The Islamic University of Gaza
Deanery of High Studies
Faculty of Engineering
Civil Engineering Department
Infrastructure Engineering

الجامعة الاسلامية – غزة
عمادة الدراسات العليا
كلية الهندسة – قسم الهندسة المدنية
هندسة البنى التحتية

Development of a Pavement Maintenance Management System for Gaza City

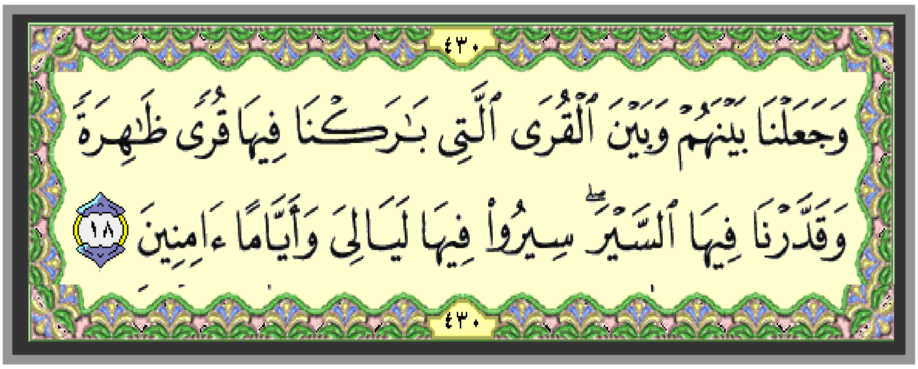
Maher Abdel Fatah Al-Hallaq

Supervised by
Associate Prof. Dr. Shafik Jendia

A Thesis Submitted in Partial Fulfillment of the Requirements for Degree of Master of Science in Infrastructure Engineering

Gaza - Palestine
January, 2004

بسم الله الرحمن الرحيم



صدق الله العظيم

سبأ (آية ١٨)

Dedication

I would like to dedicate this work to my wife and family

for their endless and generous support

Acknowledgments

First of all, all thanks and appreciations go to Allah for His unlimited blessings and for giving me the strength to complete this study.

Special thanks are extended to my supervisor Associate Prof. Dr. Shafik Jendia for his considerable effort, great help and continuous scientific directing along this study.

My appreciation is also extended to the IUG for giving me the opportunity to carry out this study. Furthermore, great thanks are also to my colleagues and lecturers in the Engineering Faculty and the Civil Engineering Department in particular for their continual encouragement and support.

Particular thanks go to Gaza Municipality; naming Eng. Munther Al Ghazali and Baha' Al Hadad for providing me all the necessary information that was helpful in accomplishing this work.

My sincere appreciation is also extended to Eng. Ramy Shameia for his valuable assistance in programming by Visual C++.

Deep thanks are to Sa'ed Al Qeshawy, Hisham Subaih, Mohammed Abu Aqlain, Mohammed Abu Sha'ban and Eng. Salih Abu Amara for their great help while performing the field inspection survey.

Finally, my most appreciations are to my parents, wife, daughters, brothers and sisters for their full support, encouragement and patience that give me the power all life.

Abstract

Gaza city, like many cities throughout Palestine, is facing a monumental challenge in dealing with aging infrastructure. For pavements in particular, it is found that many streets were built 20 or 30 years ago and they are near the end of their economic life. Other streets have been deteriorated because of misuse, overuse and mismanagement. In addition, present and future threats affect the hoped mission of these pavements for rapid, safe and comfort movements of people and goods. Moreover, the current management reveals that the system used is not flexible enough to reflect the changing conditions and poor to assist in making decisions.

This study aims to initiate a Pavement Maintenance Management System (PMMS) in which it provides a systematic process of maintaining, upgrading and operating the city pavements and tools to facilitate a more flexible approach that can enable to perform tasks better, more economically, effectively and of higher quality.

A system has been presented to facilitate the decision making process. It is based on the direct integration between Micro PAVER pavement software and GeoMedia GIS software in order to fully exploit the capabilities of each individual package. Also, a simple Graphical Interface has been developed in which it contains user-friendly menus that can help in presenting PMMS results to justify the decisions made.

A case study zone of about 14 km of roads long was inspected to analyze the proposed PMMS. Condition analysis and decisions were performed to determine maintenance needs, budgets, priorities, etc.

ملخص تواجه مدينة غزة مثل سائر المدن في فلسطين تحديا هائلا متعلقا بتقادم بنيتها التحتية. بالنسبة لرصفات الطرق على وجه التحديد، الملاحظ أن معظم هذه الرصفات قد تآكلت بسبب سوء الإستخدام، كثرة الاستخدام و سوء الإدارة. و على الرغم من كثرة التحديات الحالية و المستقبلية التي تؤثر في هذه الأرصفة إلا أنه يستدل من الإدارة الحالية لها على أن النظام المتبع غير مرن بالشكل الكافي الذي يعكس المتغيرات في وضعها و لا يساعد في عملية اتخاذ القرار. هذه الدراسة تهدف إلى تطوير نظام لإدارة صيانة رصفات الطرق في المدينة ومن خلاله يمكن وضع عملية ممنهجة لتحديث و تشغيل و المحافظة على هذه الرصفات و كذلك توفير أدوات تسهل أداء الأنشطة بشكل أفضل، أكثر اقتصادية، أكثر فعالية و بنوعية عالية. لقد تم تقديم نظام PMMS يسهل عملية اتخاذ القرار و يعتمد بشكل أساسي على التكامل المباشر بين برنامج تقييم رصفات الطرق Micro PAVER و برنامج GeoMedia كأحد برامج نظم المعلومات الجغرافية و ذلك للاستفادة من قدرات كل برنامج. و قد تم تطوير أيضا واجهة رسومية مبسطة محتوية على قوائم سهلة الإستخدام و تساعد على تقديم نتائج PMMS بشكل أفضل مدعمة بذلك عملية اتخاذ القرار.

Table of Contents

Title **Page**

Chapter Four: Development of a Pavement Maintenance Management System for Gaza City

Chapter Five: Conclusions and Recommendations

List of Abbreviations

PMMS	Pavement Maintenance Management System
GIS	Geographic Information System
GPS	Global Positioning System
MRR	Maintenance Rehabilitation and Reconstruction
CBR	California Bearing Ratio
BB	Benkelman Beam
FWD	Falling Weight Deflectometer
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
AASHTO	American Association of State Highway and Transportation Officials
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
TDV	Total Deduct Value
CDV	Corrected Deduct Value
PI	Priority Index
TF	Traffic Exposure Factor
FC	Road Classification Factor
MF	Maintenance History Factor
SR	Special Factor to emphasize Priority of Specially Designated Routs
APWA	American Public Works Association
ADT	Average Daily Traffic
FAA	Federal Aviation Administration
FHA	Federal Highway Administration
MFC	Microsoft Foundation Class
GUI	Graphical User Interface
APIs	Application Programming Interfaces
GDI	Graphical Device Interface
ID	Identification
OPG	Old Palestine Grid

List of Figures

List of Tables

CHAPTER ONE

Introduction

1.1 General

There is no doubt that the quality and efficiency of roads affect the quality of life, the health of the social system and the continuity of economic and business activity. Deterioration and catastrophic failure of these roads may occur because of aging, overuse, misuse and/or mismanagement. Therefore, their maintenance and preservation should have a great national interest.

Pavement Maintenance Management System (PMMS) is a scientific tool for managing the pavements so as to make the best possible use of resources available or to maximize the benefit for society. Thus, PMMS can be used in directing and controlling maintenance resources for optimum benefits(5).

A Maintenance Management System of a city is composed of a group of interrelated management tools designed that provide a basis for planning, scheduling, operating and controlling the highway maintenance effort with economy and effectiveness. The use of this system places continuity emphasis on the economic utilization of personnel, equipment and materials, with the available resources.

The maintenance activities need to be considered in a more flexible and integrated decision-making framework. The system should be capable of handling the various aspects in a systematic manner, in view of the changing conditions. There is a strong need to gradually introduce new technologies like Geographic Information System (GIS), Global Positioning System (GPS), work scheduling, reports and inventory management. These will enable the highway agencies to perform tasks better, more economically, effectively and of higher quality(5).

1.2 Research Problem

***Gaza City Importance*:**

Gaza city, as a part of Gaza Strip that is the main gate between Asia and Africa, has a great importance for its historical, political, and economical role. It involves a number of universities, ministries, international organizations and different institutions. Consequently, it attracts different types of transportation means. Gaza Governorate manages about 295 km long of roads in which 66 km are only in a good surface condition according to the records of Ministry of Planning and International Cooperation in 1997(6).

Current Threats:

Gaza city, like many cities throughout Palestine, is facing a great challenge in dealing with an aging infrastructure. For pavements in particular, it is sought that many streets were built 20 or 30 years ago and they are near the end of their economic life.

Indeed, as a developing city, Gaza city pavements have the following current threats:

- Increase rate of deterioration. (pavements deteriorate fast)
- Overloading of vehicles. (no commitment with the legal loading)
- Rapid traffic growth. (high increase of vehicle ownership)
- Poor maintenance. (improper materials, bad habits and wrong implementation)
- Improper design and implementation.
- Israeli occupation (direct and indirect effects)
- Limited resources (geometry, funds, equipments, materials …etc)
- Insufficient information for decision-making.
- Inefficient current traditional management system.

Future Threats:

In addition, a future challenge may face the pavements in the city. Construction of Gaza Port requires a good maintained road network for a rapid, safe and comfort movement of people and goods. It is expected that heavy loading generation will increase causing more deterioration of Gaza pavements.

***Traditional Maintenance Current System*:**

The traditional maintenance system that is currently in use in Gaza municipality reveals that:

- There is a lack of documentation. (No periodic inspections, no MRR history, etc)
- There is no use of database programs in storing and processing the system data in the Road Maintenance Department.
- The system is not flexible enough to adjust work plans and schedules to reflect changing conditions.
- The system is poor to assist in making decisions.

From the above mentioned points, there is a strong need for a comprehensive Pavement Maintenance Management System (PMMS) that involves:

Databases: facilitate the physical data of the system to be managed and allow data storing, retrieving, displaying, updating and getting information and queries.

GIS Capabilities: allow representing the inventory data and reporting in a geographical format.

Evaluation System: assists in making timely cost effective decisions related to the maintenance and rehabilitation of pavements.

Modeling System: provides information about maintenance needs, costs, priorities, etc.

1.3 Aim and Objectives

The main aim of this research is to develop a Pavement Maintenance Management System which provides a systematic process of maintaining, upgrading and operating the Gaza city pavements and tools to facilitate a more flexible approach of making the decisions necessary to achieve the road user's expectations. To achieve this goal, the following objectives are to be determined:

- Constructing a suitable database for the maintenance works of Gaza city pavements.
- Selecting an evaluation system for these pavements.
- Integrating Micro PAVER with GeoMedia professional software to review, interpret and evaluate data for supporting decisions made.
- Developing software for facilitating the management process of Gaza pavements.

1.4 Outline Methodology

In achieving the proposed system, the following steps are performed:

- Connecting Gaza pavement network into GeoMedia software with its related database.
- Breaking the Gaza pavement network into management sections.
- Inspecting the management sections and collecting their system data.
- Evaluating these sections by Micro PAVER pavement software.
- Establishing direct integration between Micro PAVER and GeoMedia databases.
- Constructing models to reflect the outputs of the systems as maintenance needs, priorities, maintenance budgets and etc.
- Applying a case study to analyze the system and obtain results.

1.5 Dissertation Contents

The chapters in this dissertation are arranged carefully in the order or sequence of steps to make it clear and understandable. Chapter One provides detailed information about the nature of this study. It discusses the research problem of the strong need of a comprehensive pavement management system for Gaza as a historical and main city. It also contains the research goals, objectives and the outline methodology.

Chapters Two and Three are oriented as a literature review about the main topic of this study; Development of a Pavement Maintenance Management System. Specifically, Chapter Two focuses only on the part "Pavement". It also illustrates the general structure of a pavement, pavement distresses, ways of failure and methods of pavement evaluation. Chapter Two also discusses pavement maintenance where maintenance aims, types, strategies, techniques and equipments are all discussed in this Chapter. On the other hand, Chapter Three emphasizes on "Management Systems". It illustrates in detail how a pavement maintenance management system can be defined and what are the benefits of installing it. This chapter also explains the general PMMS components as well as the PMMS process. It also includes, briefly, the pavement management process as it is performed in Gaza Road Maintenance Department in Gaza Municipality.

Chapter Four is considered the main core in this dissertation. It discusses the development steps of the proposed Pavement Management System for Gaza city which is the aim of this study. It also illustrates the assumed system components, the different tasks of the PMMS process and the PMMS architecture. This chapter also outlines all the practical and theoretical steps that were performed to build the proposed system.

Finally, chapter Five summarizes the findings and conclusions of this research as well as the suggested recommendations.

CHAPTER TWO

Pavement Failure, Evaluation and Maintenance

2.1 Background

Generally, pavements are divided mainly into flexible and rigid classes. Flexible pavements contribute most percent of Gaza paved roads. Therefore, focus will be concentrated on flexible pavements analysis. Figure (2.1) shows a typical flexible pavement structure. It is comprised of several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath[1, 7].

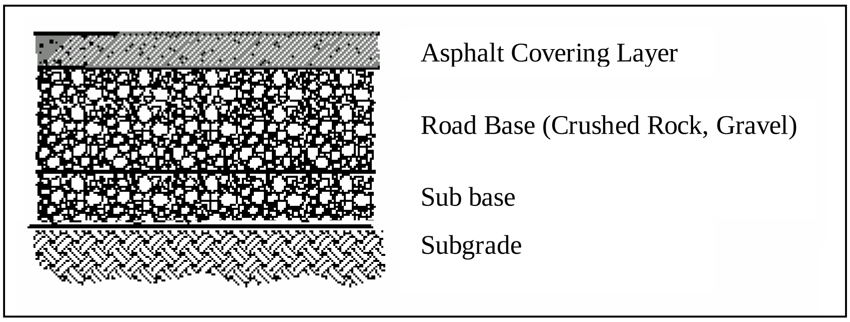


Fig. (2.1): Typical Flexible Pavement Structure.

They also support loads through bearing rather than flexural action as in rigid pavements. Figure (2.2) illustrates the distribution of load stresses in flexible pavement. The design is such that the load transmitted to each successive layer does not exceed the layers load-bearing capacity.

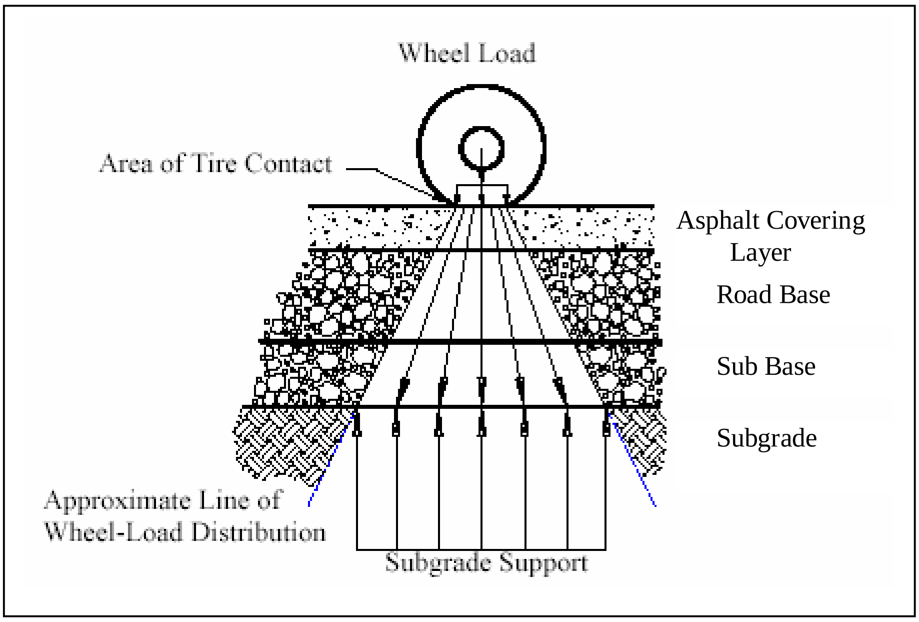


Fig. (2.2): Distribution of Load Stresses in Flexible Pavements.

The various layers comprising a flexible pavement are described below[1, 7]:

1. **Asphalt Covering Layer:** It is generally comprised of a wearing and a binder course layers. They include a mixture of various selected aggregates bounds together with asphalt cement or other bituminous binders. Its function is to prevent the penetration of surfaces water to the road base, provide smooth, well bond surface, resist the stresses and furnish a skid resistant surface.
2. **Road Base:** It is the principal structure component. It may include either crushed rock or gravel road bases. Its function is to distribute imposed wheel load to the pavement foundation: the sub base and/or subgrade. The materials comprising the base course are selected hard and durable aggregates, which are stabilized and granular.
3. **Sub Base:** This layer is used in areas where frost action is severe or in locations where the subgrade soil is extremely weak. The materials requirements are not strict as those for the road base since the sub base is subjected to lower load stresses.
4. **Subgrade:** The subgrade is the compacted soil layer that forms the foundation of the pavement system. Subgrade soils are subjected to lower stresses. The combined thickness of sub base, base and surface must be great enough to reduce the stresses occurring in the subgrade to values, which will not cause excessive distortion or displacement of the subgrade soil layer.

2.2 Pavement Distresses

Damage and deterioration of pavements are made apparent as a result of traffic, pavement and climatic or environmental factors. These factors cause surface fatigue, consolidation, or shear, developing in the subgrade, sub base, or surface[8].

Traffic factors include heavy axle-load repetitions, accelerating and decelerating traffic while pavement factors may include excess asphalt, poorly graded, inadequate particle interlock and poor subgrade drainage. Temperature variations and rainfall are examples of climatic factors that may cause damage to pavements.

The deterioration of a pavement is also apparent by various external signs and indicators called distresses. Generally, pavement distresses are fall into one of the following categories: cracking, distortion, disintegration and loss of skid resistance[7].

A. Cracking

Cracks in flexible pavements are caused by deflection of the surface over an unstable foundation, shrinkage of the surface, thermal expansion and contraction of the surface, poorly constructed lane joints or reflection cracking. The following are examples of cracks that may occur in flexible pavements[7, 9]:

1. Longitudinal and transverse cracking

A longitudinal crack follows a course approximately parallel to the centerline. On the other hand, a transverse crack runs roughly perpendicular to the roadway centerline. Both are caused by shrinkage or contraction of the asphalt surface. Development of longitudinal cracks may be accelerated due to poorly constructed lane joints.

2. Alligator Cracking

Alligator cracks are interconnected cracks that form a series of small blocks resembling an alligator skin. They may be caused by fatigue of the asphalt surface under repeated loading or by excessive deflection of the asphalt surface over unstable or weak foundations. The unstable support is usually the result of water saturation of the bases or subgrades.

3. Block Cracking

Shrinkage of the asphalt and daily temperature cycling cause block cracking. These are interconnected cracks that divide the pavement into approximately rectangular pieces. The occurrence of this distress usually indicates that the asphalt has hardened significantly. Block cracking generally occurs over a large portion of the pavement area and may sometimes occur only in non traffic areas.

4. Slippage Cracking

Slippage cracks are caused by breaking or turning wheels causing the pavement surface to slide and deform. This usually occurs when there is a low-strength surface mix or poor bond between the surface and the next layer of pavement structure. These cracks are half-moon shaped cracks having two ends pointed away from the direction of the traffic.

5. Reflection Cracking

Reflection cracks are caused by vertical or horizontal movements in the pavement beneath an overlay. These cracks reflect the crack pattern in the underlying pavement.

B. Distortion

Distortion in flexible pavements is caused by foundation settlement, insufficient compaction of the pavement courses, lack of stability in the bituminous mix, poor bond between the surface and the underlying layer of the pavement structure, swelling soils or frost action in the subgrade[(7)].

1. Rutting

A rut is a characterized as a surface depression in the wheel path. In many instances, ruts are noticeable only after a rainfall when paths are filled with water. This type of distress is caused by permanent deformation in any of the pavement layers or subgrade and is caused by consolidation or displacement of materials due to traffic loads.

2. Corrugation and Shoving

Corrugation results from a form of plastic surface movement typified by ripples a cross the surface. Shoving is a form of plastic movement resulting in localized bulging of the pavement surface. Corrugation and shoving can be caused by lack of stability in the mix and poor bond between materials layers.

3. Depression

Depressions are localized low areas of limited size. In many instances, light depressions are not noticeable until after a rain. Depressions can be caused by traffic heavier than that for the pavement was designed, by localized settlement or by poor constructing methods.

4. Swelling

An upward bulge in the pavement surface characterizes swelling. It may occur sharply over a small area or as a longer gradual wave. Both types of swell may be accompanied by surface cracking. A swell is usually caused by frost action in the subgrade or by swelling soil.

C. Disintegration

Disintegration in flexible pavements is caused by insufficient compaction of the surface, insufficient asphalt in the mix, loss of adhesion between the asphalt coating and aggregate particles or overheating of the mix[(7, 10)].

1. Raveling

Raveling is the wearing away of the pavement surface caused by dislodging of aggregate particles and loss of asphalt binder. As the raveling continues, larger pieces are broken free and the pavement takes on a rough and jagged appearance.

2. Potholes

When potholes are not accompanied by distortion of the adjacent surface, they generally result from a cracked asphalt surface which has allowed moisture to enter and soften the pavement or penetrate horizontally under the asphalt layer. Once water has entered, the cracked surfacing is prone to disintegrate and lift out under the action of traffic, particularly after rain, thereby initiating the formation of a pothole. As a general rule, repairs to potholes should be carried out before the onset of inclement weather. Any pothole which is likely to be a potential hazard to traffic should be repaired immediately after detection.

D. Loss of Skid Resistance

Loss of skid resistance is caused by too much asphalt in the bituminous mix, poor aggregate subject to wear and builds up of contaminants. Examples of this class are[7]:

1. Bleeding

Bleeding is free asphalt on the surface of the pavement caused by excessive amount of asphalt in the mix, low few voids and when asphalt fills the voids in the mix during hot weather. This type of distress often shows a shiny, glass-like reflective surface. External bleeding may cause a severe reduction in skid resistance.

2. Polished Aggregate

Aggregate polishing is caused by repeated traffic applications. It occurs when the aggregate extending above the asphalt is either very small, of poor quality or contains no rough or angular particles to provide good skid resistance.

