base, socio-economical characteristics through clipping Analyst (Extract by mask).

e. Developed Scheme to Integrate PAVER System and GIS.

f. Development of practical prediction models using number of variables based on the degree of their significance.

8. GIS GEOSTATISTICAL ANALYST

Geostatistical analyst extension provided tools to create, query, analyze and map cell-based raster data and to perform integrated vector-raster Analyst using feature-based and grid-based Layers. The following Geostatistical Analyst options could be performed when utilizing the pavement condition data-base:

a. Geostatistical Analyst using histogram Analyst: this part of GIS Geostatistical Analyst, give us min, max, count, mean, standard deviation, and indication of how the data-base is distribute. Pavement condition database were one of the best raw data suitable to create histogram Analyst.

b. QQ- Plot Analyst: In this part of GIS Geostatistical Analyst, give us indication of how the data-base is distribute around best fit line that refers to any range that the data are correct.

c. Geostatistical wizard to predication models Analyst**:** This part of GIS Geostatistical Analyst can use four steps for paver output data base to create model that predict values of PCI that GIS can use instead of using SPSS package Analyst.

9. CHART ANALYST

Charts are one of the strong Analyst tools available on the GIS through which general or specific fields' trends can be displayed. The chart displays tabular data as business graphics. Every chart is associated with a 'Veiw Table', from which it displays data from selected records and specified fields. Fields are specified in the chart properties dialog box or from avenue. The chart may also display a label for each record by reading the contents of a specified field, the record label field.

The values that a chart displays are contained in a two dimensional array with records in one dimension and fields in the other dimension. The values can be displayed on the chart in two ways. The first way to group fields and contrasts is by record. This is the default when a new chart is created. The second method groups by record and contrasts are by field.

King Hussein arterial suffers from highest amount of alligator cracking. This means that this section should be given the highest priority of maintenance concerning this type of distress. Classification of Arterials sections based on the quantity of each distress type can be performed for each type of distress to compute the severity of distress among all sections. This helps in giving a quick decision about what sections should have highest priorities for maintenance. Figure 3 shows Irbid arterials based on the alligator cracking existence associated with their quantities.

High arterials traffic volumes such as Yarmouk University which exposed to ADT of more than 58,000 vehicles per day to low traffic volumes such as Al-dustor arterial with ADT not exceeding 5000 vehicles per day. This variability in traffic levels covered in this study ensures the effect of such traffic variation on pavement condition status was covered.

10. QUERIES AND SYSTEM'S ADVANTAGES

Since one of the most important goals of this paper was to assign maintenance priorities based on PCI and available budget, a scheme for maintenance priorities assignment was developed. The scheme consisted of the following stages:

Stage 1: Perform an automated field survey to identify existing distresses and their quantities and severity levels. This was performed for all distressed sections of Irbid arterials, collectors, and locals.

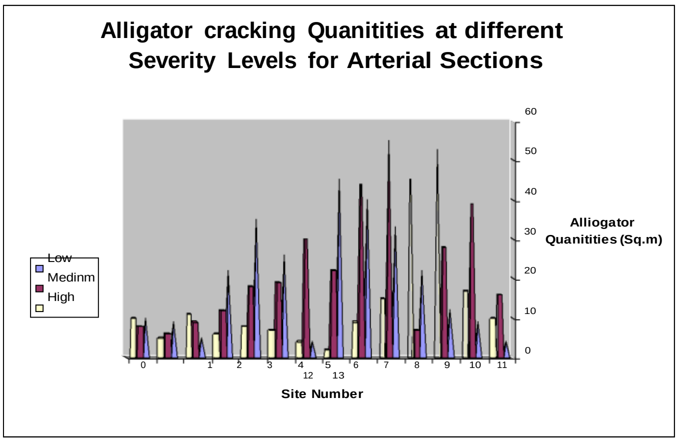

Figure 3: Arterials Classification based on Alligator Cracking Quantities

Stage 2: Collect other related data such as: geometrical elements of roads, traffic data, PSR, climate condition, etc.

Stage 3: Perform PCI computation using PAVER system.

Stage 4: Build GIS pavement condition Layer with attributes related to distresses information.

Stage 5: Select a threshold value for PCI to decide on sections to be maintained based on the available budget as discussed in previous sub-section.

Stage 6: Carry GIS query builder process using the selected threshold of PCI to find the sections contained within this query.

Stage 7: Carry another GIS query builder process to select the ranked sections based on their PCI and available maintenance budget.

