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Pavement-Management Maintenance System (PMMS) Using Geographic Information Systems (GISs) for Asphalt Pavemnt Roads

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Abstract This research aimed to identify how road networks can be managed and maintained using geographic information systems to find the most cost-effective solutions. We produced a database containing road information and analysed the data to produce a model for road-maintenance management. Maintenance can improve the condition of roads and prolong their life. Therefore, a model need to be created and adopts specialized information about the condition of roads, which can then be used to determine the road maintenance process. A pavement-management maintenance system collects and monitors information on the current condition of roads, in addition to determining maintenance priorities. Such a system can also be designed to create a set of procedures aimed at maintaining asphalt roads with an appropriate level of service. In this research, a 35-kilometre stretch of governorate roads was used as the basis for the model. The aim of this study was to use geographic information systems (GISs) to create a database of the structural condition of roads and defects, capable of evaluating the need for maintenance work. A GIS database and PMMS model could be achieved by evaluating pavement-maintenance needs through performing an inventory and condition survey for roads and determining the most cost-effective actions for the roads based on their condition. The roads in question were found to require different types of maintenance, which were described according to the severity and extent of the asphalt pavement distress. About 30% of the agricultural road from Qena to Qift was found to be in need of maintenance action in the form of reconstruction.

Keywords Asphalt Pavement, Maintenance system, Geographic information systems

1. Introduction

Repair and maintenance of roads can be problematic if they have a heavy traffic load and if disruption for long periods is to be avoided. This calls for a well-thought-out plan to divert traffic away from some streets, resurface these quickly and then reopen them to traffic. All streets inevitably need to be resurfaced at some point to avoid road users having to endure poor road conditions and to minimize damage to utility works (water lines, sewage and telephones), which are affected by road-surface quality. The Roads Directorate does not have the ability to coordinate with other agencies before starting resurfacing operations (or has sufficient authority to stop any maintenance operations affecting city street facilities), and there is competition between the devices and agencies responsible for carrying out different kinds of road works, which can result in some streets being dug up again immediately after they have been resurfaced. Therefore, it was necessary to find a way of rectifying such problems associated with road maintenance. The designed system provides relevant decision-makers with all the information they need about the condition of roads and the level of maintenance required, as well as the estimated cost of this maintenance. The Arizona asphalt road-maintenance management system was designed to be the best maintenance method. Under this system, maintenance is based on a mathematical model that studies the potential need for maintenance of an asphalt road. This calculation is then modified by maintenance decisions, taking into consideration available budgets and engineering decisions [1]. Modelling of asphalt road degradation is an important engineering process which includes improving investment allocations to rehabilitate asphalt roads in the road network. An optimized repair procedure was found for every potential collocating condition according to dynamic programming, and a series of responses to a sample of asphalt road-condition files was created [2–3]. An important aspect of asphalt preservation is the use of road maintenance to improve road function and delay the rate of deterioration. Preventive maintenance is less expensive than rebuilding a road. Road surfaces can be

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preserved by adopting maintenance systems to identify and prioritize preventive maintenance needs [4]. Geographic information systems (GISs) and a PAVER system were used in this study for the purpose of flexible pavement-distress classification and maintenance prioritization. The processes in this research have three elements of distress severity level, type and options for repair. The technique is based on a Pavement Condition Index (PCI), which helps maintenance decision-makers choose the best maintenance programme [5]. Maintenance has an important and integral role in the life cycle of asphalt roads. The pavement-maintenance management system (PMMS) is a systematic method of examination and classification of the condition of roads in the studied area. The maintenance-management system classifies every section of the road and enters this into the database. The next step is to analyse the data and convert the data into recommendations for maintenance items. The best maintenance method is then chosen in terms of cost and available budget [6]. The aim of this study was to understand the relationship between road condition and the frequency of accidents in order to develop a road-surfacing system that works to reduce accidents. From our analysis of the results, it was found that road defects such as ditching must be taken into account, as this is considered to be a key safety factor in places where rain accumulates, as well as the sites where maintenance takes place [7].

2. Pavement-Management Maintenance System (PMMS)

There are three steps in this pavement-management system. The first one is inventory data, which are collected for each road segment, e.g., type, length, width, location, lane number and direction, in addition to maintenance history data, if available. Following the inventory survey, the condition of each segment should be rated using an automated survey procedure or using a visual inspection technique. Visual inspection is more popular and is widely used by many highway agencies. The condition rating for each segment is based on evaluation of the main distresses observed on the road, using three different condition levels (low, medium and high), considering both severity and extent. According to the Egyptian Code for Road Management, there are five levels of maintenance that can be applied, depending on the type and severity of defects in the roads in question: do nothing; surface treatment; overlay; milling and overlay; and reconstruction. There are three steps for building a pavement-management maintenance system (PMMS): conducting an inventory and condition survey, analysis and packing.

3. Inventory Data

In the inventory data and condition step, the longitudinal axis of roads is determined, and nodes are used to name the intersections of these axes. Nodes represent the geometric intersection point between two roads, and links are the portion between two successive nodes, as shown in Figure (1).