3. Fuel Spillage

Continuous fuel spillage on a bituminous surface will soften the asphalt. Areas subject to only minor fuel spillage will usually heal without repair and only minor damage will result.

2.3 Pavement Failure

A failure of a flexible pavement is a complex phenomenon because it is an outcome of a series of interacting process. It may occur as a result of pavement deterioration due to accumulation of distresses. Distinction will be made between two different types of pavement failure: structural and functional[11]. The structural failure includes a collapse of the pavement structure or a breakdown of one or more of the pavement components that makes the pavement incapable of sustaining the loads upon its surface. On the other hand, the functional failure may or may not be accompanied by the structural failure but is such that the pavement will not carry out its intended function without causing discomfort to passengers and vehicles[8]. The functional failure causes distress in pavement surface resulting in cracks, depressions, rut-formation and poor riding quality. The difference between the two types of failure is important and distinguish between them should be easily known.

2.4 Pavement Evaluation

A major objective of pavement evaluation system is to assist highway engineer in making timely cost effective decision making related to the maintenance rehabilitation of pavements[11]. It is necessary to know the condition of pavements from the standpoint of setting up design criteria and for establishing maintenance and priority programs. Evaluation surveys give reasons why the pavement condition is as it is[8]. The pavement evaluation systems are basically categorized into two major types: functional and structural evaluation, depending on the failure type mentioned earlier.

2.4.1 Structural Evaluation

Structural evaluation deals with the quantitative assessment of structural adequacy of the pavement for rehabilitation. It is dependent upon the engineer's ability to evaluate the structural properties of the pavement components. Structural adequacy is the primary response of pavement to transient loads and consists in deflections, stresses, strains and pavement deformation at critical points in pavement layers. Evaluation techniques may include[8]:

- *California Bearing Ratio (CBR)*

  It is possible to obtain an estimate of the strength of a subgrade from original California Bearing Ratio tests that were made prior to the original design. However, densification of the road under traffic and environmental factors often make these estimates unreliable. It is possible to perform in-place field CBR tests.

- *Plate-Bearing Tests*

  Plate-Bearing tests can be made on individual components of the pavement for the purpose of determining modulus of deformation as well as the modulus of subgrade reaction. They require test pits of substantial size be dug and hence, is time consuming and often expensive.

- *Laboratory Tests*

In the evaluation of any pavement structure, it is necessary to perform standard laboratory tests for quality of the pavement components. These tests include grain-size distribution, density and moisture content. In addition, cores may be obtained of the pavement and properties can be determined by use of split tensile tests, compression tests and other laboratory tests.

- *Non-Destructive Field Tests*

There are methods of evaluating structural adequacy with instruments which apply vibratory forces to the pavements and then by means of velocity transducers, the response of the pavement is measured. In addition, there are also instruments which basically measure deflection as an evaluation tool. Some of these devices are:

1. ***The Benkelman Beam (BB)***

The beam was developed by A.C. Benkelman[8]. Figure (2.3) shows a schematic Benkelman instrument whereby deflection at the pavement surface is measured by means of a long beam. The deflections are recorded by means of a dial placed at one end of the beam; as shown in the figure, the deflection at point A is measured by means of the deflection dial at point F. The deflections are measured relative to the reference points at C and E.

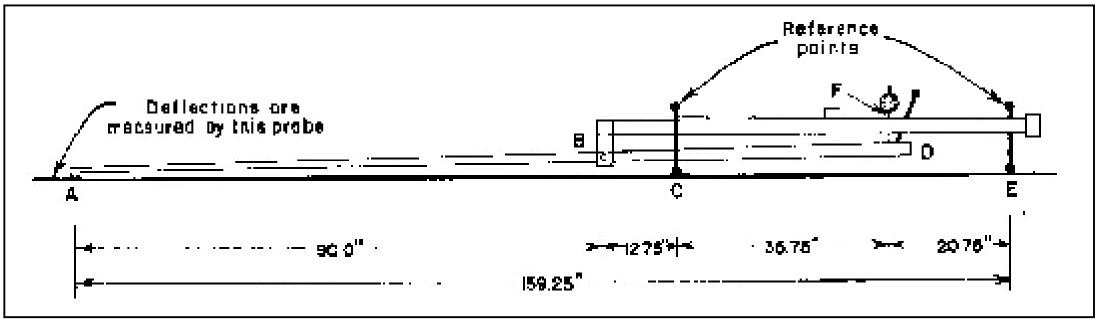


Fig. (2.3): A Schematic Benkelman Beam[8].

The BB is desired that the pointer can be placed between the dual tires of a set of duals. Generally, the measured values are the rebound of the pavement upon removal of the load.

BB measurements are taken as follows: first, the pointer of the beam is placed between the dual tires of a loaded truck over the point that is to be measured. After the dials are zeroed, the truck is driven from the location and the amount of pavement rebound is recorded as the deflection. An 18000-pound single axle is used on the test trucks. The BB principle has been mechanized so that a large number of readings can be obtained by continuous reading of deflection under a loaded axle.

2. The Falling Weight Deflectometer

Falling Weight Deflectometer (FWD) device has gained acceptance as the most efficient deflection testing due to its ability to perform rapid testing, causes no damage to the pavement, simulates actual traffic wheel loading over a large range, including very heavy loads, and its results are satisfactory. Figure (2.4) shows the Falling Weight Deflectometer device[12].

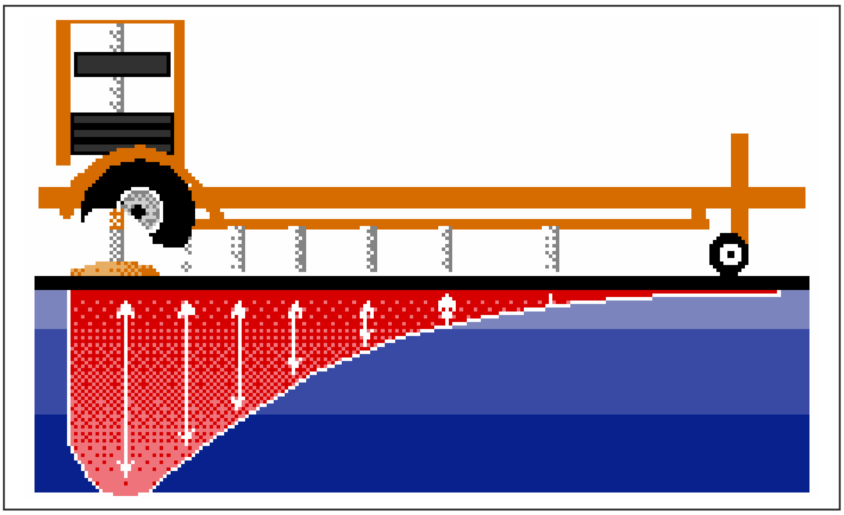


Fig. (2.4): Falling Weight Deflectometer.

The test basically involves a mass that is lifted to a predetermined height and released. The mass falls free, guided by a vertical rod, and impacts on a spring shock system resting on the pavement. The magnitude of force and duration of impulse on the pavement can be controlled by changing the height of drop and the rate of deceleration. A circular plate transmits the load caused by the decelerating mass to the pavement and the deflection of the pavement is recorded. The data obtained with the FWD is essentially the same as that obtained by using the Benkelman beam and a loaded wheel, which is the value of deflection under a specified load. This data is then used in determination of bearing strength, residual life and overlay design.

2.4.2 Functional Evaluation

Functional evaluation is a qualitative measure which is concerned with serviceability performance and deals mainly with overall behavior of a pavement and rates a pavement for its riding quality to vehicular traffic. Evaluation of the surface condition is done by the ruts, potholes, cracks, patches and uneveness of the pavement surface.

Various equipments useful in the functional evaluation pavement are Uneveness Indicator, Profilograph, Roughmeter, Bump Indicator and others. Methods of functional evaluation are:

1. Uneveness Index

The numerical Uneveness Index of the surface in cm/km length of road is useful in deciding riding quality of road. Uneveness Index values below 95 indicate excellent riding quality and above 240 indicate very poor riding quality for roads. Table (2.1) gives recommended Uneveness Index.

Table (2.1): Recommended Uneveness Index for New and Old Pavements[10].

Uneveness Index (cm/km)	Riding Quality
For New Pavements	
Below 120	Good (acceptable)
120 to 145	Fair (acceptable)
Above 145	Poor (not acceptable)
For Old Pavements	
Below 95	Excellent
95 to 119	Good
120 to 144	Fair
145 to 240	Poor (possible resurfacing)
Above 240	Very Poor (resurfacing required)

2. Present Serviceability Index (PSI)

The Present Serviceability Index Concept was first presented by Carey and Irick. It is based upon the concept of correlating user opinions with measurements of road roughness (as measured by the roughmeter or profilometer), cracking, patching and rutting. Pavements were rated on a scale runs from 0 to 5, where 0 – 1 indicated a pavement in a very poor condition, 1 – 2 was a poor condition, 2 – 3 was fair, 3 – 4 was good and 4 – 5 was very good. The average of the rating numbers for each section was termed the Present Serviceability Rating (PSR) of the section[8, 10].

The original serviceability equation for flexible pavements as developed on the AASHTO Road Test is shown below:

$$PSI = 5.03 - 1.9 \, Log \, (1 + SV) - 0.01 \sqrt{C + P} - 1.38 \overline{RD}^2$$

Where PSI = Present Serviceability Index (Pt)

SV = Mean slope variance. (measured by Slope Profilometer Instrument) Assesses surface irregularity.

C = Lineal feet of major cracking per 1000 ft^2 area

P = Bituminous patching in ft2 per 1000 ft^2 area

$\overline{RD}$ = Rut Depth in inches (both wheel tracks) measured with a 4 ft straightedge

3. *Pavement Condition Index (PCI)*

The PCI is an evaluation process that is determined in accordance with procedures contained in ASTM D 5340, Standard Test Method for Pavement Condition Index Survey. This procedure is used worldwide to provide a measurement of the condition of pavements taking into account the functional performance with implications of structural performance. Periodic PCI determinations on the same pavement will show the change in performance level with time. Because the PCI procedure is designed to be objective and repeatable, it can also be used to predict condition(14).

The PCI is a numerical rating which indicates the type and severity of the inspected distress. Figure (2.5) shows the Pavement Condition Index rating criteria.

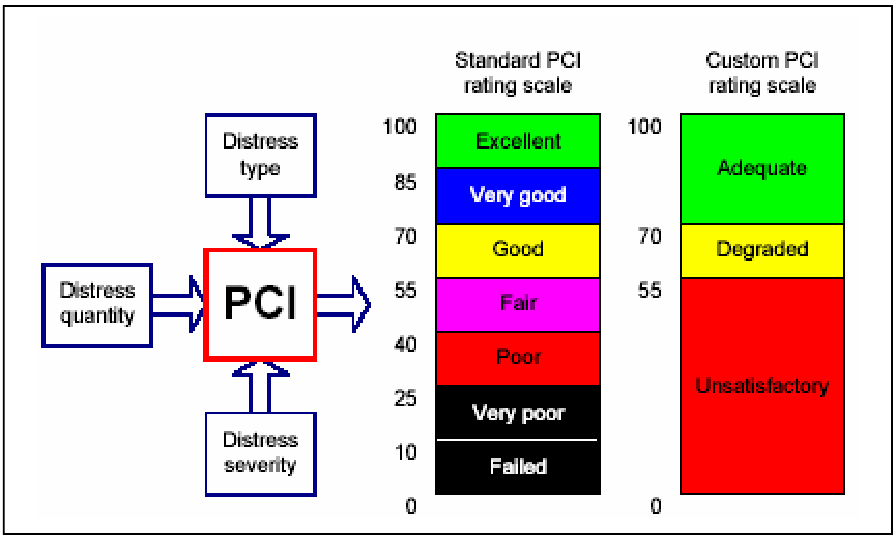


Fig. (2.5): Pavement Condition Index (PCI) Rating Criteria(15).

The steps for performing the condition survey and determining the PCI rating criteria manually are described below[16]:

1. Pavements are divided into features (sections).
2. Every pavement feature is divided also into sample units.
3. Sample units are inspected where distress types, severity and extent (density) are determined.
4. Deduct values are determined for each distress type.
5. Total Deduct Value (TDV) is computed which is the sum of all deduct values.
6. Total Deduct Value is adjusted to obtain Corrected Deduct Value (CDV).
7. Pavement Condition Index for each sample unit inspected is computed from the following equation:

$$PCI = 100 - CDV$$

8. The PCI of the entire feature is computed by taking the average of PCI's of all sample units.

2.5 Pavement Maintenance

2.5.1 General

Pavement maintenance can be defined as the planned strategy of cost-effective treatments to an existing roadway pavement system that preserves the system, retards future deterioration and maintains or improves the functional conditions of the system without including the structural capacity (does not include reconstruction or other improvements). On the other hand, highway maintenance[10] has more generality and is concerned with the task of preserving, repairing and restoring a system of roadways with its elements, to its designed or accepted configuration. System elements include carriageway surfaces, shoulders, roadsides, drainage facilities, bridges, tunnels, signs, markings and lighting fixtures.

Figure (2.6) shows a generic deterioration curve and illustrates how the overall condition of the pavement changes as it ages. When first built, the pavement is hopefully in very good condition. Typically, the condition slowly decreases in the first years of service from very good to good condition. As the pavement approaches the end of its service life, the rate of deterioration accelerates.

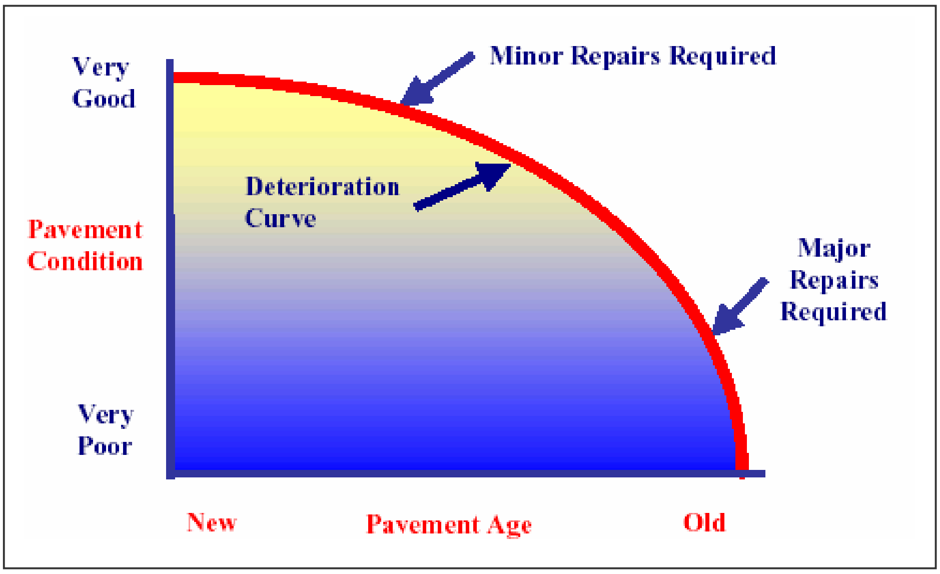


Fig. (2.6): General Pavement Deterioration Curve[17].

2.5.2 Maintenance Aim

In developing countries (as Palestine) large road networks that built at great expenses have been inadequately maintained and used more heavily than expected. From economy point of view, it is desirable that adequate maintenance operation be carried out before the existing roads get appreciably deteriorated. The approximate time to carry out maintenance is very crucial. A neglect of short term routine maintenance leads to a general deterioration, possibly to serious failure and certainly to major maintenance work. This may cost 10 times of timely preventive maintenance work[1].

A study by the World Bank which was completed some time back[18], showed that $ 45 billion invested in main roads has been eroded over the last 20 years through lack of maintenance in 85 countries. This loss could have been averted at a cost of less than $ 12 billion.

Timely maintenance programs of roads serve four main purposes:

1. Reduces the rate of deterioration and prolong life of roads.
2. Reduces vehicle operating cost by providing better riding quality.
3. Keeps roads more open continually for traffic.
4. Adds to the safety, comfort and disfatigue to the vehicle drivers and passengers.

2.5.3 Maintenance Types

Terminology concerned with highway maintenance varies considerably from country to country. It also varies from urban area to urban area and from highway authority to highway authority.

Maintenance programs can be classified according to the time of carrying out the maintenance operations as follows[10]:

1. *Routine Maintenance*: those activities that are carried out as frequently as required during each year. It could be carried out several times per a year to ensure serviceability at all times and in all weathers. It also includes normal maintenance works beginning from road sweeping, crack sealing and repair of minor damage to carriageway surfaces. In addition, urgent maintenance works, as emergency repairs to roads, may be contained in routine maintenance.
2. *Periodic Maintenance*: it covers all longer-term programmable operations required within the service life of the road. These activities which may be required only at intervals of several years may include renewal or renovation of the wearing surfaces of carriageways that become worn or deformed by use, resealing of paved roads and restoring of road markings.
3. *Extraordinary Maintenance*: it includes activities that aim to return roads to their original condition when they have severely deteriorated. Typically, they involve road strengthing, by the application of one or more structural layers (overlays) to an existing pavement, and/or reconstruction of pavement structure that has deteriorated.

Pavement maintenance activities can also be grouped and classified according to the purpose of treatment[10, 19]:

1. *Preventive Maintenance*: it is used to describe actions taken to prevent premature deterioration and/or to retard the progression of deficiencies so as to reduce the rate of deterioration and effectively increase the useful life of pavement. Preventive maintenance involves applying the right treatment to the right pavement at the right time. Figure (2.7) illustrates the benefit of preventive maintenance.

2. *Corrective (Remedial) Maintenance*: it is used to refer to maintenance actions taken to correct deficiencies which are potentially hazardous, e.g. to repair defects which seriously affects a pavement operation so as to keep the highway within a tolerable level of serviceability.

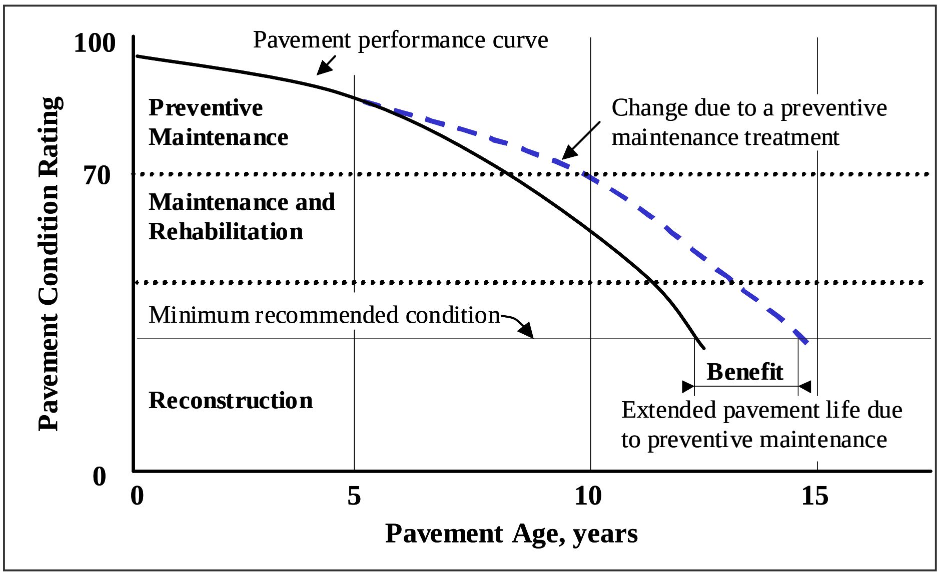


Fig. (2.7): Benefit of Preventive Maintenance[19].

In general, preventive maintenance programmes automatically include routine maintenance activities, whilst corrective maintenance actions tend to encompass many of the activities carried out in the course of routine, periodic and extraordinary programmes.

2.5.4 Maintenance Strategies

Engineering studies have determined that there are preferred strategies for the different levels of pavement deterioration. As a pavement ages and the amount of deterioration increases, the strategy changes. When the pavement is in a good condition, relatively inexpensive preventive maintenance treatments are cost-effective. When the pavement reaches the end of its design life, expensive reconstruction will be necessary. Maintenance type versus pavement condition is shown in Figure (2.8).

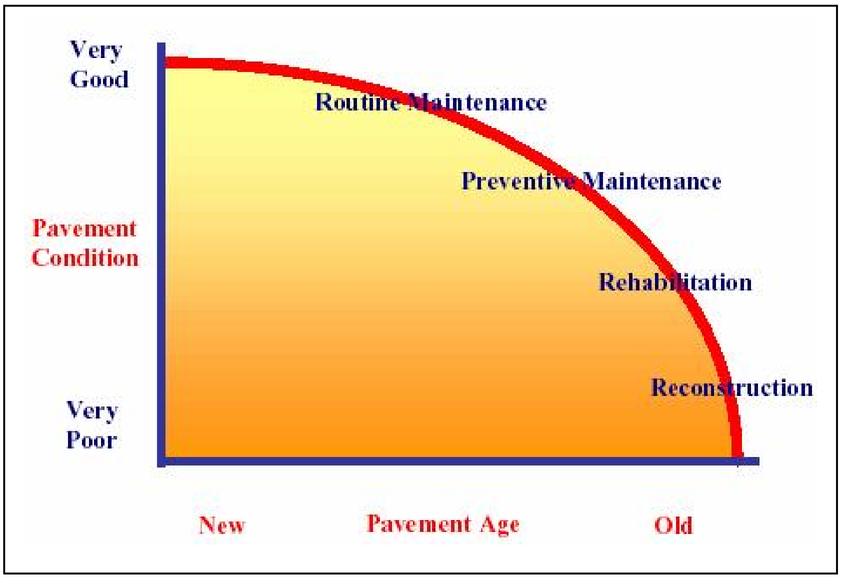


Fig. (2.8): Maintenance Type versus Pavement Condition[17].

In general, there are four maintenance/repair strategies that should be considered for road surfaces. Those are[9]:

1. *Routine Patching*

   Isolated responses to minor pavement failure caused by subgrade problems or poor pavement construction. This includes filling potholes, covering trenches dug for utility work and other miscellaneous repair.

2. *Crack Sealing*

   Placement of an asphalt sealing material in major cracks to prevent moisture from entering the pavement and causing potholes or street failure.

3. *Slurry Seal*

   Spreading a very thin layer of asphalt/sand/small aggregate mixture over the pavement to reduce moisture penetration, improve skid resistance and slows the rate of deterioration. It extends the pavement life by 3 – 5 years.