Pavement condition data was fruitful material for different queries. Queries like the existence of various distresses and their respective severity levels on certain sections were helpful to study factors contributed to make such distresses appeared on those specific locations. Another advantage of the developed system was its ability to perform combinations of logical operations on the collected pavement management data. Figure 4 shows an example of the complex queries that could be built by combing expressions together with the (a*nd*) and *(or*) operators. Results of this query indicated that only one section out of 35 arterials' sections contributing to about 2.85% of the total sections of Irbid arterials contained both H-severity alligator cracking and polished aggregate types of distresses. The existence of these distresses on these sections was an indicator for high traffic volumes and poor maintenance program adapted by Irbid municipality.

Traffic volumes data were also useful for queries to obtain useful indicators for traffic variations on different arterials. The traffic variance on different arterials could be correlated in a way or another to variance of distresses occurrence on these sites. The arterials' sections with ADT values above 20.000 VPD. These sections were subjected to high traffic condition lead to high pavement deterioration rate compared to other sections. Query results showed that 27 out of 35 arterials had ADT values greater 20.000 VPD. Most of these arterials were exposed to uniform heavy traffic volumes associated with truck movements in the peak periods that resulted in higher deterioration rates.

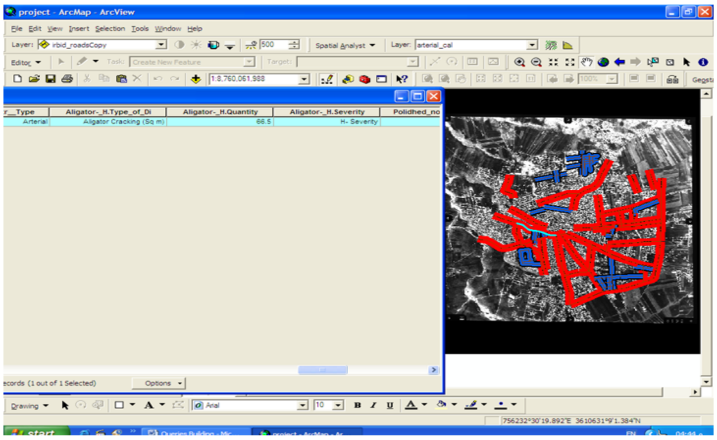

Figure 4: Example of Complex Logical Query Building Operations

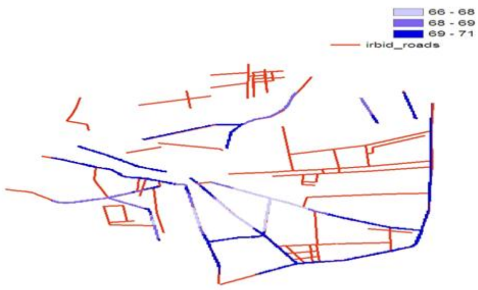

Figure 5: Clipping Results, showing PCI Values for Arterial Sections

11. GIS Spatial Analyst

Spatial analyst extension provided tools to create, query, analyze and map cell-based raster data and to perform integrated vector-raster Analyst using feature-based and grid-based Layers. The following spatial Analyst options could be performed when utilizing the collected data-base:

a. Clipping Analyst (Extract by mask) of polygon sections over density of center points of same sections could be made for pavement data-base, traffic data-base, and socio-economical characteristics.

b. Clipping operation output for arterials, collectors, and locals for PCI, PSR, Traffic, Density of populations, Ratio of number of vehicles to number of houses in every section zone. Figure 5 shows clipping results, that showing PCI values for Arterial Sections.

12. Integration PAVER System And GIS

The developed scheme to integrate PAVER system and GIS. PAVER output system was used as input shape file layers in GIS that gives a linkage for wise-based decisions in the field of highways transportation.

A new scheme has been developed to integrate GIS and PAVER System. It consists of the following steps:

1- Collect data (distress type, quantity, and its' severity) and use them as input into the data-base to run PAVER system.

2- Compute PCI, and rate of PCI, through the PAVER system.

3- Insert PAVER output data-base into ArcGIS as a shapefile.

4- Select the ArcGIS GIS shapefile layer that will make linkage between it and the PAVER shape file output layer..

5- Link the PAVER data-base shapefile layer with ArcGIS GIS shape file layer by right click on the name of the ArcGIS GIS shape file layer. Then select "Join and relate", and select join.
6- Select the section number from the " join data window" that link the two layers of the PAVER system and GIS system.
7- Check linkage by open the attribute table of ArcGIS GIS shape file layer, where PAVER output data-base became as a part of ArcGIS GIS shape file layer. Figure 6 shows a view of new GIS shape file layer after linkage.