4. *Cape Seal*

   Liquid asphalt sprayed on pavement followed with a layer of small stone chips followed 1 week later with a slurry seal to reduce moisture penetration. This method can also be utilized with a rubberized asphalt mixture which improves its long term performance. It extends the pavement life by 5 – 7 years.

Slurry seals are generally applied to roads surfaces that are basically in a good condition but cape seals are applied to roads that have at least a fair condition rating.

Rehabilitation Strategies may include:

1. *Pavement Overlay*

   Adding a new layer of hot-mix asphalt to the existing pavement reduces moisture content, improves skid resistance and restores pavement surface to like new condition. It extends the pavement life by 10 years.

2. *In-Place Cold Recycling*

   It is a process with specialized equipment that grinds and removes several inches of the existing pavement surface, mixes it with a rejuvenating agent and new asphalt binder and places it back on the road. This is followed later with a thin overlay surface, improves skid resistance and restores pavement surface to like new condition.

3. Reconstruction

It occurs by removing the existing pavement and base and installing an entire new road section. This strategy is a last resort because of the high cost and disruption to traffic. Reconstructed pavements are designed to a 20 –year design period.

2.5.5 Maintenance Techniques

Remedial measures for different types of distress severity are shown in Table (2.2). As an example, rutting distress requires shallow patching when its severity is medium but deep patching is required when it is high.

Table (2.2): Remedial Measures for Different Types of Distress Severity[21].

ID	Distress Type	Distress Severity (Density)		
		Low	Medium	High
1	Alligator Cracking	X3	X1	X1
2	Block Cracking	X3	X3	X3
3	Edge Cracking	X3	X3	X1
4	Reflection Cracking	X3	X3	X1
5	Slippage Cracking	X1	X1	X1
6	Longitudinal and Transverse Cracking	X3	X3	X1
7	Corrugation and Shoving	-	X1	X1
8	Depression	-	X2	X2
9	Rutting	-	X1	X2
10	Swelling	-	X2	X2
11	Utility Cut Patching	-	X1	X1
12	Potholes	X1	X1	X2
13	Raveling	-	X4	X4
14	Bleeding	-	X5	X5

X1 = Shallow Patching   X2 = Deep Patching   X3 = Sealing
X4 = Overlaying   X5 = Spreading and rolling fine gravel aggregate

Table (2.3) shows the suggested pavement maintenance treatment according to the *PCI* condition evaluation of the network segments. When *PCI* of a segment ranges between 70 and 100 (condition is excellent or very good), routine maintenance including small patching and crack sealing is required while reconstruction is needed for segments of failed or very poor condition.

Table (2.3): Suggested Pavement Maintenance Treatment versus PCI Ranges[21].

PCI Range	Pavement Condition	Condition Class	Suggested Maintenance
70 – 100	Excellent / Very good	I	Routine Maintenance (RM)
55 – 70	Good / without effect of loads	II	Routine Maintenance (RM)
55 – 70	Good / with effect of loads	III	Very thin Asphalt Overlay layer (AO1)
25 – 55	Fair / Poor	IV	Doubled Asphalt Overlay layer (AO2)
0 – 25	Very Poor / Failed	V	Reconstruction (RC)

2.5.6 Maintenance Equipment

There are many different types and models of equipment that can be used for pavement maintenance. The equipment types that are commonly used by maintenance crews include: pavement removal, maintenance, compaction, crack and joint sealing and removal of pavement marking equipment[7].

A. Pavement Removal

1. Power Saws: These saws are capable of cutting straight line through asphalt and leaving vertical sides.
2. Cutting Disks: The cutting disk is much faster than sawing and is recommended where larger areas must be removed. However, it is limited to approximately 3 inches (75 mm) in cutting depth.
3. Jack Hammers: They are commonly used for cutting pavement surfaces.
4. Pavement Grinders: The grinder may outline an area to be patched by cutting a vertical faced trench into the existing pavement that will anchor the feathered edge of a patch.

5. Cold Milling Machines: Cold Milling Machine use a rotating mandrel with cutting bits to remove various depths of pavement material.
6. Hand Tools: They can be used to make vertical cuts through pavements as will as to break up deteriorated pavement.

B. Maintenance Equipment

1. Asphalt Kettle: They are usually small tractor mounted units that have a capacity of heating and storing 0.15 m3 to 2.0 m3 of bituminous material. These units are used for priming and tacking on small jobs and for crack or surface sealing of bituminous surfaces.
2. Aggregate Spreaders: They can be either truck mounted or separate units. They are used to evenly place a controlled amount of sand or aggregate on an area.
3. Hand Tools: They are used to move and level material after it has been placed in a patch area.

C. Compaction Equipment

1. Vibratory Plate Compactors: They are hand operated units used to compact granular base or bituminous plant-mix materials.
2. Vibratory Steel-Wheel Rollers: They are used to compact material including bituminous concrete in patch work areas. Smaller rollers can be hand operated while larger ones are self-powered.
3. Rubber-Tired Rollers: They are self-powered and used to compact bituminous concrete.

D. Crack and Joint Sealing Equipment

1. Joint Router: it is used to clear existing cracks or joints to be resealed.
2. Power Brush: A power-driven wire brush may be used to clean joints after all of the old joint sealer has been removed.
3. Air Compressors: Cracks should be blown out with compressed air immediately prior to application of new sealer.

4. Pavement Sweeper: It can be used for cleaning the pavement surface and removing excess aggregate. Cleaning operations are necessary in preparation for seal coating and crack filling.
5. Heating Kettle: It is a mobile indirect-fired double boiler used to melt hot applied sealing material.
6. Pouring Pot: It is hand carried and used to pour hot sealing materials into previously prepared cracks.
7. High-Pressure Water Sprayers: They can be used to clean out cracks prior to resealing and vertical faces of pavement to be patched.

E. Removal of Pavement Markings

1. Water Jetting: By making use of high-pressure water with proper selection of spray nozzle and pressure.
2. Abrasive Blasting: Pavement markings can be removed by the impact of edged particles accelerated by pressurized air.
3. Solvent Cleaning: Chemical agents can be employed to remove markings from pavement with proper attention to environmental concerns.

CHAPTER THREE

Pavement Maintenance Management Systems

3.1 PMMS Definition

Pavements represent a huge investment and it is very important to protect them. Initiating a PMMS can be the base to help in protecting these pavements. With this tool, decision-makers can act to preserve these road assets.

A pavement maintenance management system can be defined as a systematic methodology to assist in making decisions to provide, evaluate and maintain pavements in an acceptable condition. Its objective is to facilitate the coordination of activities and assess the consequences of decisions in a consistent manner, in order to preserve pavements in the best possible condition with available funds[(20)].

Pavement maintenance management system is also a scientific tool for managing the pavements so as to make the best possible use of resources available or to maximize the benefit for society. Thus, PMMS can be used in directing and controlling maintenance resources for optimum benefits[(5)].

The American Public Works Association (APWA) also defines a pavement maintenance management system as, " A systematic method for routinely collecting, storing and retrieving the kind of decision- making information needed (about pavements) to make maximum use of limited maintenance dollars." [(21)].

Through a systematic analysis of pavement life cycles, a PMMS can determine the most appropriate time to rehabilitate pavement, what the most cost effective method is, and how much budget it will take to maintain a roadway system at a desirable condition level.

It is also a set of steps or computer routines for quickly using the information and making the calculations necessary to arrive at these decisions.

PMMS is not an end product in itself, but rather an additional tool to help the engineer, the budget director, the maintenance manager and others to do their jobs better. In all cases, professional judgment is enhanced, not replaced by a PMMS.

3.2 PMMS Benefits

There are a number of benefits in using a PMMS instead of using engineering experience and judgment a lone. A PMMS can[(20)]:

- provide an inventory of pavements that includes data on location, type of pavement, functional classification, mileage, pavement area, etc.

- provide a comprehensive database containing information relating to pavement condition, traffic levels, construction, maintenance and rehabilitation histories, and any additional quantifiable information that may be needed or specified.
- show the current condition of the pavement network based on systematic and sound engineering procedures for obtaining objective pavement condition information.
- help to predict the projected condition of the network over time, as a function of the funds available to make improvements.
- define an estimated budget required to bring the total roadway network from its current condition to desired condition levels.
- define estimated budgets to maintain a roadway network at specific levels of performance for multiple years, i.e., 5 to 20 or more, depending on the level of sophistication included in the system.
- provide specific programs and proposed budgets for single or multi-year programming cycles.
- list ways to prioritize expenditures when funding is less than required to meet specific performance objectives.
- be a base for communication among groups such as planning, design, construction, and maintenance within an agency.
- be a base for communication among groups outside an agency, such as state legislatures, city councils, the media, public interest groups, etc.
- serve as a base for comparing alternate preservation strategies for maintenance, rehabilitation, and reconstruction of pavements within the network.
- produce a list of maintenance and rehabilitation projects. This list will be reviewed by the agency for final project selection.

A PMMS will not:

- be an "all or nothing" proposition that requires replacement of an agency's current procedures with a fully computerized system.
- act as a substitute for proper maintenance.
- replace engineering evaluation of individual projects.
- make all the decisions at the press of a button.
- provide agencies with all the answers.

3.3 PMMS Components

Pavements Maintenance Management Systems consist mainly of two major components[20]:

1. An information system to collect, store and manage data and information. It could be able to treat inventory data of the pavement segments, condition data, like distress surveys, and traffic data including ADT and heavy traffic axle loading.
2. Decision support systems to process the data and information for decision making. They include pavement condition, pavement performance, investment and engineering analysis.

Figure (3.1) shows a typical flow of data in a generic pavement management system where inventory and condition data are both analyzed to generate information that can help in decision making.

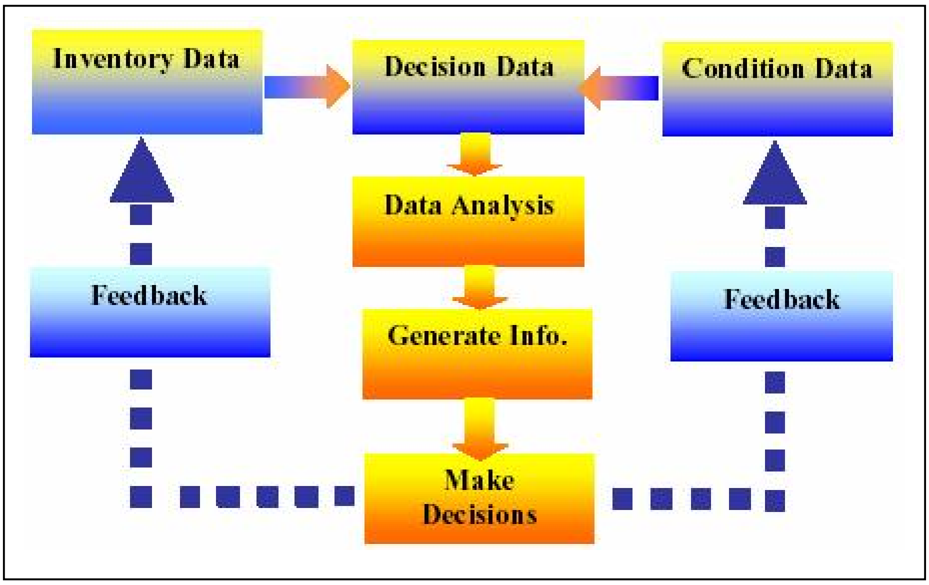


Fig. (3.1): Data Flow in a PMMS[17].

The scope and definition of a pavement management varies from one system to another and from one road agency to another. Generally, it includes the following elements for Project-level management and Network-level management[20]:

a) Location Reference System.
b) Sectioning of Network.
c) Database.
d) Data Acquisition.
e) Pavement Evaluation.
f) Pavement Performance Prediction.
g) Maintenance and Rehabilitation Planning.
h) Prioritization and Optimization.

Elements (a) to (e) constitute the information system and elements (f) to (h) constitute the decision support system.

Project-level management is concerned with selecting the most appropriate and cost effective alternative for an individual section of the road. The process is similar for both selecting the initial design and the maintenance and rehabilitation treatment for the road without any consideration of other roads in the network. Network-level management involves the assessment of needs and making decisions for funding the entire network[20].

Figure (3.2) shows a typical Highway Asset Management System in which it includes an information system, asset data and institutional data where they are all gathered in a common database and formed a decision support system through the analysis process:

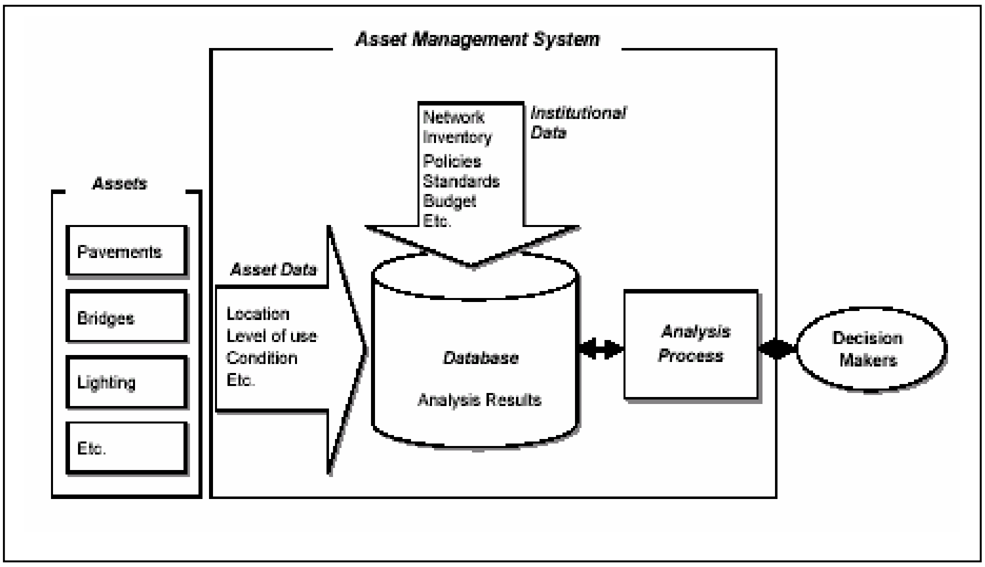


Fig. (3.2): A Typical Highway Asset Management System[22].

3.4 PMMS Process

The implementation of PMMS to a specific pavement network is completed with a systematic procedure that involves a variety of tasks on a periodic basis. This procedure is used worldwide with very little variation. A PMMS process tasks include[21]:

1. Defining the roadway network by breaking it into management segments (sections) and creating an inventory for each segment.
2. Gathering and inspecting the pavement condition and maintenance data of each segment.
3. Calculating the pavement condition assessment by selecting an evaluation criterion.

4. Determining the treatment strategy and cost for each segment based on pavement condition.
5. Developing a method of prioritizing segments when funding constraints exists in a pavement maintenance program.
6. Documenting and reporting results.

Basic PMMS tasks are discussed in detail below:

3.4.1 Network Definition

One of the key factors in building a PMMS is deciding how the network should be defined. For a roadway system to be manageable, it needs to be broken down into *branches* that may be taken as city streets. Because a street does not always have consistent characteristics and thereby does not require the same maintenance and rehabilitation treatment at the same time throughout its entire length, therefore, it is divided into smaller manageable *segments* (sections). This will also help efficiently in data collection and making analysis. Segments are defined so that the pavement within their boundaries is consistent in terms of physical and functional characteristics. Any one of the following factors could define the boundary between two segments[21]:

- A change in the number of traffic lanes.
- A change in pavement type.
- A change in traffic patterns or volume.
- A change in pavement structure (thickness, material, etc.).
- A change in natural subgrade characteristics.
- Roadway intersections
- Rivers or streams.
- City or township limits.
- Railway crossings.

It is important to note that more the sections, more records are created, maintained and manipulated resulting in more expensive data collection and processing, therefore, it is preferable to have as few sections as possible, but these must satisfy the criterion of homogeneity[20].

3.4.2 Roadway Inventory

The roadway inventory is the foundation of any pavement management system; since it supports the other system components and provides the information those components will need to function. Network management segments inventory contains all the roadways that the agency is responsible for managing. The basic purpose of the inventory is to provide information describing the pavements physical features. Certain basic information must be known about each roadway in the inventory. The minimum required data for each street segment includes[21]:

- Data entry date or construction year (last surface).
- Street name, number and segment designation.
- Beginning and ending location of the segment.
- Functional classification.
- Number of lanes.
- Pavement type.
- Pavement thickness.
- Pavement length, width and area of the segment.
- Average Daily Traffic (ADT).

This data does not change with time until major work, such as, reconstruction or realignment of the road is carried. Therefore, this data has to be collected only once.

A good inventory may require a computer system. A computer can quickly and easily manipulate large amount of data and may be desirable in many cases. An inventory can be recalled and used easily for making sound management decisions.

3.4.3 Roadway Condition Evaluation

After the pavement management inventory has been created and all the data has been collected for each segment, pavement condition evaluation can begin. Regularly scheduled pavement condition inspection is one of the most important steps in implementing a comprehensive PMMS. The purpose in performing pavement condition surveys is to document the progressive deterioration of each of the network segments.

For this data to be useful in predictive way, consistency in locating, defining, observing and recording the surface distresses is critical. In general, surface distresses are classified and rated according to type, severity and extent. The definition of severity for a given distress varies with each distress and is generally a measure of how badly or to what intensity a given defect has deteriorated. Examples are crack widths, crack deterioration or spalling and loss of material[23].

In most cases, three levels of severity are defined: low, medium and high. As an example, the severity of rutting can be determined by the average rut depth in the wheel path for the segment or sample as shown in Table (3.1):

Table (3.1): Severity Criteria for Rutting[23].

Rut Depth (inch)	Severity
1/4 - 1/2	Low
1/2 - 3/4	Medium
Over 3/4	High

More details about other distresses can be shown in reference (23). Extent is the measure of area, length or count associated with a given distress. It is how much and how far a given defect has progressed.

For determining pavement condition, the visual rating method is most commonly used. The visual rating process may be based on PCI criteria which have been discussed in Chapter Two (2.4.2). A pavement condition rating gives an approximate percentage of remaining pavement life and is primarily determined by measures of the extent and severity of pavement surface distress collected by field surveys.

Visual rating surveys may be automated or manual. The automated visual method uses a vehicle equipped with cameras that videotape the pavement surface as the vehicle moves down the roadway. This data is transferred to a tape for further processing, either by a software program or by individuals[21]. Manual visual inspections are usually performed by one or two people involving driving roadway segments at slow speeds and stopping occasionally, or walking the entire segment. Walking provides more accurate data than driving but is more expensive and time consuming.

An inspection scheduling procedure should be developed to assist in determining which segments should be reinspected. A recommended pavement condition inspection policy helps to identify those pavement segments which need reinspection and it minimizes the overall inspection effort required of the agency. A two year inspection interval after construction or after surface treatment is normal[21]. Those which are deteriorating fast should be inspected more often.

3.4.4 Maintenance Prioritization

After preparing a list of projects to be undertaken, they may need to be ranked according to their emergency, importance or cost-benefit. In most cases, funding needs may exceed available funding. One of the methods for prioritizing and optimizing will be needed in order to prepare a maintenance and rehabilitation program. The following are a list of methods for establishing priorities, however, alternate methods can be developed based on an agency's policies and administrative decisions(21):

- The matrix method can be based on such factors as condition and traffic; the highest priority is given to pavements in the worst condition and with the heaviest traffic.
- The condition index method can be based on relative scores usually ranked from zero (for worst) to 100 (for best). Priorities can combine condition score with such factors as functional classification or traffic in order to develop a final list of projects.
- The benefit-cost ratio process, the segments with the highest benefit-to-cost ratio would have the highest priority. The benefit-cost ratio can provide high priorities for pavements in fair to poor condition rather than always starting with the pavements in the worst condition.
- The cost-effectiveness procedure is similar to benefit-cost ratio except that the function is to maximize the performance of the segment while considering cost. This method does not require a "worst first" approach.
- The maximum benefits procedure is inherent in most optimization methods. For example, that group of projects from all candidate projects which maximizes the combined benefit-cost ratio or cost effectiveness for a specific budget would be selected for maintenance and rehabilitation treatments.

As an example for maintenance prioritization, the following formula was developed by (Khoury et al, 1992) (24) for priority ranking index:

$$PI = \left(\frac{1}{PCI}\right) \times TF \times FC \times MF \times SR$$

Where:

PI = Priority Index.

TF = Traffic Exposure Factor.

FC = Road Classification Factor.

MF = Maintenance History Factor.

SR = Special Factor to emphasize Priority of Specially Designated Routs.

A larger *PCI* value indicates better road condition and hence lower priority ranking number for improvement. Thus, the priority ranking system will indicate needs for maintenance as a function of *PCI* in a descending order, while the other factors modify the priority ranking index.

In South Dakota Department of Transportation in USA[(25)], the priority ranking depends on ten factors. These factors are contributed to a percentage to the priority ranking number as follows:

Surface Condition	25 %
Rideability	23 %
Remaining Surface Life	22 %
Drainage Adequacy	7 %
Surface Thickness	5 %
Surface Maintenance	5 %
Roadway Strength	4 %
Current Traffic	3 %
Current Truck Traffic	3 %
Friction	3 %

The sections are then prioritized within funding category in worst-first order. When ranks are equal, pavements with higher functional class and higher traffic volumes would prioritize ahead.

3.5 Pavement Management in Gaza City

The Department of Road Maintenance at Gaza Municipality is responsible for performing routine and periodic maintenance works for the city streets. The available resources at the Department in terms of technical skills, human resources and the quantity and condition of equipment should form the backbone for its capability to carry out the road maintenance and rehabilitation programs. From a field survey, Table (3.2) shows the available equipment at the Maintenance Department and their condition as informed by the Department Director while, the manpower is also shown in Table (3.3).

It is observed that the listed current resources (personnel and equipment) at the Department need to be updated and can not efficiently help in performing maintenance activities. For road network maintenance and due to limited resources, the Department policy depends on the application of minimal maintenance to await total road deterioration before new construction is required. This policy requires a larger amount of budget but at fewer intervals. Experience shows that the policy of application of periodic maintenance at specified condition levels is more profitable for society and easier to manage although it requires a larger budget but at less often intervals. The Department considerably suffers from budgeting constraints since its financial resources based mainly on external funds. These funds are generally presented in terms of materials and equipments.

Table (3.2): Equipment and their Condition at Gaza Road Maintenance Department.

Equipment	No.	Condition
Pick up	1	Good
Hand Roller	1	Fair
Roller #214 with driver	1	Fair
Vibration Plate	2	Poor
Excavator	1	Fair
Asphalt Saw	3	Poor

Table (3.3): Manpower at Gaza Road Maintenance Department.

Personnel	No.
Civil Engineer	1
Unit Chief	2
Technician	8
Worker	10
Coordinator	1

Good efforts were performed for evaluating different segments of Gaza pavement network through graduate projects conducted in the Islamic University of Gaza[2, 3, 4]. It may be considered the first step toward the right management to the pavement assets. All of these projects used Micro PAVER in assessing these pavement segments. References (2) and (3) recorded the evaluation results into GIS software, while Reference (4) is limited to perform comparison between manual and Micro PAVER evaluations.

Although, the following points can be highlighted:

1. These projects evaluate only individual segments of Gaza pavement network rather than the whole network.
2. There is no clear coding system that can be used to define the network segments.
3. There is also no observed linking between Micro PAVER and GIS software.
4. Needs along the network can not be determined.
5. There is no modeling analysis performed to achieve maintenance needs, budgets, etc.

CHAPTER FOUR

Development of a PMMS for Gaza City

4.1 Scope

This chapter discusses the development of the proposed Pavement Management System for Gaza City which is the main objective of this study. It illustrates the assumed system components, the different tasks of the PMMS process and the PMMS architecture. This chapter also outlines all the practical and theoretical steps that were performed to build the proposed system.

4.2 The Proposed PMMS Components

The assumed PMMS depends mainly on the following three complementary management software components:

1. *Micro PAVER*

   It is used as a pavement management tool to store the inventory information, distress data and *PCI* values. It helps in evaluating the city streets. Furthermore, roads condition assessment can be performed easily and rapidly by using this software program.

2. *GeoMedia Professional*

   It is used as a Geographic Information System (GIS) tool that offers a complete set of spatial analysis and provides a high-performance decision support.

3. *Visual C++*

   It is used as a modeling tool. It contains a simplified graphical user interface that provides information and decisions about the city maintenance needs, treatments, budgets …etc.

As stated earlier in Chapter Three, any PMMS consists mainly of two major components:

- An information system to collect, store and manage data and information.
- Decision support system to process and analyze these data for decision making.

Clearly, the above three software use the Access database format and consequently the information system is contained. In addition, the three components also have the capability to perform models and make comprehensive analysis. Therefore, the decision support system is also included within this proposed system.

4.2.1 Micro PAVER

Micro PAVER is a Pavement Management System developed by the US Army Corps of Engineers. It was first released in 1981 and supported by many agencies in the USA like US

Army, US Air force, Federal Aviation Administration (FAA) and Federal Highway Administration (FHA).

Micro PAVER aids pavement managers in deciding when and where to appropriate funds for pavement maintenance and rehabilitation. Micro PAVER provides pavement management capabilities to:

- ý Develop and organize the pavement inventory.
- ý Assess the current condition of pavements.
- ý Develop models to predict future conditions.
- ý Report on past and future pavement performance.
- ý Develop scenarios for pavement maintenance based on budget or condition requirements.

Micro PAVER inventory management is based on a hierarchical structure composed of networks, branches and sections, with the section being the smallest managed unit. Figure (4.1) shows the main page screen of the Micro PAVER.

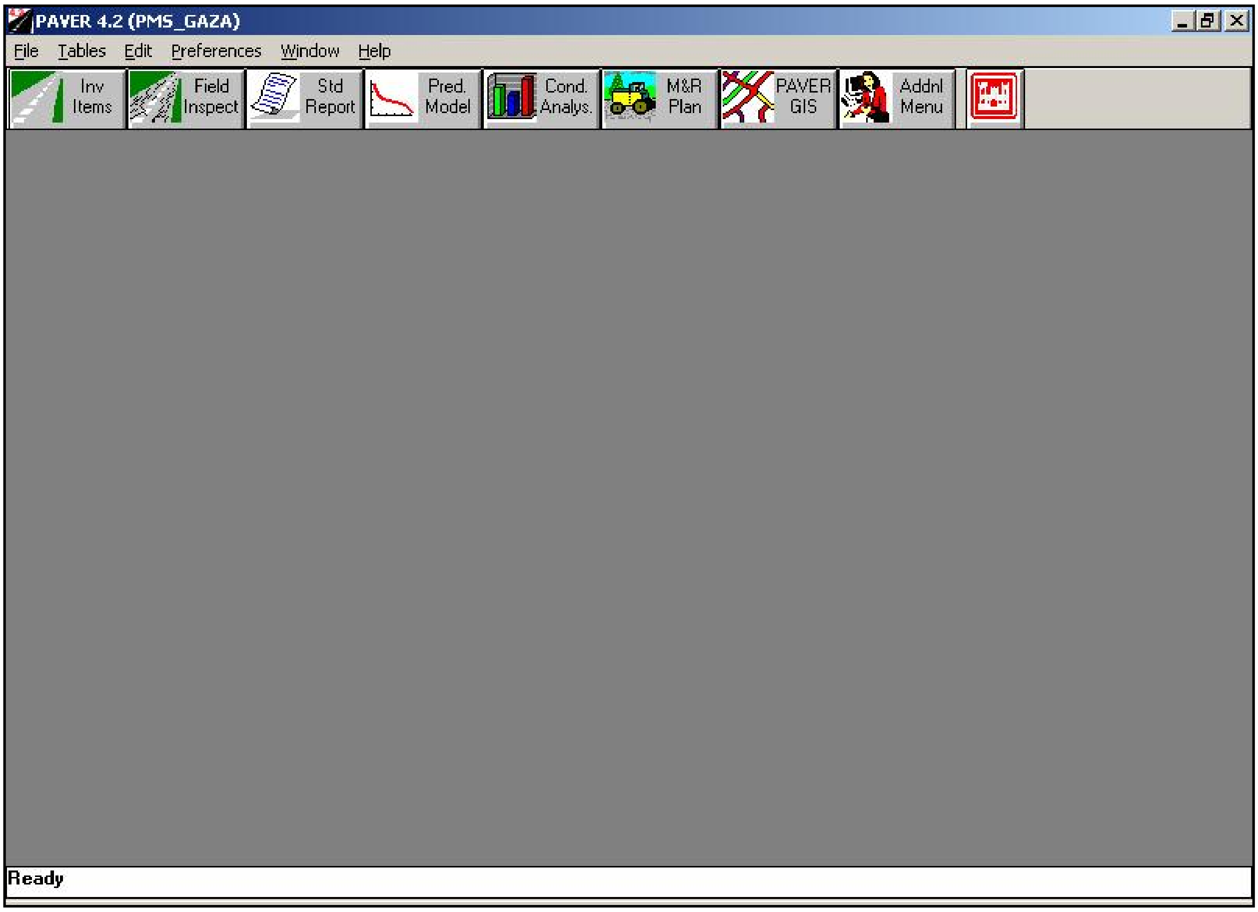


Fig. (4.1): The Main Page Screen of Micro PAVER.

To assess pavement condition, Micro PAVER uses the Pavement Condition Index (PCI) as the primary standard. Micro PAVER also provides users an interface for recording the results of an inspection. In addition, condition analysis, condition prediction and work plans can be made by it.

4.2.2 GeoMedia Professional

Intergraph GeoMedia Professional is the first spatial data collection and management product specifically designed to work with standard relational databases. It is focused on high productivity data capture and editing, data analysis and reporting. It also includes all the power to provide a complete GIS solution from capture, display and output. GeoMedia also provides high-performance decision support and establishes new ways of communicating geographically.

GeoMedia Professional supports a variety of data development categories, including vector and raster registration, digitizing, feature editing, attribute processing, geometry and connectivity validation, bulk database loading and data import and export.

GeoMedia Professional contains several settings that can be used as needed. SmartSnap settings automatically identify features such as vertices, endpoints, origins, midpoint, raster corners, intersections, end of lines, open and closed symbols and centers. SmartSnap tools guarantee that the desired topological relationship exists and ensure accurate digitizing and editing with minimal view display adjustments.

There are several different approaches to data collection and development work flows. Users can digitize all the graphics and then add nongraphic feature attributes. Conversely, users may work with features that have attributes but no geometry. A third approach is to attribute the geometry as it is digitized. GeoMedia Professional can automatically produce an attribute entry dialog as each feature is digitized.

To view feature data in a GeoWorkspace or to import features into a read/write warehouse type, a warehouse connection must be first established. The warehouse connection wizard allows to connect easily to warehouses and to edit existing warehouse connections. It can be connected to data created in the following formats:

- ACCESS
- ARC/INFO
- ARC View shapefile
- MapInfo
- FRAMME™
- ODBC Tabular
- Oracle Object Model
- CAD (AutoCAD, Micro Station/IGDS)
- Modular GIS Environment (MGE)
- SQL Server Read-Only Server
- SQL Server Read/Write Server
- MGE Data Manager (MGDM)
- MGE Segment Manager (MGSM)
- Oracle Relational Model

4.2.3 Visual C++

Visual C++ is an object-oriented C++ compiler from Microsoft and is used as a tool for programming under windows environment. Microsoft Visual C++ is a powerful tool that contains everything necessary to create anything from simple console DOS programs to sophisticated application for 32-bit Windows applications.

The Microsoft Foundation Class Library (MFC Library) is a C++ class library released with Microsoft Visual C++ to support application development on Microsoft Windows. Although, MFC is most often used in Graphical User Interface (GUI) applications, it can be used to develop any type of application. The MFC Library consists of a numerous classes that are thin wrappers for high level Application Programming Interfaces (APIs). All the Win32 Kernel, Graphical Device Interface (GDI) and user objects have associated MFC classes. The MFC library is called a vertical library, as it uses class inheritance heavily with very little C++ templates.

4.3 PMMS Process

The implementation of PMMS to Gaza pavement network is completed with a systematic procedure that involves the following tasks on a periodic basis:

1. Defining the Gaza roadway network by breaking it into management segments and creating an inventory for each segment.
2. Inspecting and Gathering the pavement condition and maintenance data of each segment in the network.
3. Calculating the pavement condition by selecting an evaluation criterion.
4. Determining the treatment strategy and cost for each segment based on pavement condition.
5. Developing a method of prioritizing segments when funding constraints exists in a pavement maintenance program.
6. Documenting and reporting results.

These tasks are illustrated in the following chart in Figure (4.2) and discussed below:

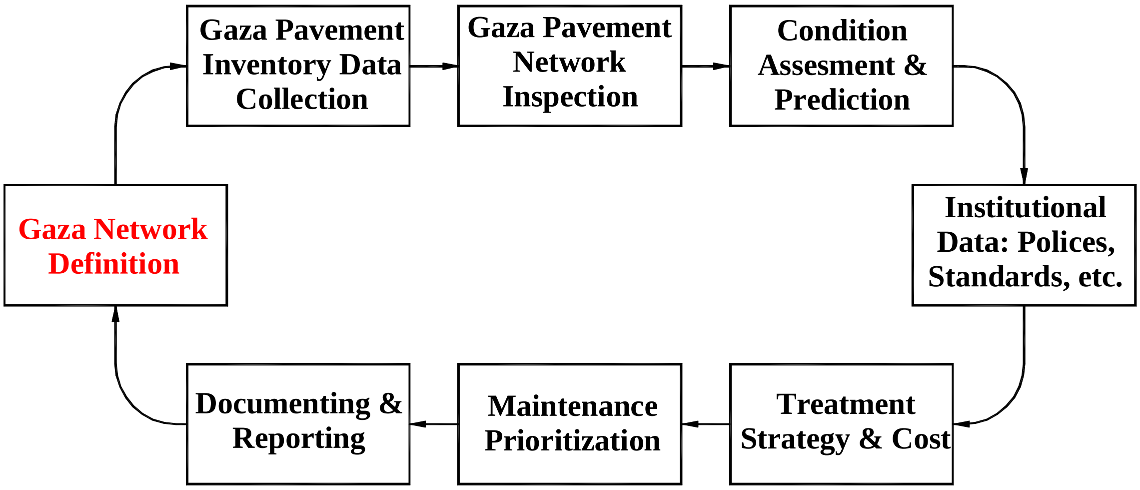


Fig. (4.2): Gaza PMMS Process.

4.3.1 Gaza Roadway Network Definition

For a pavement network to be defined, it is very important to choose a detailed referencing system. A referencing system defines one segment of a pavement network from another. Actually, Gaza Municipality has already established a street coding for its roads and buildings to help in field surveys in order to improve the quality of services offered to the citizens. In this research, it is better to make use of this road coding but with some modifications in sectioning to suit with pavement maintenance requirements.

Gaza roads are classified functionally into the following three categories:

1- *Arterial Roads*

Those roads that pass through the whole city and they hold numbers taking the Identification (ID) form (X00), where X is between 1 and 9.

2- *Main Roads*

They are the roads that have large lengths and widths and they are considered as main roads. They are given the ID form (XX0).

3- *Local Access Roads*

The roads that have small lengths and widths and they are numbered in the ID form (XXX).

Two major roads are selected as reference roads: Ommar Al-Mukhtar and Al Rasheed Streets. The first extends longitudinally from west to east and given road ID 200. The other extends transversely from north to south and given road ID 100.

Each road should have a unique code number. Other roads are numbered according to the following criteria:

- Longitudinal arterial roads (X00) have even numbering:

Road Name	Road ID	Road Name	Road ID
Ommar Al-Mukhtar Str.	200	Baghdad Str.	400
Khalil Al-Wazeer Str.	600	Street No. 8 (Own Al-Shawa)	800

- Transverse arterial roads (X00) have odd numbering:

Road Name	Road ID	Road Name	Road ID
Al Rasheed Str.	100	Al Aqssa Str.	300
Al Jalaa Str.	500	Salah Eddin Str.	700
Al Karama Str.	900		

- Longitudinal main roads (XX0) have even numbering to the right of the reference longitudinal arterial but odd to the left as follows:

  R: 220, 240,….280, …...420, 440, …...480, ..….620, …...820, etc

  L: 210, 230,….290, …...410, 430, …...490, ..….610, …...810, etc

- Transverse main roads (XX0) have even numbering to the right of the reference transverse arterial but odd to the left as follows:

  R: 120, 140,….180, …...320, 340, …...380, ..….520, …...720, etc

  L: 110, 130,….190, …...310, 330, …...390, ..….510, …...710, etc

- Local access roads (XXX) have even numbering if they are to the right of the longitudinal reference road (Ommar Al-Mukhtar street) and they are odd if they are to the left of it.

- Any continuous road intersects with a reference road has two numbers. As Al Kanal and Al Jalaa streets.

- Any road that has a length more than 100 m should have a single number.

- If the road length is less than 100 m, it will have a sub number of the road that is perpendicular to it. For example, if a street has length less than 100 m and perpendicular to another street has ID 270, the number of this street will be 2701, 2702, …..etc.

For Gaza pavement network system to be efficiently managed, it is broken down into small units, branches, where they are taken here as the city streets. Because a branch does not always have consistent characteristics and thereby does not require the same maintenance and rehabilitation treatment throughout its entire length, therefore, it is divided into smaller manageable *sections* (segments). To identify these sections, they must be measured from one reference point to another. The boundary between two sections of a branch in Gaza network is defined according to one of the following factors:

- A change in the number of traffic lanes.
- A change in pavement or surface type.
- A change in pavement width.
- Roadway major intersections.
- Gaza city limits.
- Recommended length (every one km, one mile or others).
- Pavement condition.

While dividing the network into sections, it is important to identify each one with a unique number. Numbering the sections is very important to ensure that those using the PMMS can easily identify the segment and locate them for inspections and repair work. The start of numbering for the longitudinal branch sections is chosen to begin from the transverse reference road (Al Rasheed Str.) or from west to east. On the other hand, numbering of any transverse branch sections begins from the reference longitudinal road (Ommar Al-Mukhtar Str.) i.e. from south to north for those roads to the right of Ommar Al-Mukhtar Str. and from north to south to roads to the left of Ommar Al-Mukhtar Street. Exceptions are made to the transverse branches, Al Rasheed, Salah Eddin and Al Karama streets where numbering begins from north to south without referring to the reference road (Ommar Al-Mukhtar Str.). As an example for branch sections numbering:

- Al Rasheed Str. which has ID 100 is divided to 9 sections (1/100, 2/100, 3/100, …9/100) starting from the northern boundary of Gaza city.
- Mostafa Hafiz Str. which holds number 360 has sections 1/360, 2/360, etc. Numbering starts from Ommar Al-Mukhtar Str.
- Branches, that have medians, are divided into sections holding the symbols R or L to define the location of the section right or left this median. Example: 2R/800, 2L/800, etc

4.3.2 Network Data Collection

This section covers the inventory data collection, Gaza pavement network inspection and institutional data tasks shown in Figure (4.2). Once the network is in manageable sections, all the data associated with each section needs to be collected. The network data collection is the foundation of any pavement management system. The intent of gathering data is to collect enough detailed information about the network to relate it to pavement condition, traffic, cost and funding. The process of collecting general data can be accomplished over time and should be done in three phases:

- Determining the types of data needed.
- Determining which data already exists in office records.
- Determining the remaining data which must be gathered by a survey team.

One of the most required data is the *inventory* data. The basic purpose of this inventory is to provide information describing the pavement physical features. A survey team should be selected to conduct the physical inventory. The team members should have a basic knowledge of roadways in the network, the concept of sectioning and reference points and the inventory data collection procedure. As much data, as possible, should be gathered in the office before beginning the field inventory. Generally, the inventory is recorded once and will not be updated unless physical characteristics change.

It is important to realize that the PMMS is only as good as the data stored in a database. The minimum required data for each street section includes:

- Data entry date or construction year (last surface).
- Street name, number and section designation.
- Beginning and ending location of the section.
- Functional classification.
- Number of lanes.
- Pavement type.
- Pavement thickness.
- Pavement length, width and area of the segment.
- Average Daily Traffic (ADT) and traffic composition based on truck data.

Another type of required data that need to be calculated is the *institutional* data. The institutional data will include administration goals, policies, standards, resources, budget details and annual constraints.

After the pavement management inventory and institutional information have been created and all the data has been collected, pavement *condition* data survey can begin. Regularly scheduled pavement condition inspection is one of the most important steps in implementing a comprehensive PMMS. The purpose in performing pavement condition surveys is to document the progressive deterioration of each network section.

For Gaza pavements in particular, an extensive field survey was performed to collect the network system and condition data. Unfortunately, a lot of difficulties were faced either due to insufficient information or nonexistent of previous office records (traffic data, system data, etc). Although, satisfactory inventory database was created about the city pavement sections including street name, street ID, section ID, section length and width, etc. Table (4.1) shows the major branches that are considered in the network. These branches constitute a large representative sample and additional branches or branch sections can be added in the future as needed.

Information about sections can be shown in Table (4.2) which illustrates part of the section data in Gaza pavement network. As an example, the table shows section ID, number of lanes, surface type, true area and inspection date for each branch section. Section (1/100) of branch Al Rasheed Street has Asphalt Concrete (AC) surfacing and its true area is 4900 m^2.

Evaluating the condition of Gaza pavement network will be based on detailed visual inspection survey. It deals with the identification of pavement distress type, its extent and the level of severity of each type and it is also based on PCI criteria. Although, other methods including automated data collection, hand held computers, tablet computers or pocket inspectors may be developed to facilitate inspection and to eliminate data entry errors.

As a case study, a visual inspection survey was conducted to a case study zone illustrated in Figure (4.3). This zone is bordered by the segments of roads of Al Aqssa, No. 8, Al Rasheed and Jammal Abdel Nasser streets. It is also been throughout by Jammet Al-Doul, Al Quds, Tunis, Mostafa Hafiz and Cairo streets with approximately 14 km long of roads.

Table (4.1): Major Branch Data in Gaza Pavement Network.

Branch ID	Branch Name	Number of Sections	True Area (SM)
100	Al Rasheed	9	57,080.00
116	Sharl Degool	1	4,340.00
128	Al Majdal	1	3,780.00
160	Al Quds	3	13,440.00
170	Ezeddin Al Kassam	6	24,568.00
190	Al-Nassr	12	41,720.00
200	Ommar Al-Mukhtar	16	62,840.00
20285	Bostan	2	7,840.00
20661	Abu Bakr	1	9,800.00
230	Al Wehda	8	39,144.00
240	Jammal Abdel Nasser	10	38,570.00
300	Al Aqssa	6	24,080.00
340	Jammet Al-Doual Alarabia	4	17,108.00
360	Mostafa Hafiz	2	11,760.00
380	Al Moghrabi	4	22,680.00
390	Al Yarmouk	7	21,945.00
400	Baghdad	4	25,770.00
420	Buirut	3	9,170.00
422	Al Basateen	2	4,620.00
430	Al Sahaba	3	8,750.00
460	Cairo	3	8,610.00
500	Al Jalaa	12	59,745.00
520	Najm Eddin Al Gazzi	1	2,100.00
526	Al Kanal	2	6,440.00
530	Port Saed	6	12,810.00
546	Ali Bin Abi-Talib	1	2,450.00
560	Om Al-Limon	2	3,220.00
570	Yafa Str.	3	15,050.00
600	Khalil Al-Wazeer	13	71,494.00
690	Ommar Bin Al Khatab	6	33,152.00
700	Salah Eddin	16	82,320.00
710	Fahmi Bake	1	1,015.00
780	Al Mamadani	1	2,100.00
800	Street No. 8	16	51,260.00
810	Ghassan Kanafani	2	6,984.00
830	Salah Khalaf	8	39,620.00
870	Al Shaaf	4	17,280.00
880	Al Mannsoura	3	17,460.00
900	Al Karama	5	30,520.00
940	Al Shamaa	3	9,170.00
986	Ferass	1	2,380.00

Table (4.2): Part of Section Data in Gaza Pavement Network.