13. DEVELOPMENT OF DISTRESS MODELS

Information related to pavement condition including: PCI, ADT, pavement age, climate condition, socio-economical characteristic were used as independent variables to develop statistical models that expressed PCI as dependent variable. The significance of these statistical prediction models was to forecast the pavement condition index given ADT, climate condition, socio-economical characteristic and pavement age by using linear multiple regression or log10 transformation models, or power multiple regression of all of previous data. Multiple regression models were used to predict these distresses according to the following equations:

PCI=-472.843+63.730*(MinofMinTemp)-1.886*(Age)+2.266*10^{-4})*(Traffic)+3.107*(Collector) (1)
-5.277*(Min Humidity)+17.170*(Max of Max Temp), for all Streets Types

PCI = 2711.871 - 500.021*log (Min of Min Temp)-20.966*log(Age)+6.750*log(Traffic)-1198.252 (2)
*log (Max Humidity), for all Streets Types.

PCI = 100 - 4.85*10 -63**(Max of Max Temp)$^{56.283}$* Age 0.633 *Traffic $^{-6.35*10-}$ (3)
for all Streets Types.

PCI = 109.544 + 7.703 *(Min of Min Temp) - 1.803 * (Age) - 0.615 * (Max Humidity), for Arterial Streets (4)

PCI = 2495.288 - 1500.74 * log (Max of Max Air Temperature) -19.188 * log (Age), for Arterial Streets. (5)

PCI= 100 - (4.29*10^{-36}) *(Age$^{0.632}$) *(Max of Max Temp$^{23.918}$), for Arterial Streets. (6)

PCI= 191.542 - 1.195 *(Max Humidity) - 1.914* (Age) +275.271 * (Density), for Collector Streets. (7)

PCI = 2656.390 - 1695.809 * log (Max of Max Air Temperature) -17.745 (8)
* log (Age), for Collector Street

PCI = 100 - (2.74*10^{10}) *(Age$^{0.729}$) *(Min Humidity$^{-5.613}$), for Collector Streets (9)

PCI= 289.846 - 2.360 *(Max Humidity) - 1.664* (Age), for Local Streets. (10)

PCI = -101.991 + 297.712 * log (Min of Min Air Temperature) -19.654 * log (Age), for Local Streets. (11)

PCI= 100 - (1.19*10^{-34}) *(Age$^{0.489}$) *(Max of Min Temp$^{26.196}$), for Local Streets (12)

Table 4 through 6 summarizes the statistical characteristics and independent variables of the developed models represented by the coefficient of multiple determinations (R^2), adjusted R^2 and significant level for each of the developed models.

Table 4: Statistical characteristics of the developed distresses models

For all Streets Types							
Model	R^2	Adjusted R^2	Significant Level	F-Value	T-Value	Df	α-acceptance Criterion
Linear Multiple Regression	0.888	0.886	0.001	384.42	-1.795	263	0.1
Logarithmic Multiple Regression	0.891	0.888	0.093	356.524	8.051	175	0.1
Power Multiple Regression	0.793	0.789	0.000	224.534	-14.661	176	0.1
For Arterial Streets							
Model	R^2	Adjusted R^2	Significant Level	F-Value	T-Value	DF	α-acceptance Criterion
Linear Multiple Regression	0.950	0.949	0.000	643.415	2.693	101	0.1
Logarithmic Multiple Regression	0.936	0.934	0.093	490.159	19.275	67	0.1
Power Multiple Regression	0.778	0.281	0.000	117.266	-6.886	67	0.1
For Collector Streets							
Model	R^2	Adjusted R^2	Significant Level	F-Value	T-Value	Df	α-acceptance Criterion
Linear Multiple Regression	0.949	0.946	0.001	417.51	48.61	68	0.1
Logarithmic Multiple Regression	0.965	0.929	0.000	308.144	17.270	45	0.1
Power Multiple Regression	0.773	0.763	0.000	76.806	6.055	45	0.1
For Local Streets							
Model	R^2	Adjusted R^2	Significant Level	F-Value	T-Value	Df	α-acceptance Criterion
Linear Multiple Regression	0.93	0.938	0.001	694.090	45.798	90	0.1
Logarithmic Multiple Regression	0.91	0.916	0.000	335.710	-10.057	59	0.1
Power Multiple Regression	0.912	0.909	0.000	304.055	-18.093	59	0.1

Table 5: Names of Independent Variables of Statistical Models.