Branch ID	Branch Name	Section ID	Inspect. Date	Surface	Lanes	True Area (SM)
100	Al Rasheed	1/100	09/01/2003	AC	2	4,900.00
100	Al Rasheed	2/100	09/01/2003	AC	2	10,150.00
100	Al Rasheed	3/100	09/01/2003	AC	2	2,310.00
100	Al Rasheed	4/100	09/01/2003	AC	2	2,905.00
100	Al Rasheed	5/100	09/01/2003	AC	3	7,665.00
100	Al Rasheed	6/100	09/01/2003	AC	3	7,800.00
100	Al Rasheed	7/100	09/01/2003	AC	3	4,300.00
100	Al Rasheed	8/100	09/01/2003	AC	3	9,850.00
100	Al Rasheed	9/100	09/01/2003	AC	2	7,200.00
116	Sharl Degool	1/116	09/01/2003	AC	2	4,340.00
128	Al Majdal	1/128	09/01/2003	AC	2	3,780.00
160	Al Quds	1/160	09/01/2003	AC	2	3,990.00
160	Al Quds	2/160	09/01/2003	AC	2	2,940.00
160	Al Quds	3/160	09/01/2003	GR	2	6,510.00
170	Ezeddin Al Kassam	1/170	09/01/2003	AC	3	5,460.00
170	Ezeddin Al Kassam	2/170	09/01/2003	AC	3	3,870.00
170	Ezeddin Al Kassam	3/170	09/01/2003	AC	3	4,788.00
170	Ezeddin Al Kassam	4L/170	09/01/2003	AC	2	2,880.00
170	Ezeddin Al Kassam	4R/170	09/01/2003	AC	2	2,880.00
170	Ezeddin Al Kassam	5/170	09/01/2003	GR	2	4,690.00
190	Al-Nassr	1L/190	09/01/2003	AC	2	2,730.00
190	Al-Nassr	1R/190	09/01/2003	AC	2	2,730.00
190	Al-Nassr	2L/190	09/01/2003	AC	2	3,780.00
190	Al-Nassr	2R/190	09/01/2003	AC	2	3,780.00
190	Al-Nassr	3L/190	09/01/2003	AC	2	3,010.00
190	Al-Nassr	3R/190	09/01/2003	AC	2	3,010.00
190	Al-Nassr	4L/190	09/01/2003	AC	2	3,360.00
190	Al-Nassr	4R/190	09/01/2003	AC	2	3,360.00
190	Al-Nassr	5L/190	09/01/2003	AC	2	4,690.00
190	Al-Nassr	5R/190	09/01/2003	AC	2	4,690.00
190	Al-Nassr	6L/190	09/01/2003	AC	2	3,290.00
190	Al-Nassr	6R/190	09/01/2003	AC	2	3,290.00

A pavement condition inspection form was prepared for this purpose. This form containing for example the condition data of Jammet Al-Doual Alarabia street is shown in Figure (4.4).

Not all parameters need to be inspected every year, but an inspection scheduling procedure should be developed to assist in determining which sections should be re-inspected. A recommended pavement condition inspection policy minimizes the overall inspection effort of the city. A 2-3 year inspection interval at maximum is recommended [21].

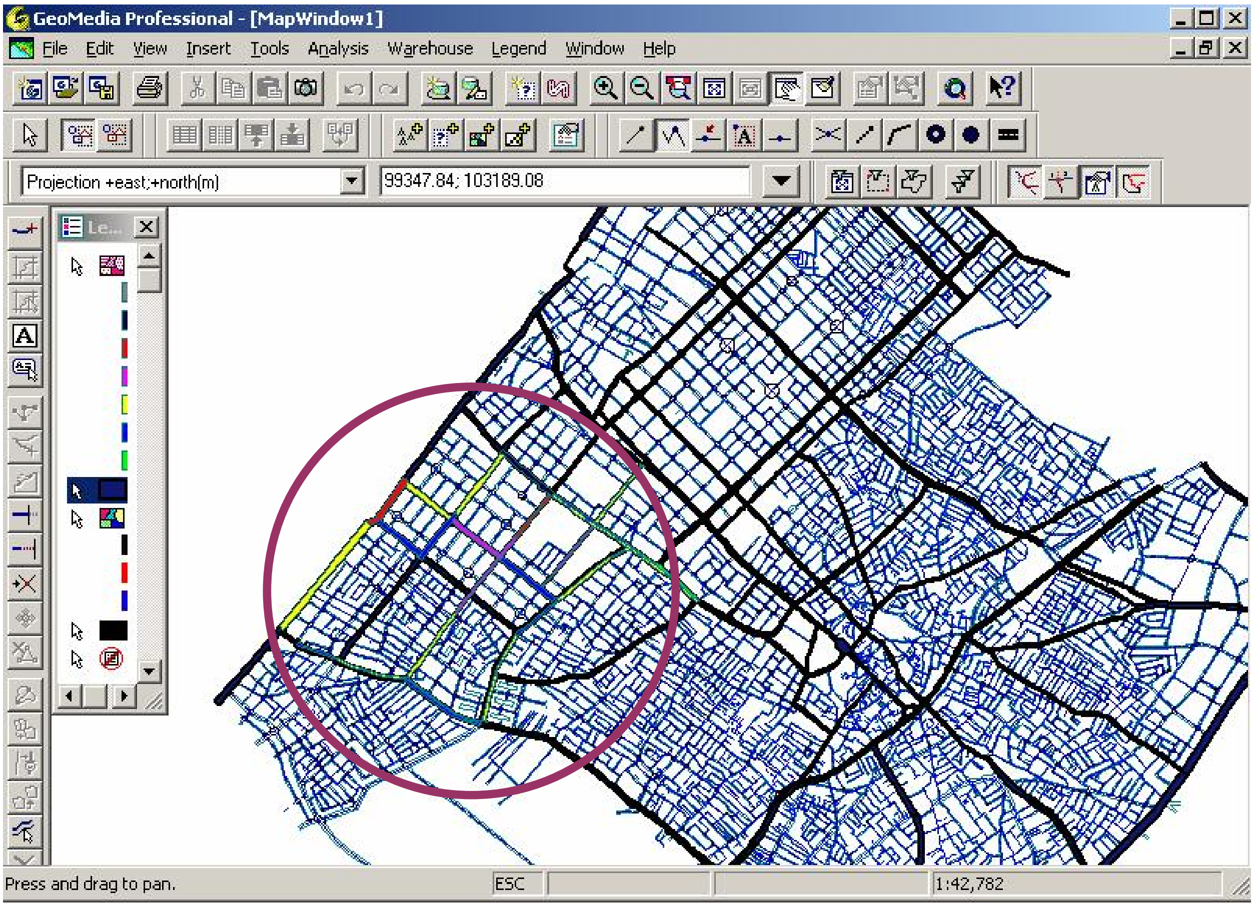


Fig. (4.3): The Case Study Zone.

INVENTORY INFORMATION		**DATE: 1/9/2003**
Street name: Jammet Al-Doul Alarabia	Street ID: 340	Functional class: Μαιν
Section ID: 2/340	From: 280	To: 420
Section length: 170 m	Section width: 7 m	Number of lanes: 2

DISTRESS INFORMATION

1. Alligator Cracking	8. Reflection Cracking	15. Rutting
2. Bleeding	9. Lane/Shoulder Drop Off	16. Shoving
3. Block Cracking	10. Long. & Trans.	17. Slippage Cracking
4. Bumps and Sags	11. Patching & Util. Cut	18. Swell
5. Corrugation	12. Polished aggregate	19. Weathering & Raveling
6. Depression	13. Potholes	
7. Edge Cracking	14. Railroad Crossing	

Distress type		5	6	10	11	12	15	19	
		80 L	5 M	3 H	5 M	80	20 L	5 L	
		81 L	5 H	10 L	10 M	80	30 L		
				20 M	5 M				
				15 L					
Total Severity	Low	161 L		25 L			50 L	5 L	
	Medium		5 M	20 M	20 M	160			
	High		5 H	3 H					

Comments:

Notes: 1. Distress (13) is counted as *number* of potholes.

2. Other distress types are measured in m^2 except (4 – 7 – 8 – 9 – 10) in *m*.

Fig. (4.4): Pavement Condition Inspection Form for Jammet Al-Doual Alarabia street.

4.3.3 Condition Assessment and Prediction

After inspecting the pavement network, the condition assessment of each section is performed by using Micro PAVER. The PCI value for each section or branch can then be determined and consequently the current condition can be identified. Table (4.3) shows the condition of the case study zone sections as calculated by Micro PAVER.

Table (4.3): The PCI Values of the Case Study Zone Sections.

Branch ID	Branch Name	Section ID	Inspection Date	Lanes	Section Area m^2	PCI
100	Al Rasheed	7/100	09/01/2003	3	4,300.00	28.00
100	Al Rasheed	8/100	09/01/2003	3	9,850.00	65.00
160	Al Quds	1/160	09/01/2003	2	3,990.00	59.00
160	Al Quds	2/160	09/01/2003	2	2,940.00	75.00
240	Jammal Abdel Nasser	2/240	09/01/2003	2	3,500.00	14.00
240	Jammal Abdel Nasser	4R/240	09/01/2003	2	4,760.00	67.00
240	Jammal Abdel Nasser	3R/240	09/01/2003	2	4,410.00	70.00
240	Jammal Abdel Nasser	3L/240	09/01/2003	2	4,410.00	84.00
240	Jammal Abdel Nasser	4L/240	09/01/2003	2	4,760.00	86.00
300	Al Aqssa	3R/300	09/01/2003	2	4,830.00	66.00
300	Al Aqssa	1R/300	09/01/2003	2	4,410.00	69.00
300	Al Aqssa	2R/300	09/01/2003	2	2,800.00	74.00
340	Jammet Al-Doual Alarabia	1/340	09/01/2003	3	4,095.00	37.00
340	Jammet Al-Doual Alarabia	2/340	09/01/2003	2	1,190.00	55.00
340	Jammet Al-Doual Alarabia	3/340	09/01/2003	3	5,680.50	55.00
340	Jammet Al-Doual Alarabia	4/340	09/01/2003	3	6,142.50	59.00
360	Mostafa Hafiz	2/360	09/01/2003	2	6,090.00	51.00
360	Mostafa Hafiz	1/360	09/01/2003	2	5,670.00	59.00
420	Buirut	2/420	09/01/2003	2	2,940.00	52.00
420	Buirut	1/420	09/01/2003	2	2,800.00	67.00
420	Buirut	3/420	09/01/2003	2	3,430.00	75.00
460	Cairo	1/460	09/01/2003	2	2,730.00	74.00
800	Street No. 8	3L/800	09/01/2003	2	3,598.00	59.00
800	Street No. 8	2L/800	09/01/2003	2	2,275.00	75.00
800	Street No. 8	4L/800	09/01/2003	2	3,846.00	76.00
800	Street No. 8	4R/800	09/01/2003	2	3,846.00	76.00

Over time, the Gaza PMMS database will contain a great amount of historical pavement condition data about the network. This information can be used to develop pavement performance curves (models) that predict how a certain type of pavement will perform based on how it has performed in the past.

4.3.4 Maintenance Strategy and Cost

After having determined a PCI score for each branch section of the network, calculating a range that the score falls within will be needed to assist in selecting a possible treatment. For example, if a section is in good condition with a PCI of 84, it would receive a different treatment than a section in poor condition rated as 35. In general, maintenance strategies based on the pavement condition range from routine patching, crack sealing, overlaying to reconstructing as a last option. Suggested pavement treatment of a section can be selected according to the range that the PCI of this section belongs to as illustrated previously in Table (2.3).

One of the key activities in Gaza pavement management is budgeting since funding needs are always much lower than available funding. After all needed pavement information has been collected into the database; methods to analyze that information are needed to make budget decisions at network and project levels. Decisions at network level are related to program and policy issues for the entire network and they constitute the most use and interest to the municipality mayor, manager, budget director, etc. Decisions about network level include:

- Establishing pavement preservation polices.
- Identifying priorities.
- Estimating funding needs.
- Allocating budgets for maintenance, rehabilitation and reconstruction.

Network level analysis is best used for overall budget estimates, examining hypothetical, projected circumstances or "what if" questions.

Project level analysis is a series of steps to determine the cause and extent of pavement deterioration. This level of analysis will be done by the engineering and technical staff to identify cost-effective maintenance and rehabilitation repairs for specific pavements at specific locations.

To get the most cost-effective methods for providing satisfactory pavement condition, all strategies possible within a set time frame can be economically analyzed. All costs associated with each strategy can then be totaled for comparison with other strategies and the desired strategy will be the one with the least total cost.

4.3.5 Maintenance Prioritization

After the condition of all network sections have been calculated and the treatment and cost determined, the application of a method for choosing a logical order to address the section is needed. As stated earlier in Chapter Three, there are different methods which can be developed for establishing priorities. Prioritization can be as simple as a "best section first" or "worst section first". The ranking index formula which was developed by Khoury and et al considers a combination of section condition, functional classification and traffic exposure. On the other hand, it neglects the effect of cost in making decisions.

$$PI = (\frac{1}{PCI}) \times TF \times FC \times MF \times SR$$

Any prioritization method should be selected carefully to suit the circumstances of Gaza as a developing city.

4.3.6 Documenting and Reporting

Once a prioritization list of roadways is developed, they should be formulated into a budget document and reported to the decision makers. Due to the technical nature of the data and the analysis, it is desirable to translate the findings from the PMMS into clear terms that are understandable to decision makers. In presenting the PMMS findings, it is important to be brief and point out key facts which will enable them to make better decisions. Areas of presentation may include:

- The current condition of the pavement network.
- The future condition of the pavement network, at different funding levels.
- How much deferred maintenance will occur and what its cost will be if the current funding level does not allow for all of the roads to be fixed.

Gaza PMMS reports or computer outputs can be divided into different categories for management, engineers, legislators, etc. Examples of the types of reports available from a PMMS include:

- The current condition of pavements, by project or section.
- Budget requirements to meet performance objectives.
- Summary of distress levels over time.
- Site specific plans for maintenance and rehabilitation.

- Priorities for allocating maintenance and rehabilitation funds by pavement projects, or sections.
- A history of maintenance and rehabilitation by project, section or year.
- Estimated maintenance and rehabilitation costs.

4.4 Gaza PMMS Software

As mentioned earlier in this chapter, Gaza PMMS depends on the direct integration between Micro PAVER and GeoMedia Professional software programs. Condition 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. Visual C++ is used to provide a simple user interface that can help in making sound decisions about Gaza pavements. Getting started in building Gaza PMMS is discussed deeply in the following topics stated below.

4.4.1 Micro PAVER Work

The following steps are performed to construct Micro PAVER work that constitutes the input software program in the proposed Gaza PMMS.

1. A new database named (PMS_Gaza) is opened from "File" menu.
2. "Inventory Items" icon is first clicked to show Network, Branch and Section sub icons.
3. "Network" sub icon is also clicked to enter Network ID and name. For Gaza case, Figure (4.5), the network is named "Gaza_City" and its ID is set "01". Other pavement networks like Khan Younis, Rafah, etc can be added.

Fig. (4.5): Gaza Network Name and ID Establishment in the PAVER.

4. All information about Gaza streets "Branches" are entered in the PAVER by clicking the "Branch" sub icon, including branch name, branch ID and the pavement use as shown in Figure (4.6).

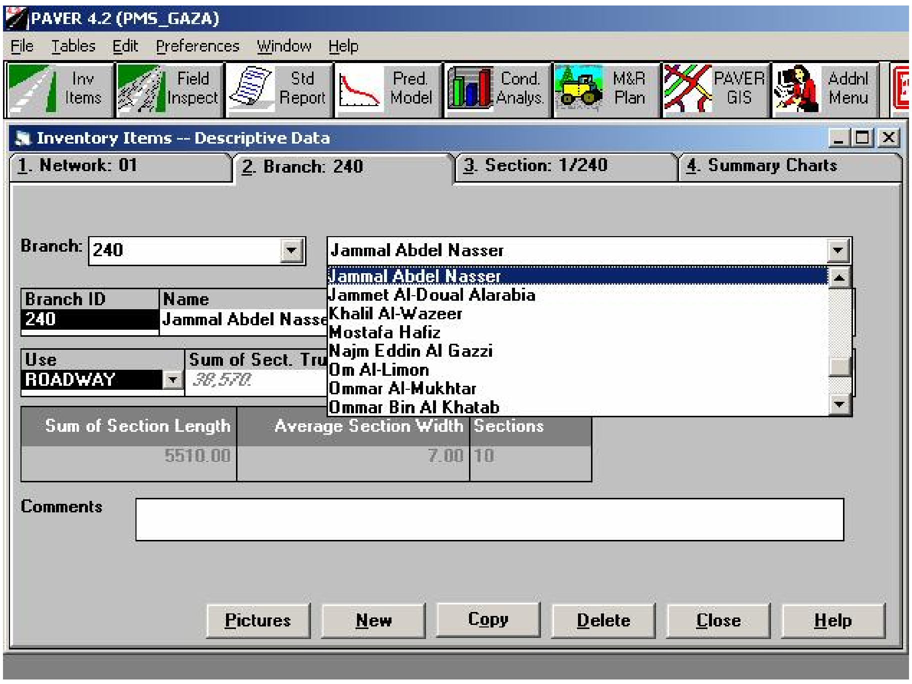


Fig. (4.6): Gaza Pavement Branch Definition in the PAVER.

5. Sectioning Gaza pavement network in the PAVER is then established by using the "Section" sub icon and selecting "New" button to enter the section data as shown in Figure (4.7).

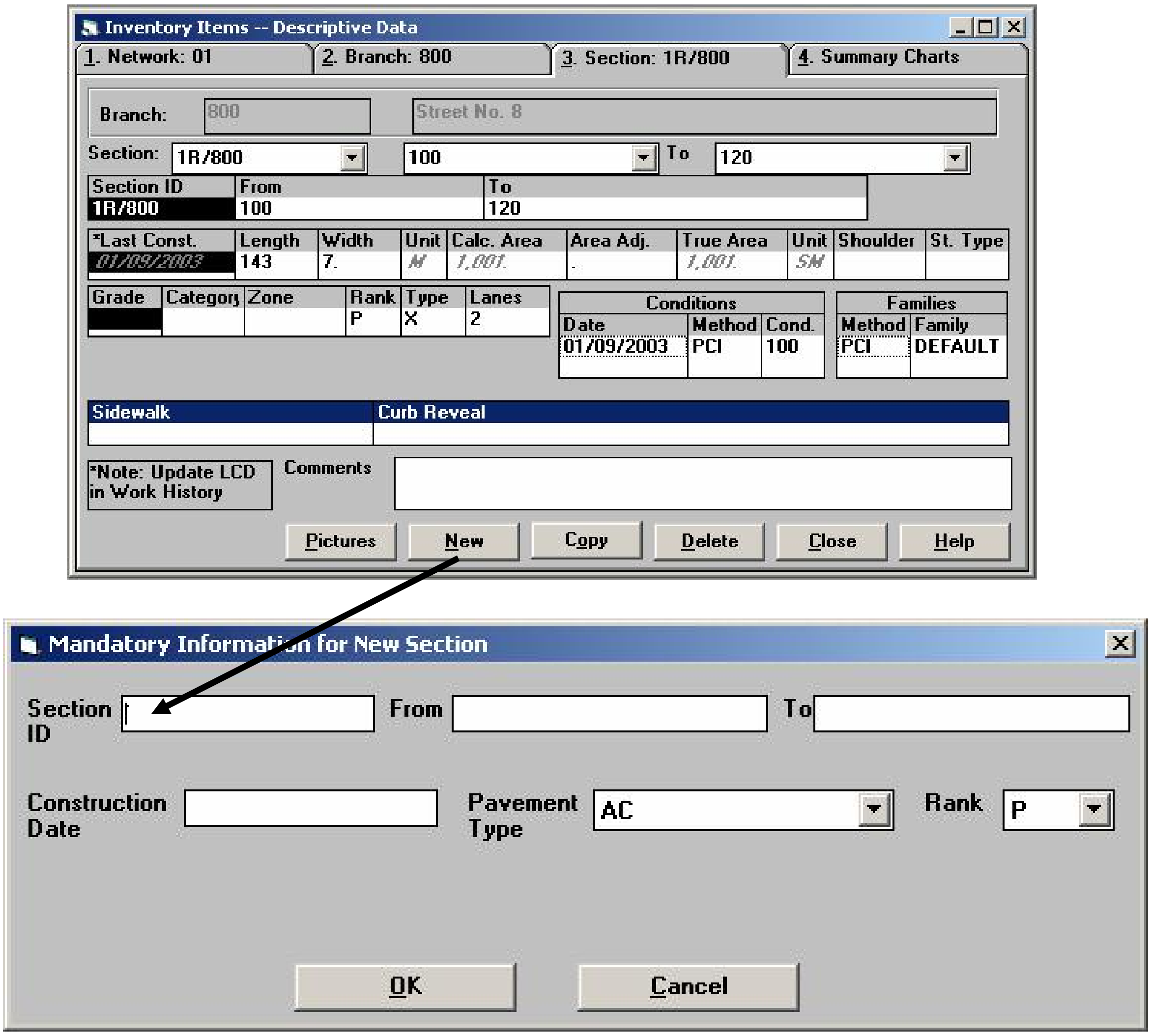


Fig. (4.7): Gaza Pavement Section Definition in the PAVER.

6. After defining all the elements of Gaza network, the inspection data entry has been established by pressing "Field Inspect" icon. Fig. (4.8) illustrates the inspection data entry in the PAVER for "Jammal Abdel Nasser Str. - Section 2/240".

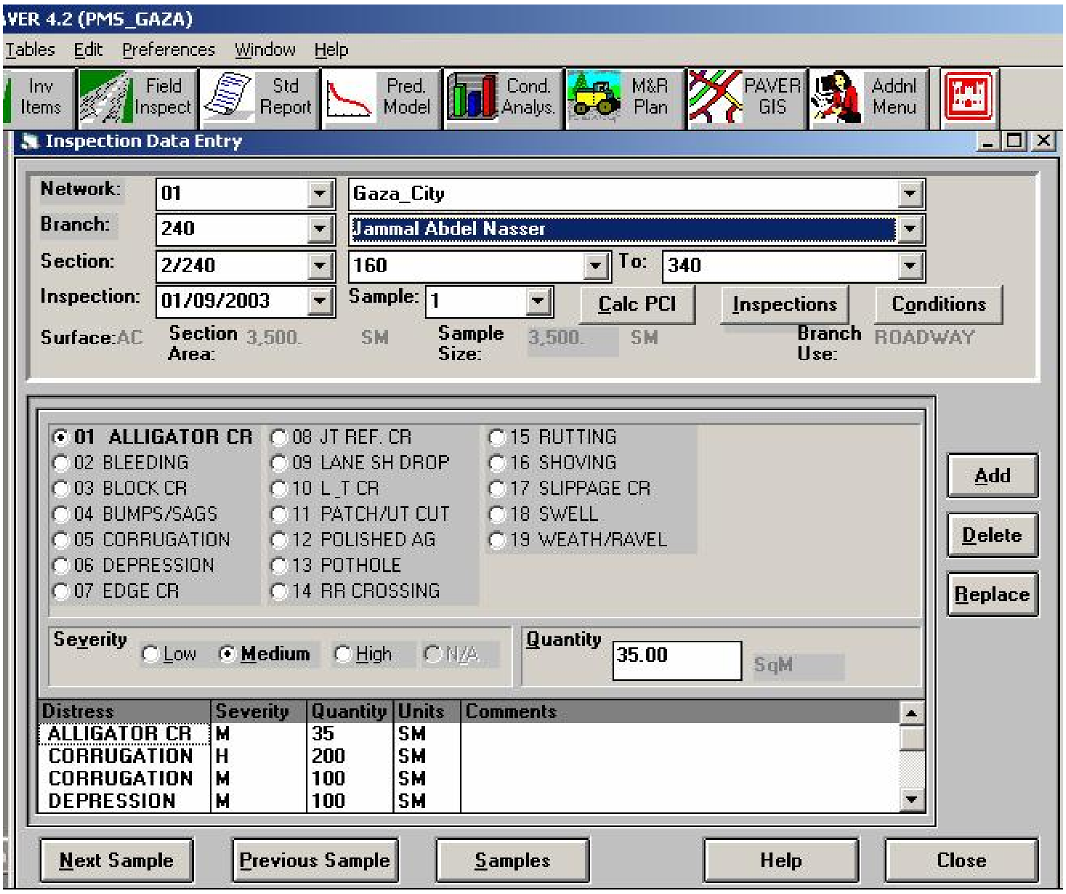


Fig. (4.8): Gaza Inspection Data Entry in the PAVER.