Model Name	All Types of Streets	Arterials	Collectors	Locals
Linear Model	Min of Min Air Temperature(C°)	Age of pavement(Year)	Age of pavement(Year)	Age of pavement(Year)
	Age of pavement(Year)	Min of Min Air Temperature(C°)	Max Humidity	Max Humidity(%)
	Traffic (vehicle/day)	Max Humidity (%)	Density of population(Number/m-square)	-
	Max of Max Air Temperature(C°)			
	Min Humidity (%)			
Power Model	Min of Max Air Temperature(C°)	Age of pavement(Year)	Age of pavement(Year)	Age of pavement(Year)
	Traffic (vehicle/day)	Max of Max Air Temperature(C°)	Min Humidity (%)	Max of Min Air Temperature(C°)
	Age of pavement(Year)			
Logarithmic Model	Min of Min Air Temperature(C°)	Max of Max Air Temperature(C°)	Max of Max Air Temperature(C°)	Min of Min Air Temperature(C°)
	Age of pavement(Year)	Age of pavement(Year)	Age of pavement(Year)	Age of pavement(Year)
	Max Humidity (%)			
	Traffic (vehicle/day)			

From the values of R^2 and adjusted R^2, it is clear that the developed models could be used for prediction purposes. This result confirmed the significant role of the involved variables in each distress model on the distress development and extension. In most of the developed models ADT and Pavement age variables played the vital role in distresses development with slightly higher effect of pavement age. This result emphasized on the fact that traffic and environmental–based loads were the primer generator of distresses on flexible pavements roads. Figures 7 - 9 show SPSS relationships of linear, $\log_{10}$, and power models.

Table 6: Best Models Results of Statistical Analysis

Power Multiple Regression	Logarithmic Multiple Regression	Linear Multiple Regression	Model Name
		√	PCI for all Streets Types
		√	PCI for Arterials
		√	PCI for Collectors
		√	PCI for locals

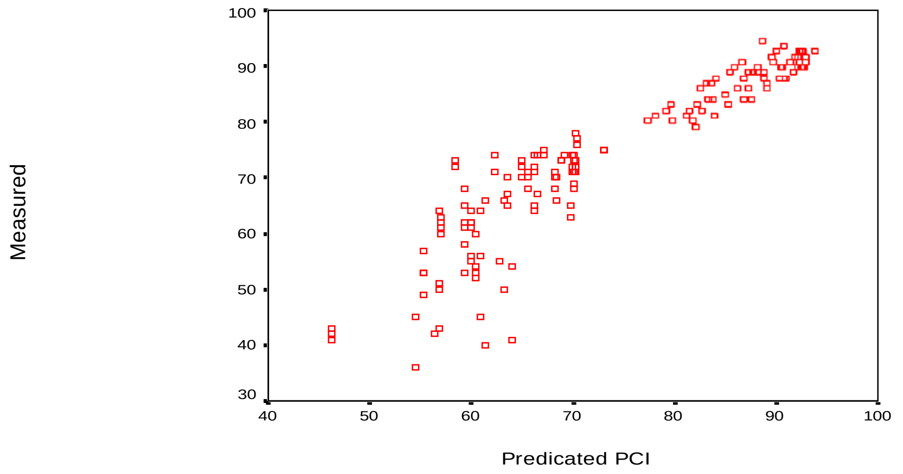

Figure 7 : Scatter plot of Predicated PCI versus Measured PCI for all Streets Types using Linear Model.

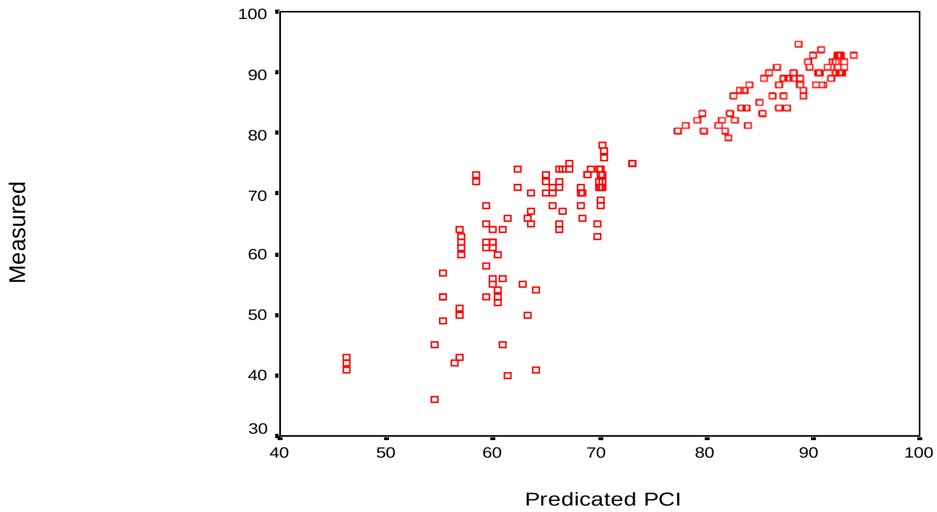

Figure 8: Scatter plot of Predicated PCI versus Measured PCI for all Streets Types using Log Model.