The condition of this section (2/240) may be shown by pressing "Calc PCI" button as illustrated in Figure (4.9).

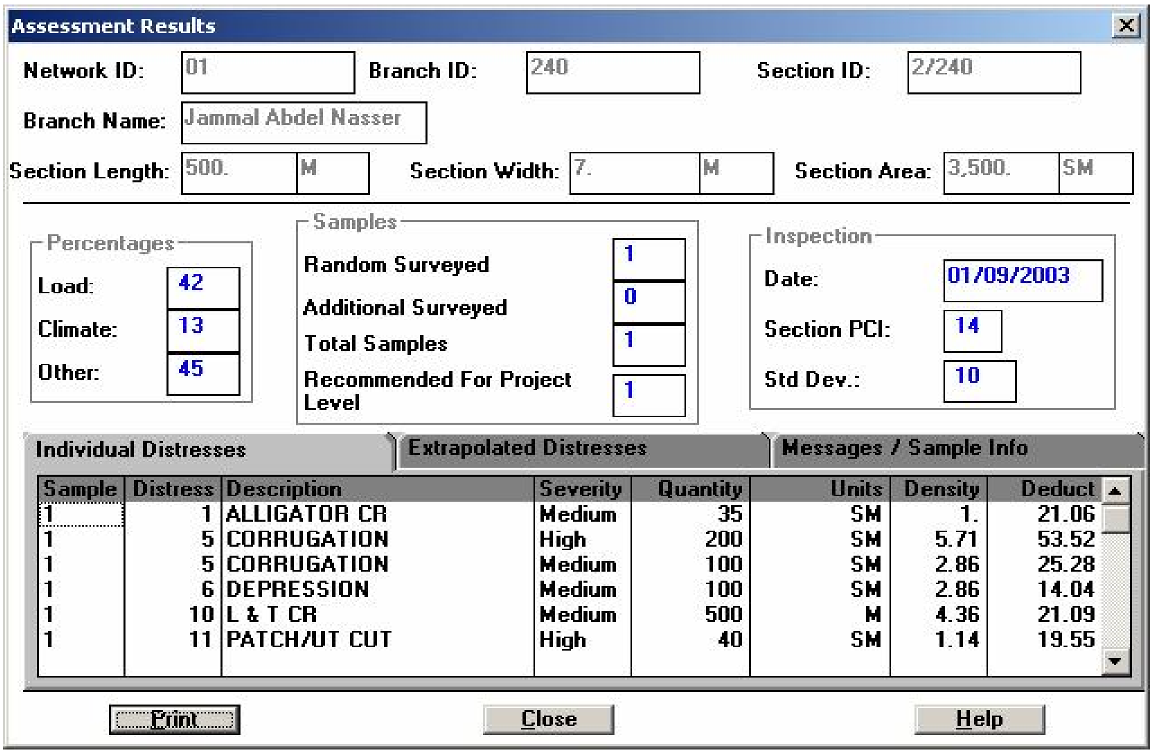


Fig. (4.9): PAVER Condition Assessment of Section (2/240).

7. Figure (4.10) shows how to get standard reports including branch listing, work history, branch condition and section condition reports. Part of section condition report is illustrated in Figure (4.11).

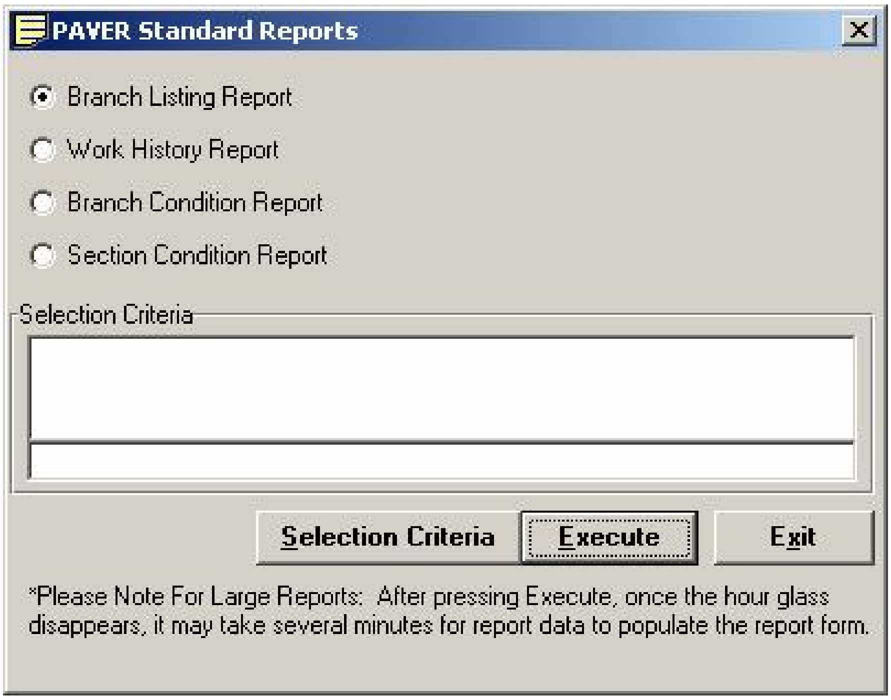


Fig. (4.10): PAVER Standard Reports.

1 of 9 | 100% | Total:213 | 100% | 213 of 213

Date: 12 /23/2003

Section Report

Pavement Database: PMS_GAZA   NetworkID: 01

1 of 9

Branch ID	Section ID	Last Const. Date	Surface	Use	Rank	Lanes	True Area (SM)	Last Inspection Date	Age At Inspection	PCI
100 (Al Rasheed)	1/100	09/01/2003	AC	ROADWAY	P	2	4,900.00	09/01/2003	0	100.00
100 (Al Rasheed)	2/100	09/01/2003	AC	ROADWAY	P	2	10,150.00	09/01/2003	0	100.00
100 (Al Rasheed)	3/100	09/01/2003	AC	ROADWAY	P	2	2,310.00	09/01/2003	0	100.00
100 (Al Rasheed)	4/100	09/01/2003	AC	ROADWAY	P	2	2,905.00	09/01/2003	0	100.00
100 (Al Rasheed)	5/100	09/01/2003	AC	ROADWAY	P	3	7,665.00	09/01/2003	0	100.00
100 (Al Rasheed)	6/100	09/01/2003	AC	ROADWAY	P	3	7,800.00	09/01/2003	0	100.00
100 (Al Rasheed)	7/100	09/01/2003	AC	ROADWAY	P	3	4,300.00	09/01/2003	0	28.00
100 (Al Rasheed)	8/100	09/01/2003	AC	ROADWAY	P	3	9,850.00	09/01/2003	0	65.00
100 (Al Rasheed)	9/100	09/01/2003	AC	ROADWAY	P	2	7,200.00	09/01/2003	0	100.00
116 (Sharl Degool)	1/116	09/01/2003	AC	ROADWAY	P	2	4,340.00	09/01/2003	0	100.00
128 (Al Majdal)	1/128	09/01/2003	AC	ROADWAY	P	2	3,780.00	09/01/2003	0	100.00
160 (Al Quds)	1/160	09/01/2003	AC	ROADWAY	P	2	3,990.00	09/01/2003	0	59.00

Fig. (4.11): Gaza Section Condition Report in the PAVER.

8. There are other icons that can be helpful in prediction modeling and condition analysis.

4.4.2 GeoMedia Professional Work

The following steps are performed to construct GeoMedia work that provides the dynamic segmentation of Gaza pavement network:

1. Defining the local coordinate system of Palestine in the GeoMedia, Old Palestinian Grid (OPG), from the accompanying program "Define Coordinate System File". This step is established by entering the storage, projection and ellipsoidal parameters that defines OPG system. These parameters are obtained from the Computer Department in Gaza Municipality. This task is illustrated in Figure (4.12).

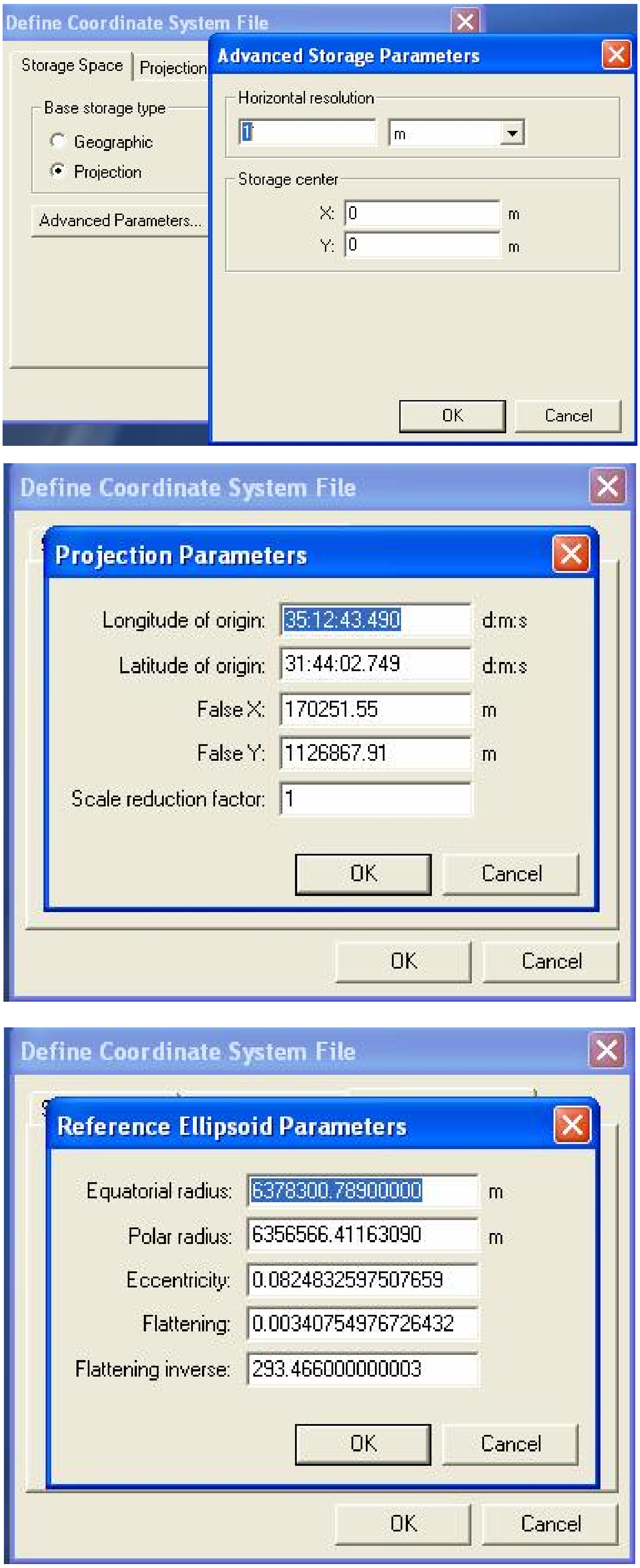


Fig. (4.12): Gaza Coordinate System (OPG) Definition.

2. Gaza network, as a CAD file, is connected in the GeoMedia by using the accompanying file "Define CAD Server Schema File". To accomplish this task, three steps are to be performed. The first, calling Gaza CAD file from its place in the hard disk by clicking "Files" button as in Figure (4.13a). The second, relating the OPG file to Gaza network map in the server by clicking "Coordinate Systems" button as in Figure (4.13b). Finally, defining all the features characteristics of the map by using "Feature Definition" button as shown in Figure (4.13c).

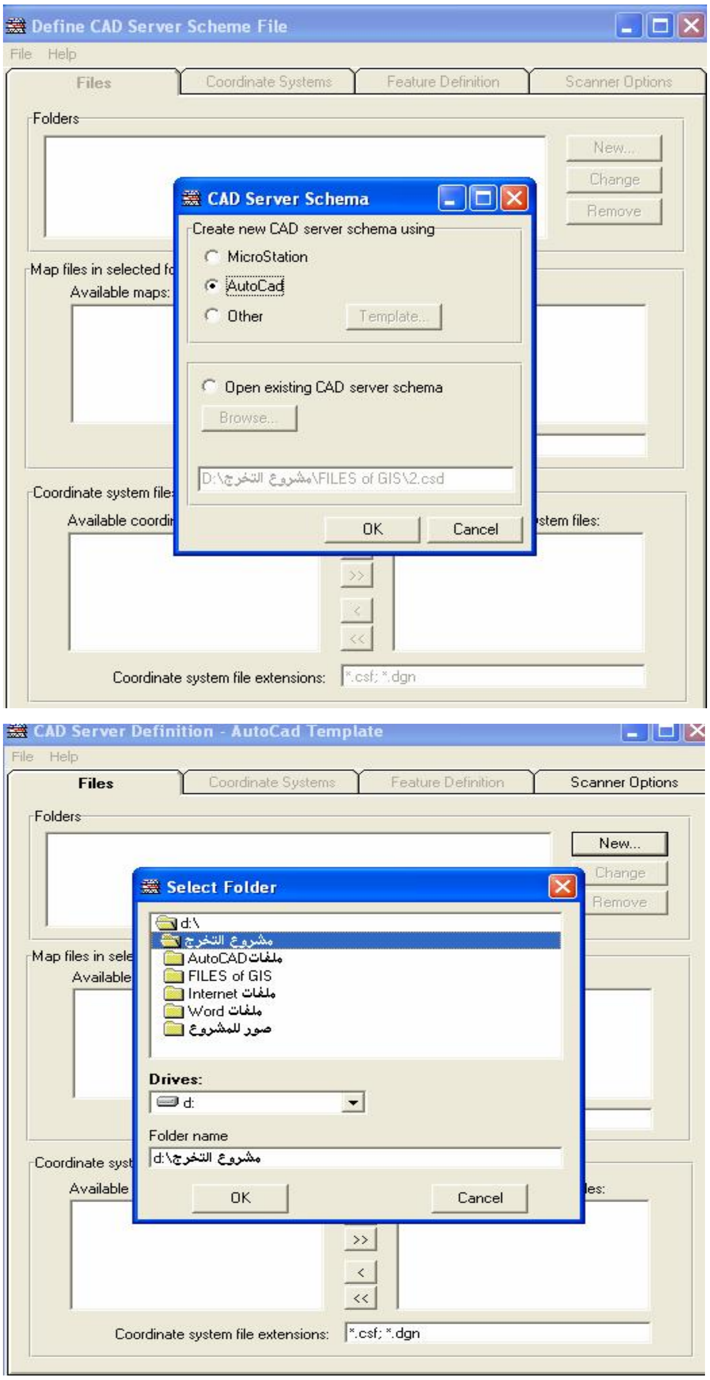


Fig. (4.13a): Calling Gaza CAD File from the Hard Disk.

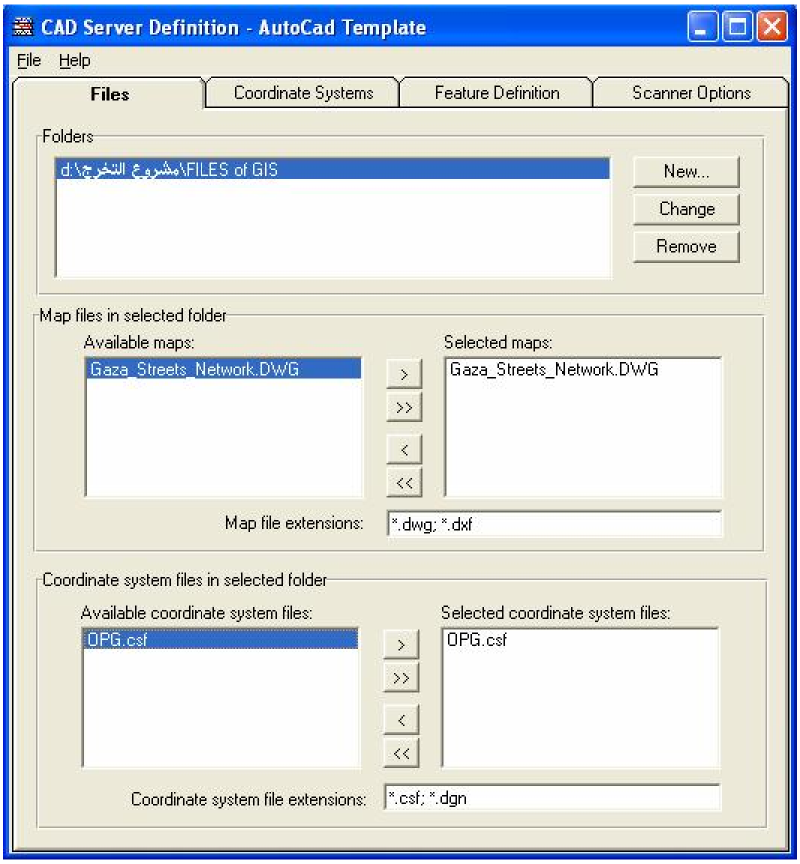
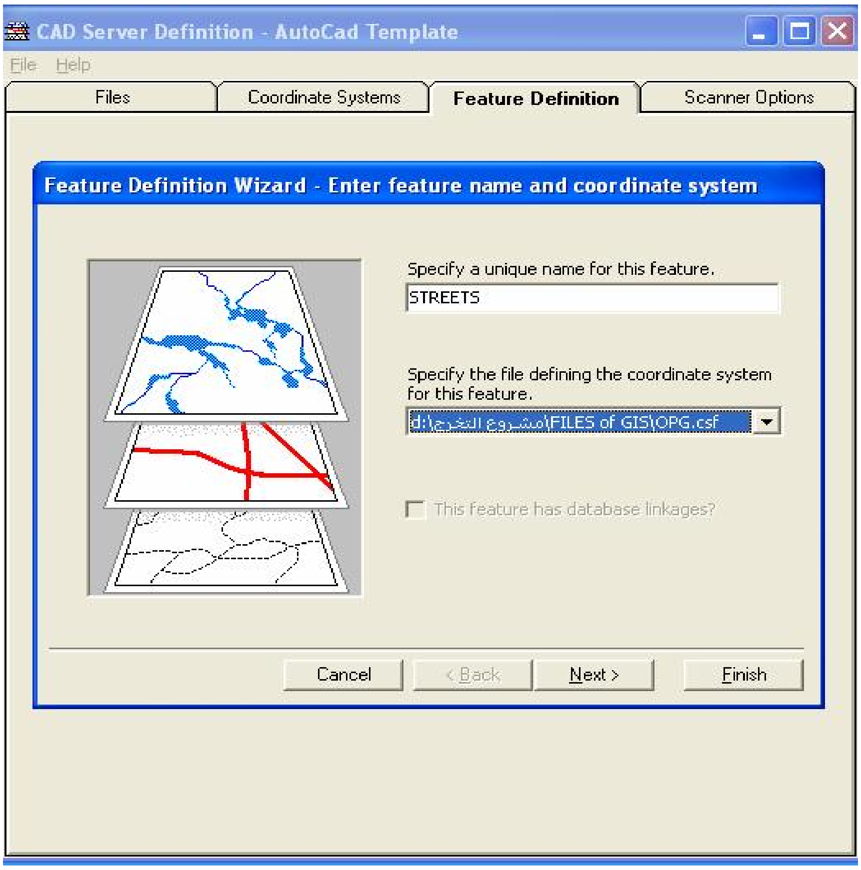
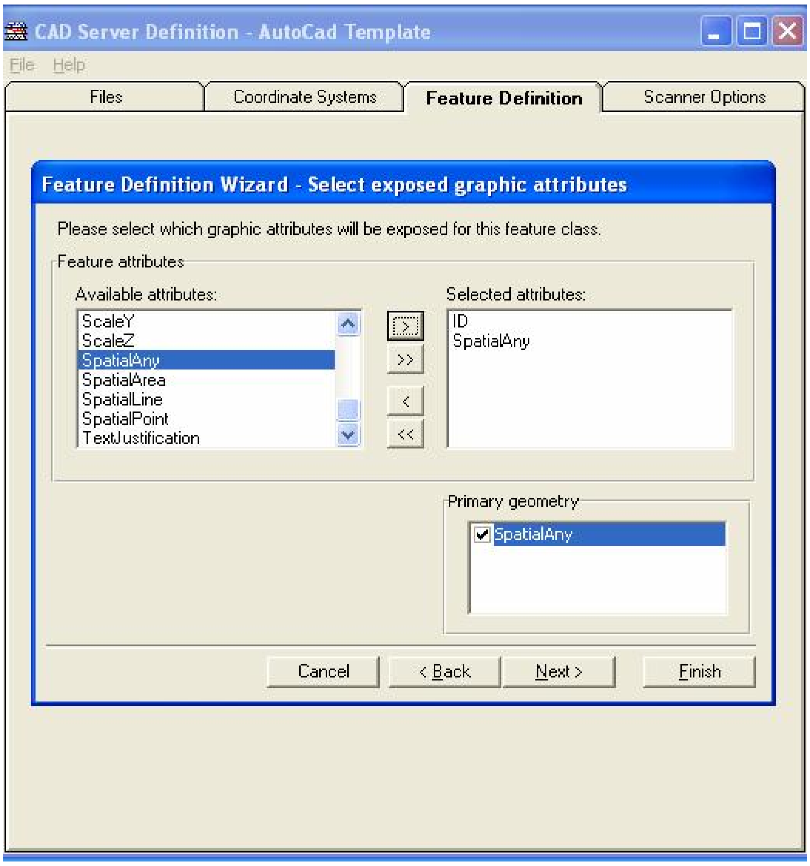


Fig. (4.13b): Relating OPG File to Gaza Network CAD File.





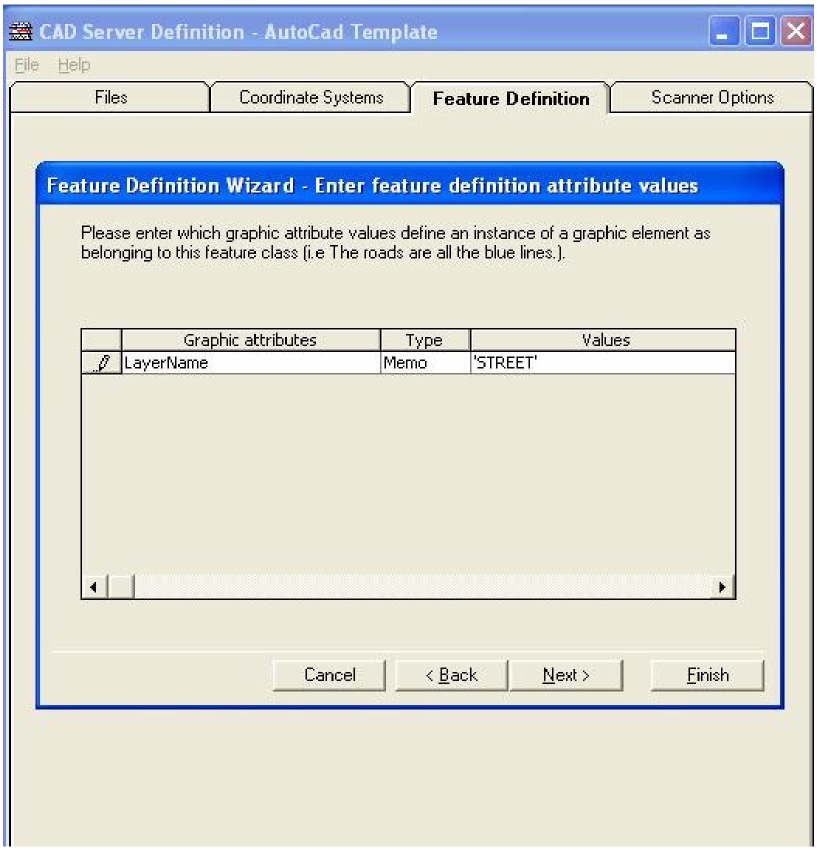


Fig. (4.13c): Defining Gaza Network CAD File as a Feature in GeoMedia.

3. The CAD file is connected to the map window from menu "Warehouse" and "New Connection" command as shown in Figure (4.14).

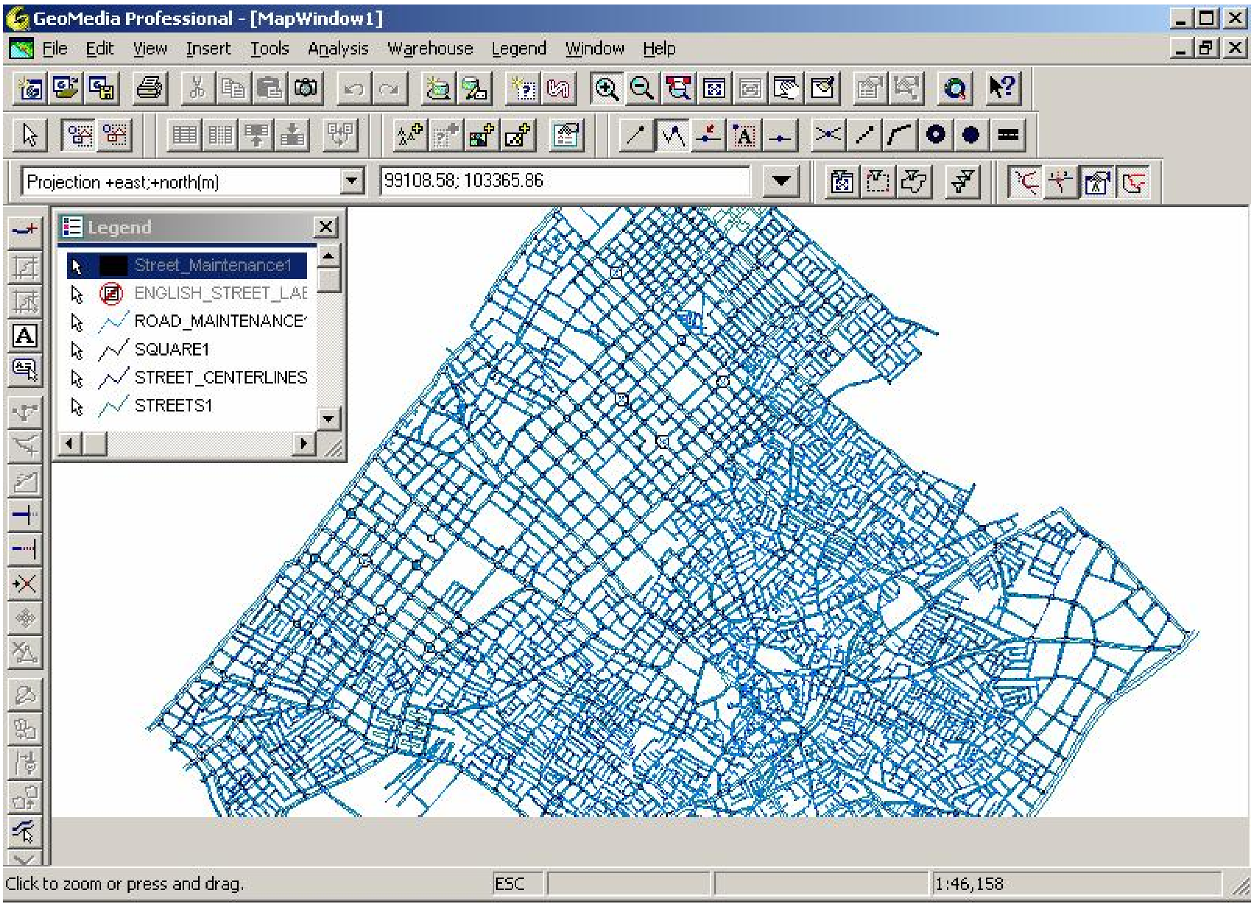


Fig. (4.14): Warehouse Connection of Gaza Network CAD File.

4. Sectioning the pavement network of Gaza, as in PAVER, is then established inside the GeoMedia by building a new feature class named "Street Maintenance 1" by using "Feature Class Definition" command from "Warehouse" menu. After that, a suitable database is constructed as shown in Figure (4.15).

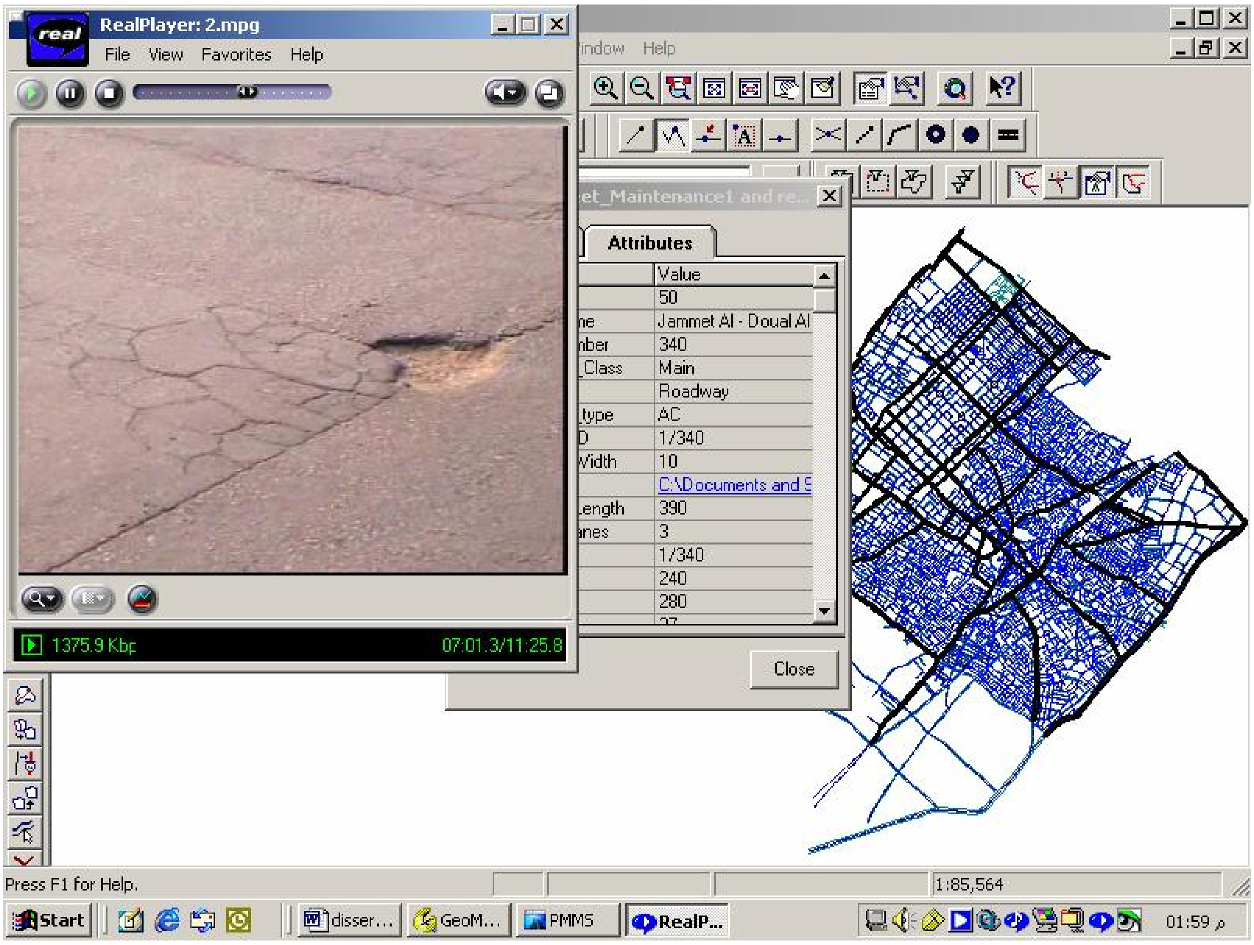


Fig. (4.15): Warehouse Connection of Gaza Network CAD File.

4.4.3 Join between Micro PAVER and GeoMedia

Join between Micro PAVER and GeoMedia aims to make benefits from the capabilities of both software packages. This will enable the results given by the PAVER to be represented geographically and analyzed spatially to facilitate the management process. Although, the join process was very complicated because of the old version of Microsoft Access database that the PAVER uses to store data. GeoMedia can not easily connect such old database version because of its complex architecture. To accomplish this process, the following steps were performed:

1. An Access 2000 file named "linkpavement" is first constructed and saved inside the folder that contains the Access file of the PAVER "pavement".
2. A table query named "Results" is created within the "linkpavement" file and linked to read the required data from the PAVER database including a field of Gaza sections ID.
3. "Results" table is connected into the GeoMedia Warehouse by selecting "New Connection" command from "Warehouse" menu in the GeoMedia.

4. Table "Results" is then joined with table "Street Maintenance 1" which was previously constructed in the GeoMedia based on the similar field of section ID in both tables. This step is executed by using "Join" command from "Analysis" menu.

Figure (4.16) illustrates part of the join process.

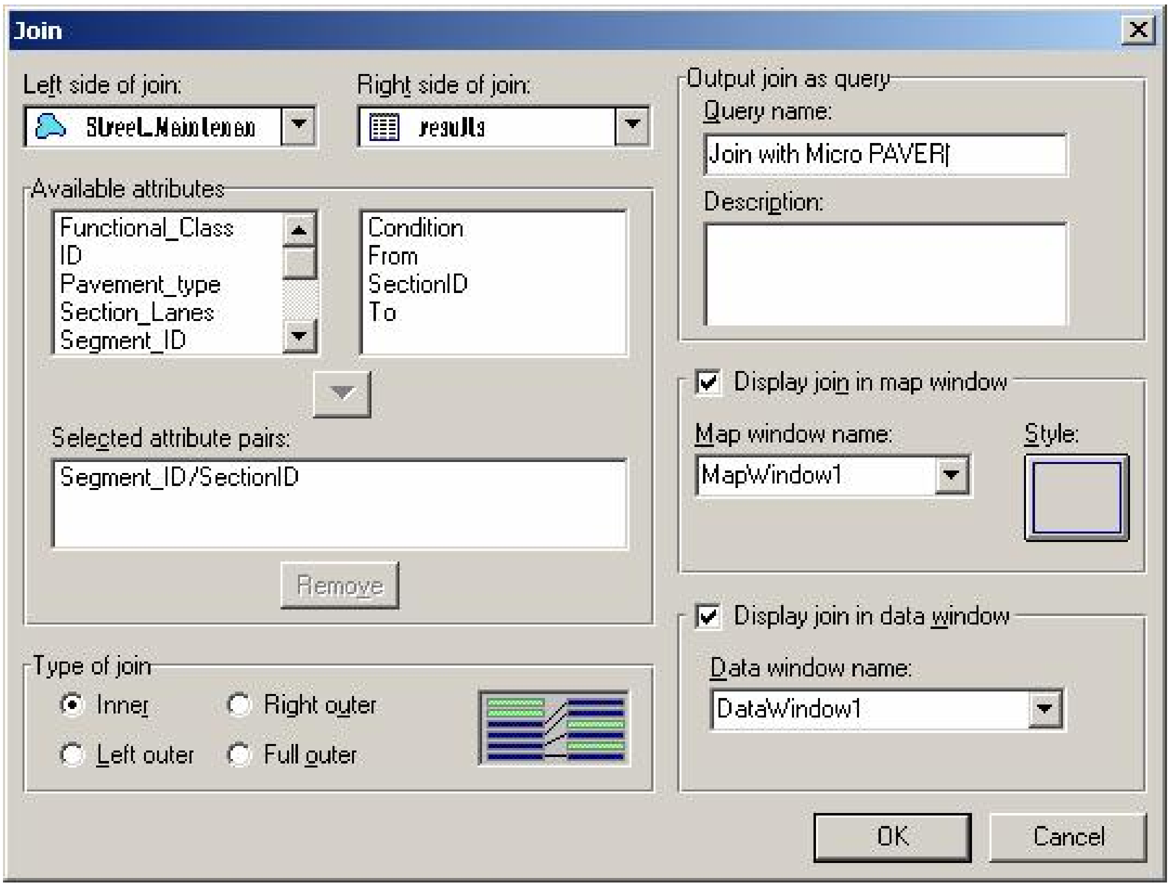


Fig. (4.16): Join between GeoMedia and Micro PAVER.

4.4.4 Development of Graphical User Interface

A simple GUI, named PMMS, has been developed to help in presenting the PMMS results and to justify the decisions that are taken. This GUI contains user-friendly menus that can call the Micro PAVER and GeoMedia files. It has also capabilities to execute rapid queries and perform different types of reporting. In addition to, 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:

1. *Pavement Type*

   Which sections are unpaved?

   Which sections are closed?

2. *Pavement Condition*

   Which sections or branches are failed, poor, excellent, etc?

3. *Pavement Maintenance*

   Which sections require routine maintenance?

   Which sections require thin or thick overlaying?

   Which sections require reconstruction?

4. *Treatment Cost*

   What are the treatment cost of each section, each branch or overall?

Figure (4.17) shows the main page screen (GUI) of the developed PMMS.

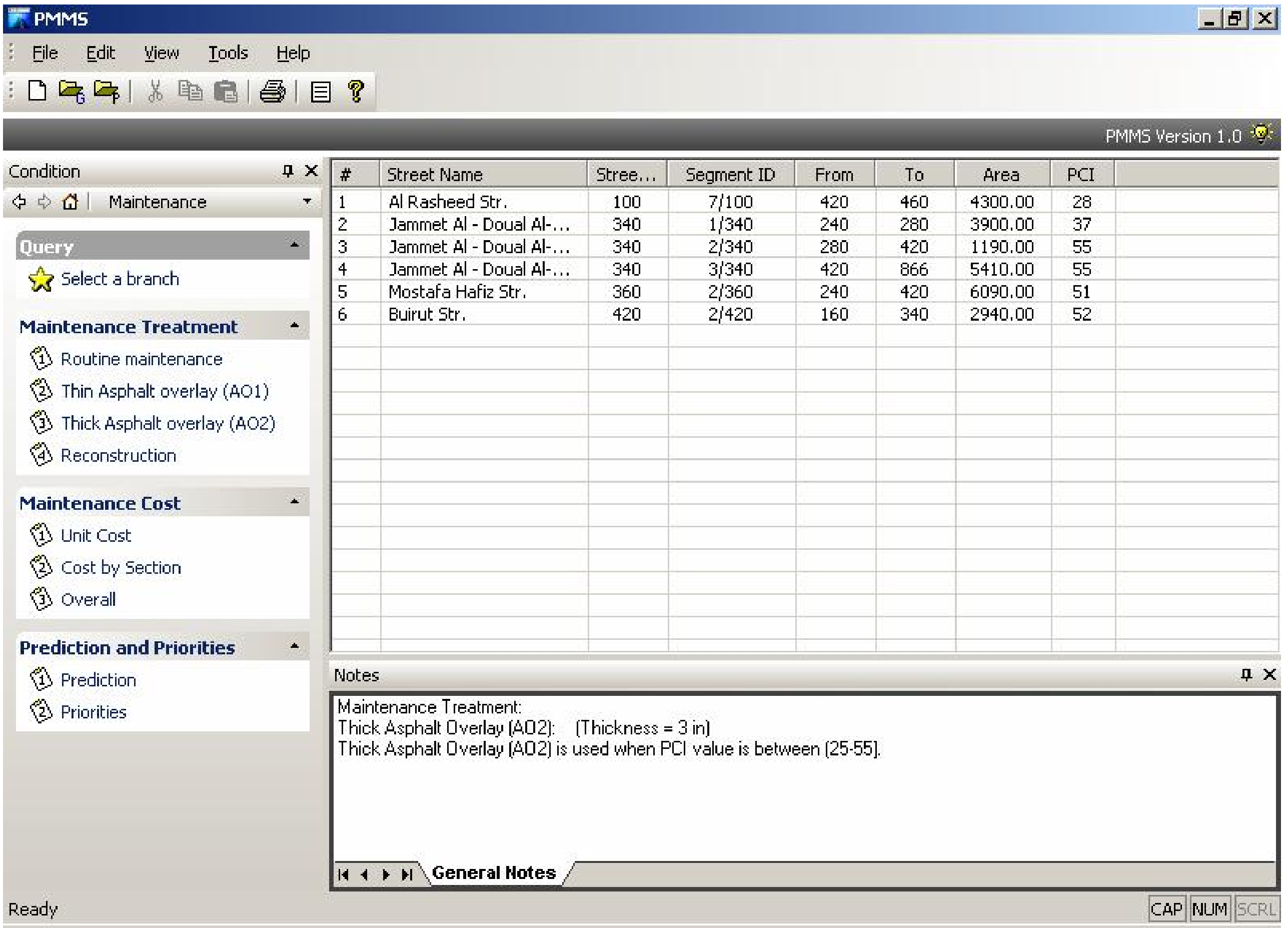


Fig. (4.17): The Developed PMMS Graphical User Interface.

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 as shown in Figure (4.18).

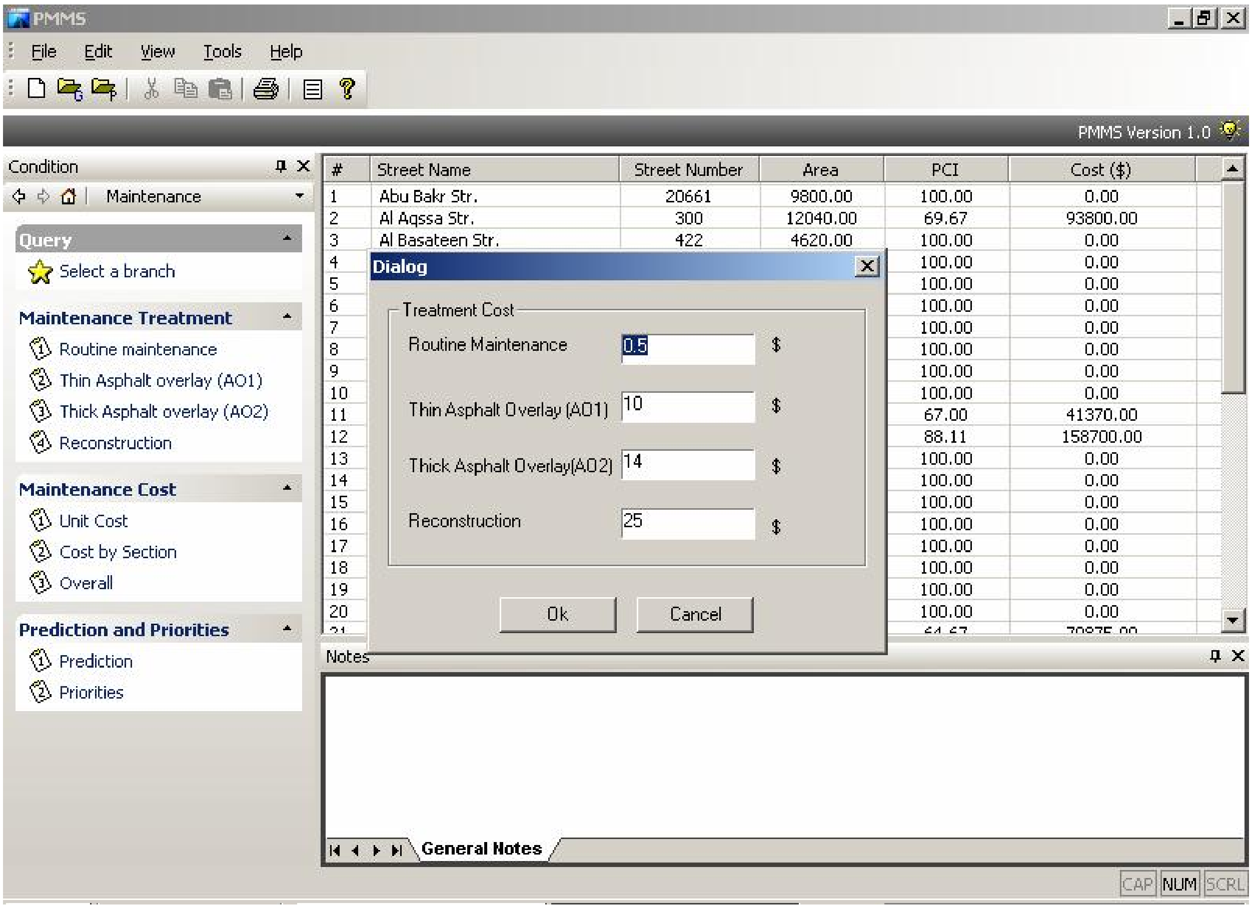


Fig. (4.18): PMMS Unit Cost Entry.