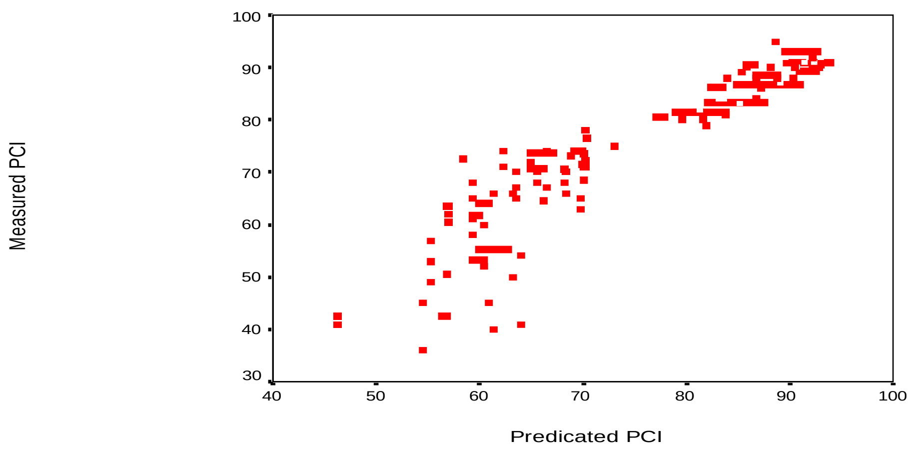

Figure 9: Scatter plot of Predicated PCI versus Measured PCI for all Streets Types using Power model

Conclusions

The following conclusions were drawn from the Analyst and modeling in this research:

1.An automated system that integrated GIS and PAVER system was developed. The system was of great help for pavement distresses data collection, Analyst, manipulation, displaying and classification. The system's development is a step toward real-time distresses classification.

2.The developed system could provide users with numerous advantages including:

a. Various analytical tools provided through the GIS system such as spatial Analyst option that include: density, clipping (extract by mask), and Geostatistical Analyst.

b. Wide space for chart Analyst – this Analyst was preformed by GIS analytical tools – that provide graphical representations of specified fields of the data-base attributes. General or specific trends characterized different fields were produced.

c. Identifying sections with certain types of distresses associated with their severity levels and quantities. This would help in assigning the concentrations of this severe types of distresses over the network, and hence. The weak pavements points on the roadway network can be identify. Therefore, pavement weakness could be improved, rehabilitated and located.

d. Performing various practical applications and different probabilities of queries. This could help in obtaining useful trends and results through query building process for pavement condition, and other data-bases.

3. A scheme that integrate the output of paver system into the GIS system was developed.

4. Pavement conditions Analyst results show that sections located in the center of Irbid city and due to their exposure to high traffic levels and low maintenance experience, suffer from different types of distresses related to traffic and pavement age parameters.

5.Statistical models were developed to quantify PCI values. These models utilized influencing variables including ADT, climate condition, socio-economical characteristic and pavement age. The developed prediction models were reliable, accurate, and highly significant represented by the high values of their respective R^2.

6.ADT and pavement age were the most important factors in predicting PCI quantities.

7.Pavement conditions Analyst results showed that sections located in the center areas and due to high traffic levels exposures and low maintenance experience, suffered from different types of distresses related to traffic and pavement age parameters.

8.The integration of GIS and PAVER system is anticipated to open the door for high technological, automated, informative, practical and reliable systems.

The following recommendations could be suggested:

1. Widening the application of such integrated system over the great municipalities to provide up-to-date, precise, and comprehensive pavement condition data-base having the capability to assign maintenance priorities activities and to compare between current and future pavement conditions.

2. Appling the PCI concept criterion to setup maintenance priorities, maintenance cost, and pavement management programs.

3. Adapting traffic management options by municipalities to relieve traffic pressure from roadway network and to reduce traffic effect on distresses development.

4. Adapting comprehensive maintenance programs based on the integrated developed system would direct maintenance activities to sections with high deterioration rates rather than random selection of streets to be maintained.

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