Figure (4.19) shows an example of reports that the PMMS can perform. This report illustrates the treatment cost by section.

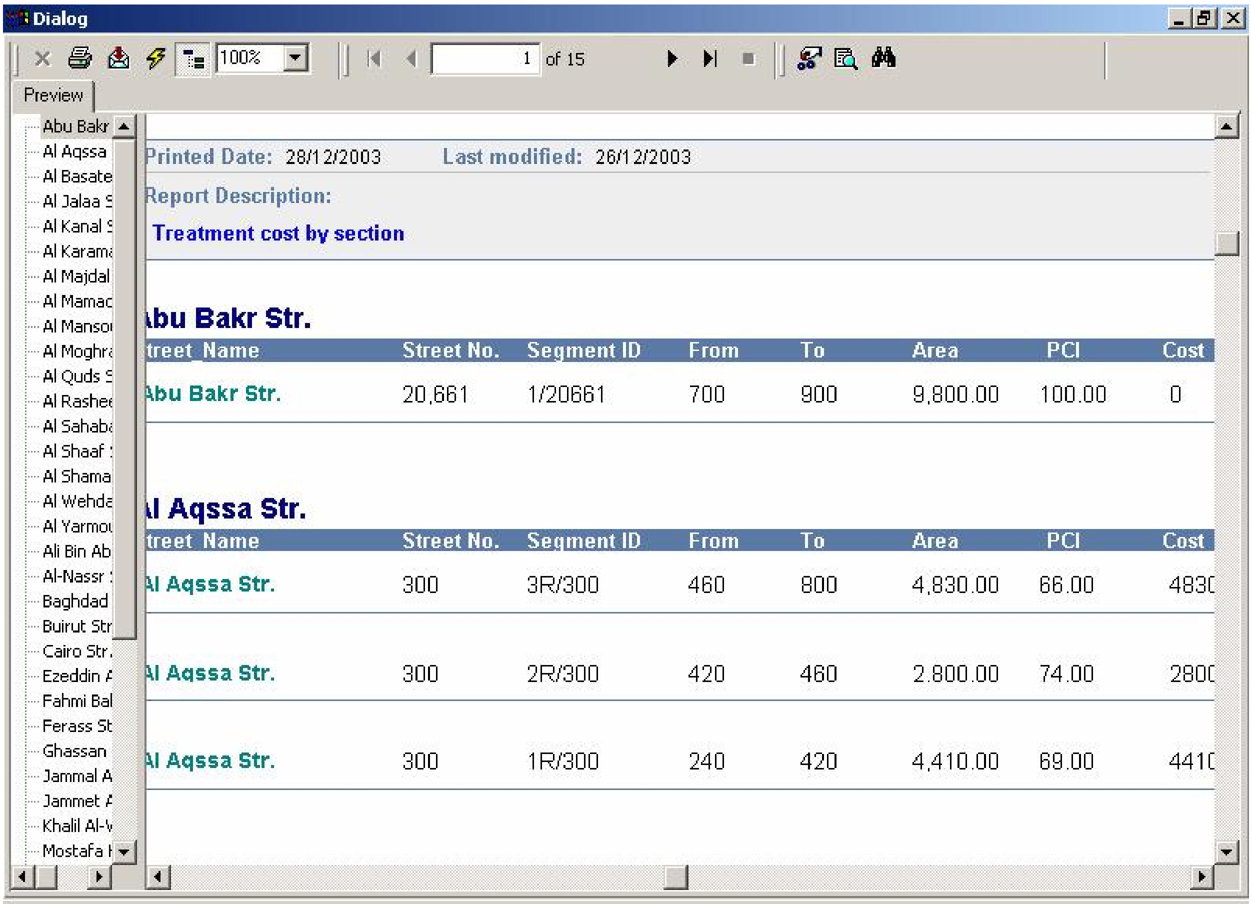


Fig. (4.19): Treatment Cost Report in PMMS Graphical User Interface.

4.4.5 Gaza PMMS Architecture

Gaza PMMS constitutes a computer environment in which Micro PAVER, GeoMedia Professional and Visual C++ has been integrated for supporting:

- ý Maintenance works performing.
- ý Management of maintenance operations.

Each one of Gaza PMMS software components provides functionalities for supporting the concrete tasks of the PMMS process. The overall system architecture is presented in Figure (4.20).

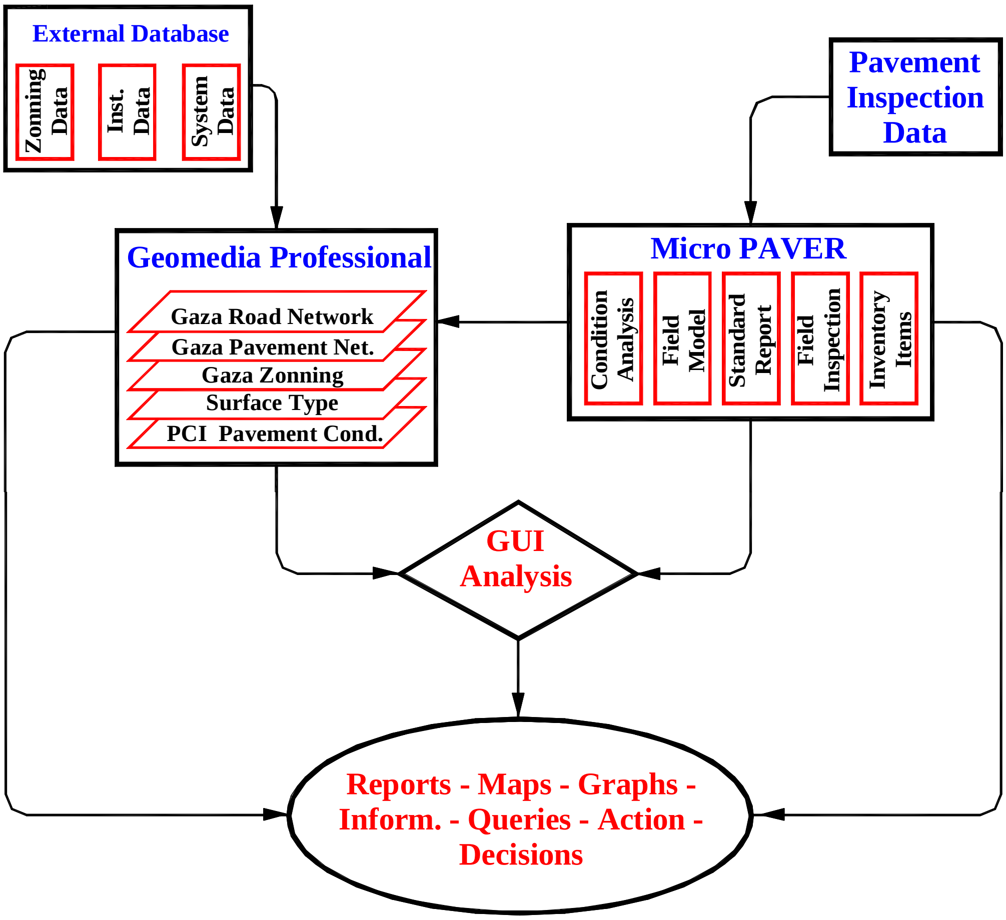


Fig. (4.20): Gaza PMMS Architecture.

4.5 Gaza PMMS Outputs

Gaza PMMS provides variable outputs that can help in reducing the time allocated to the maintenance activity and facilitating the decision making process. The following are examples of these outputs:

1. *Reports*

Different types of reports can be provided including branch condition, section condition, surface type, required treatment and maintenance budgeting reports. (See Appendix: A1 – A9)

2. *Thematic Maps*

Several thematic maps can also be presented based on surface type, pavement condition (by branch or section), functional classification, etc. (See Appendix: A10 – A14)

3. Charts

Charts and figures can be obtained in different formats (Bar, Pie, XY charts, etc) and illustrating condition analysis, predictions, pavement types and other needed relationships.

4. Queries

Various information about Gaza pavement network can be performed through the developed Graphical User Interface, PAVER and GeoMedia packages.

5. Decisions

Gaza PMMS can assist in decision supporting process about the actions that should be taken and related to the maintenance needs, required budgeting, section treatment priorities, etc.

CHAPTER FIVE

Conclusions and Recommendations

5.1 Conclusions

At the end of this study, the following points can be concluded:

1. The current management for Gaza pavements is traditional and can not help in decision making for enhancing the maintenance activities in the city to match the road user's expectations. A strong need for comprehensive PMMS is required.
2. Adequate database for Gaza pavement network has been created to allow data storing, retrieving, displaying, updating and performing queries. It handles all the necessary inventory data for Gaza city pavements.
3. Pavement Condition Index (PCI) has been selected as a tool for Gaza pavements network condition assessment.
4. This study shows that both Micro PAVER and GeoMedia Professional can be good tools for enhancing the management process of Gaza Pavement Network.
5. This study shows that a PMMS which is based on the direct integration between Micro PAVER and GeoMedia Professional can be used to facilitate the decision making process for managing Gaza city pavements.
6. A simple Graphical Interface which contains user-friendly menus can be developed to present PMMS results to justify the decisions made.
7. Maintenance Department staff in Gaza should be trained and educated to recognize the right ways of performing the PMMS tasks. Equipment used also need to be updated.

5.2 Recommendations

1. A PMMS should be initiated to serve and protect Gaza pavements and this will encourage other cities in Gaza Strip to establish their own PMMS for enhancing the management process and to maximize the benefits to the society through a centralized PMMS.
2. Future developments should be made to ensure full integration between the Micro PAVER and the GeoMedia.
3. Future developments to include all elements of highway maintenance management system are to be considered.
4. There is a great need of long-term commitment of officials, pavement managers, public and road users towards the conservation and protection of pavement assets.

References

المراجع العربية:

(١) شفيق جندية: هندسة الطرق-التصميم الإنشائي.غزة. مكتبة المنارة.2000

(٢) هشام صبيح، شادي سكيك، عبد الرحمن حجو، و أخرون: تقييم رصفات الطرق و دراسة الأوزان المحورية للمركبات في مدينة غزة و توثيق النتائج باستخدام نظم المعلومات الجغرافية (GIS). بحث تخرج لنيل درجة البكالوريوس. إشراف د.م شفيق جندية، الجامعة الاسلامية ، غزة . 2003.

(٣) اسماعيل قشطة، سامي عدوان، صلاح الدين قشطة، وآخرون: استخدام برنامج Micro PAVER ونظم المعلومات الجغرافية (GIS) في تقييم وتوثيق رصفات طرف في مدينة غزة. بحث تخرج لنيل درجة البكالوريوس. إشراف د.م شفيق جندية، الجامعة الاسلامية ، غزة . 2002.

(٤) هاني عبدربه، نور الدين عدوان، مازن تنيرة، وآخرون: دراسة في إدارة وصيانة الطرق في مدينة غزة. إشراف د.م شفيق جندية، الجامعة الاسلامية ، غزة . 2001.

المراجع الأجنبية:

(5) Sood V. K., "Highway Maintenance Management System – An Overview", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(6) Ministry of Planning and International Cooperation, "Fact Book", Gaza, 1997.

(7) U. S. Department of Transportation, Advisory Circular AC 150/5380-6A, "Guidelines and Procedures for Maintenance of Airport Pavements", Federal Aviation Administration, 1995.

(8) Yoder E. J. and Witczak M. W., "Principles of Pavement Design", 2nd ed., John Willy & Sons, Canada, 1976.

(9) Washington State Transportation Department, "Maintenance Manual", Olympia, March 2002.

(10) O'Flaherty C. A., "Highway Engineering", 3rd ed., Volume 2, Edward Arnold, Great Britain, 1988.

(11) Marathe P. D., "Flexible Pavement Evaluation System", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(12) Chari C. T., "Use of Falling Weight Deflectometer in Airfield Pavement Evaluation", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(13) Singh G. and Singh J., "Highway Engineering", 5th ed., Nai Sarak, Delhi, 1999.

(14) ERES Consultants, Inc., "Eye on ERES", Volume 5, Number 1, Champaign, Illinois, 1998.

(15) http// www.conted.uiuc.edu/techctr/software/software.html

(16) Department of the Army and the Air Force, TM 5-826-6/AFR 93-5, "Procedures for US Army and US Air Force Airfield Pavements Condition Surveys", Washington, DC, July 1989.

(17) http//www.civil.ualberta.ca/courses/cive618/OUTLINE.DOC

(18) Gupta D. P., "Halting the Growing Neglect in Maintenance of Roads and Bridges", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(19) The National Guide to Sustaining Municipal Infrastructure, "Timely Preventive Maintenance for Municipal Roads", www.infraguide.ca, 2003.

(20) Prakash A., "Pavement Management Begins at Design Stage", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(21) Washington State Department of Transportation, "A Guide for Local Agency Pavement Managers", TransAid Service Center, Olympia, December 1994.

(22) USA Department of Transportation, DSTI/DOT/RTR/IMI (2000)1, "Asset Management for the Roads Sector", 2000.

(23) Washington State Transport Center, “Pavement Surface Condition: Rating Manual”, WSDT, Washington, USA, 1992.

(24) Ali G. A. and Al-Qatabi Kh., "Efforts in Road Maintenance Management in Oman: Development and Sensitivity Analysis", in Proceedings International Conference on New Horizons in Roads and Road Transport, Vol. 1, ICORT-95, December 11-14, 1995.

(25) South Dakota Department of Transportation (SDDOT), "SDDOT'S Enhanced Pavement Management System", South Dakota, Feb. 2002.

Appendix

1. Surface Type of Gaza Pavement Network Reports

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Surface type: Closed

Khalil Al-Wazeer Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Khalil Al-Wazeer Str.	600	5L/600	530	951	7,068.00	100
Khalil Al-Wazeer Str.	600	5R/600	530	951	7,068.00	100
Khalil Al-Wazeer Str.	600	4L/600	390	530	6,232.00	100
Khalil Al-Wazeer Str.	600	4R/600	390	530	6,232.00	100

Street No. 8

Street Name	Street Number	Segment ID	From	To	Area	PCI
Street No. 8	800	1L/800	100	120	1,001.00	100
Street No. 8	800	1R/800	100	120	1,001.00	100

Printed Date: 06/01/2004 **Last modified:** 29/12/2003

Report Description:

Surface type: Unpaved

Al Aqssa Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Aqssa Str.	300	2L/300	420	460	2,800.00	100
Al Aqssa Str.	300	1L/300	240	420	4,410.00	100
Al Aqssa Str.	300	3L/300	460	800	4,830.00	100

Al Quds Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Quds Str.	160	3/160	460	800	6,510.00	100

Bostan Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Bostan Str.	20,285	1/20285	870	10147	3,500.00	100
Bostan Str.	20,285	2/20285	10147	600	4,340.00	100

Cairo Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Cairo Str.	460	2/460	160	340	2,940.00	100
Cairo Str.	460	3/460	340	300	2,940.00	100

Ezeddin Al Kassam Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Ezeddin Al Kassam Str.	170	5/170	490	690	4,690.00	100

Khalil Al-Wazeer Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Khalil Al-Wazeer Str.	600	10/600	20635	900	4,560.00	100
Khalil Al-Wazeer Str.	600	9/600	20285	20635	5,776.00	100

Ommar Bin Al Khatab Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Ommar Bin Al Khatab St	690	1R/690	100	190	8,140.00	100

Port Saed Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Port Saed Str.	530	4/530	510	600	1,680.00	100

Street No. 8

Street Name	Street Number	Segment ID	From	To	Area	PCI
Street No. 8	800	8R/800	560	700	3,360.00	100
Street No. 8	800	7R/800	764	560	3,948.00	100
Street No. 8	800	6R/800	718	764	3,850.00	100
Street No. 8	800	3R/800	160	340	3,598.00	100
Street No. 8	800	2R/800	120	160	2,275.00	100

2. Condition by section of Gaza Pavement Network Reports

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Condition: Very Good

Al Aqssa Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Aqssa Str.	300	2R/300	420	460	2,800.00	74

Al Quds Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Quds Str.	160	2/160	420	460	2,940.00	75

Buirut Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Buirut Str.	420	3/420	340	300	3,430.00	75

Cairo Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Cairo Str.	460	1/460	100	160	2,730.00	74

Jammal Abdel-Nasser Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammal Abdel-Nasser S	240	3L/240	340	300	4,410.00	84

Street No. 8

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Street No. 8	800	4L/800	340	300	3,846.00	76
Street No. 8	800	4R/800	340	300	3,846.00	76
Street No. 8	800	2L/800	120	160	2,275.00	75

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Condition: Good

Al Aqssa Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Aqssa Str.	300	3R/300	460	800	4,830.00	66
Al Aqssa Str.	300	1R/300	240	420	4,410.00	69

Al Quds Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Quds Str.	160	1/160	240	420	3,990.00	59

Al Rasheed Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Rasheed Str.	100	8/100	460	800	9,850.00	65

Buirut Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Buirut Str.	420	1/420	100	160	2,800.00	67

Jammal Abdel-Nasser Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammal Abdel-Nasser S	240	4R/240	300	380	4,760.00	67
Jammal Abdel-Nasser S	240	3R/240	340	300	4,410.00	70

Jammet Al - Doual Al-Arabia

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammet Al - Doual Al-Ar	340	4/340	866	800	5,850.00	59

Mostafa Hafiz Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Mostafa Hafiz Str.	360	1/360	200	240	3,780.00	59

Street No. 8

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Street No. 8	800	3L/800	160	340	3,598.00	59

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Condition: Fair

Buirut Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Buirut Str.	420	2/420	160	340	2,940.00	52

Jammet Al - Doual Al-Arabia

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammet Al - Doual Al-Ara	340	3/340	420	866	5,410.00	55
Jammet Al - Doual Al-Ara	340	2/340	280	420	1,190.00	55

Mostafa Hafiz Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Mostafa Hafiz Str.	360	2/360	240	420	6,090.00	51

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Condition:Poor

Al Rasheed Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Al Rasheed Str.	100	7/100	420	460	4,300.00	28

Jammet Al - Doual Al-Arabia

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammet Al - Doual Al-Ar	340	1/340	240	280	3,900.00	37

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Condition: Very Poor

Jammal Abdel-Nasser Str.

Street_Name	Street_Number	Segment_ID	From	To	Area	Condition
Jammal Abdel-Nasser Str.	240	2/240	160	340	3,500.00	14

3. Maintenance Treatment of Gaza Pavement Network Reports

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Maintenance Treatment: Thin Asphalt Overlay (A01)

Al Aqssa Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Aqssa Str.	300	3R/300	460	800	4,830.00	66
Al Aqssa Str.	300	1R/300	240	420	4,410.00	69

Al Quds Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Quds Str.	160	1/160	240	420	3,990.00	59

Al Rasheed Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Rasheed Str.	100	8/100	460	800	9,850.00	65

Buirut Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Buirut Str.	420	1/420	100	160	2,800.00	67

Jammal Abdel-Nasser Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Jammal Abdel-Nasser S	240	4R/240	300	380	4,760.00	67
Jammal Abdel-Nasser S	240	3R/240	340	300	4,410.00	70

Jammet Al - Doual Al-Arabia

Street Name	Street Number	Segment ID	From	To	Area	PCI
Jammet Al - Doual Al-Ar	340	4/340	866	800	5,850.00	59

Mostafa Hafiz Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Mostafa Hafiz Str.	360	1/360	200	240	3,780.00	59

Street No. 8

Street Name	Street Number	Segment ID	From	To	Area	PCI
Street No. 8	800	3L/800	160	340	3,598.00	59

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Maintenance Treatment:Thick Asphalt Overlay (A02)

Al Rasheed Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Al Rasheed Str.	100	7/100	420	460	4,300.00	28

Buirut Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Buirut Str.	420	2/420	160	340	2,940.00	52

Jammet Al - Doual Al-Arabia

Street Name	Street Number	Segment ID	From	To	Area	PCI
Jammet Al - Doual Al-Ar	340	3/340	420	866	5,410.00	55
Jammet Al - Doual Al-Ar	340	2/340	280	420	1,190.00	55
Jammet Al - Doual Al-Ar	340	1/340	240	280	3,900.00	37

Mostafa Hafiz Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Mostafa Hafiz Str.	360	2/360	240	420	6,090.00	51

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Maintenance Treatment: Reconstruction

Jammal Abdel-Nasser Str.

Street Name	Street Number	Segment ID	From	To	Area	PCI
Jammal Abdel-Nasser S	240	2/240	160	340	3,500.00	14

4. Treatment cost of Gaza Pavement Network Reports

Printed Date: 06/01/2004 Last modified: 29/12/2003

Report Description:

Treatment cost by section

Abu Bakr Str.

Street_Name	Street No.	Segment ID	From	To	Area	PCI	Cost
Abu Bakr Str.	20,661	1/20661	700	900	9,800.00	100.00	0

Al Aqssa Str.

Street_Name	Street No.	Segment ID	From	To	Area	PCI	Cost
Al Aqssa Str.	300	3R/300	460	800	4,830.00	66.00	48300
Al Aqssa Str.	300	2R/300	420	460	2,800.00	74.00	1400
Al Aqssa Str.	300	1R/300	240	420	4,410.00	69.00	44100

Al Basateen Str.

Street_Name	Street No.	Segment ID	From	To	Area	PCI	Cost
Al Basateen Str.	422	1R/422	560	940	2,310.00	100.00	0
Al Basateen Str.	422	1L/422	560	940	2,310.00	100.00	0

Al Jalaa Str.

Street_Name	Street No.	Segment ID	From	To	Area	PCI	Cost
Al Jalaa Str.	500	4R/500	600	490	3,360.00	100.00	0
Al Jalaa Str.	500	6R/500	690	830	5,100.00	100.00	0
Al Jalaa Str.	500	2R/500	230	611	3,710.00	100.00	0
Al Jalaa Str.	500	1L/500	200	230	2,700.00	100.00	0
Al Jalaa Str.	500	6L/500	690	830	5,100.00	100.00	0

Page 1 of 14