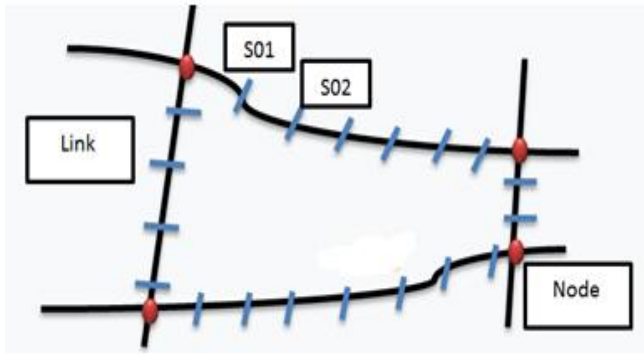

Figure 1. Longitudinal axis of road links, nodes and segments

Each road is given a unique number called the link ID. The link information contains a detailed description of a special number for each link. This number indicates the identity of the link in terms of the name of the street in which the governorate, village or nag\ is located. The starting point of the link is also added, which is located between two segments. The link also contains the coordinates of the starting point, the end point and the length of the link as part of the main road. In terms of description of the segments, key data include the following: the identity number associated with the link in which the segment is located; reference to the direction of the road; the lane number; and the length of the segment We had previously divided the link into 100-metre segments, but the last length of the link in the segment could be less than 100 metres, depending on the length of the link. Key information to ascertain when describing the segment is its distance from the starting point of the link. This helps when choosing the log for maintenance, as it is necessary to know where it is located in relation to the starting point of the link.

4. Evaluation of Asphalt Concrete Pavement Distress (Condition Data)

Three main pavement distresses were evaluated in this research: fatigue cracks, rutting and potholes. Fatigue cracks occur in asphalt concrete as a result of repeated dynamic loads. These cracks begin under the asphalt surface where tensile stress and strain are high under the weight of tyres, and they then spread to the surface in the form of parallel longitudinal cracks. As a result of the effect of repeated movement loads, these cracks begin to spread in all directions in the form of sharp corners (similar to the skin of a crocodile); hence the name “crocodile cracks”. These cracks always occur in locations where the movement loads are frequent, especially in tyre tracks. Fatigue cracks reduce the life of roads and lead to collapse, making roads unusable.

Among the factors affecting road efficiency are frequent loads and temperature changes [8–9]. The severity level of a crack, according to the Egyptian code for roads, can be classified as low (<1 cm), medium (1–2.5 cm) or high (>2.5 cm).

Rutting is one of the main problems associated with roads, i.e., a drop in the longitudinal direction of the road and the formation of grooves. Rutting occurs as a result of increased loads, exceeding the design loads, an increase in the father's ratio in the asphalt mix and lack of proper compaction of the soil. A rutting (permanent deformation) result from an increased volume of traffic and high tyre pressure and is one of the most common forms of distress in asphalt concrete roads [10]. The severity level of a crack, according to the Egyptian code for roads, can be Low (6–13 mm), medium (13–25 mm) or high (>25 mm).

Potholes are a deformation of the road surface in the form of a basin, and they vary in depth, breadth and underlying cause. They are usually the result of water in the road soil structure and traffic passing over the affected area. Water affects the asphalt layer; traffic movement, in turn, affects the surface layer of the asphalt, and continuous traffic takes away all of the asphalt and road soil materials, creating a pit in the road that impedes traffic and may cause accidents. Identification of defects in asphalt roads is of great importance for determining the age of roads [11]. Table (1) presents evaluation values for potholes according to the Egyptian code for roads.

Table 1. Degree of severity of asphalt potholes

Pothole diameter	10–15 cm	15–45 cm	45–75 cm
Pothole depth	Severity		
1.25–2.5 cm	Low	Low	Medium
2.5–5 cm	Low	Medium	High
More than 5	Medium	Medium	High

Figure 2. Asphalt concrete pavement distress

Finally, levels of road distress are calculated by dividing the defective area by the area being studied. The extent of cracking, rutting and potholes, according to the Egyptian code for roads, is classified as "Occasional" (<25%), "Frequent" (25%–50%) or "Extensive" (>50%).

Figure 2 shows different types of asphalt concrete pavement located in the roads under studied area.

5. Road Condition (State)

In this study, we evaluated the condition of roads by analysing the three kinds of defects described earlier, as well as the extent of this distress (three levels, i.e., low, medium and high), so the road condition is 27 cases. Table (2) shows all expected cases of asphalt concrete pavement distress. Having ascertained the number indicating the condition of the road, this number can be linked with different maintenance levels.

Table 2. Condition Number indicating the state of roads

Condition Number	Cracking	Rutting	Potholes
1	Low	Low	Low
2	Low	Low	Medium
3	Low	Low	High
4	Low	Medium	Low
5	Low	High	Low
…..	…..	…..	…..
…..	…..	…..	…..
27	High	High	High

An equation was used to calculate the relationship between road condition and maintenance levels. If a stretch of road was found to have the lowest level of all forms of distress being studied, then there was no need for maintenance work. But if the road was classified as having two kinds of distress in the low-level category and one kind in the medium-level category, then the maintenance requirement was deemed to be surface maintenance. If the road condition was such that one kind of distress was low-level and two fell into the medium-level category, the maintenance level was deemed to be creation of a new surface layer. In the event that the whole stretch of road was medium-level or was classified as having one kind of high-level distress and two kinds of medium-level distress , the road was deemed to be in need of scraping and a new surface layer. In the event that the road condition was classified as having two categories of high-level distress and one in the medium-level category (or all three types of distress were classified as high-level), the road was deemed to be in need of reconstruction.

From experience in the field of road maintenance, cases of severity of asphalt pavement distress can be distributed on the five maintenance levels according to the attached table. Table (3) represents the relation between road Condition state and maintenance-level.

Table 3. Relation between road state and maintenance-level ID

Maintenance Level	Maintenance-Level ID	Road-Condition Number
Do nothing	1	1,10
Surface treatment	2	2,4,5,11,13,14
Overlay	3	3,6,7,8,12,15,16,17
Milling & overlay	4	19,20,21,22,23,24
Reconstruction	5	9,18,25,26,27

6. Geographic Information Systems (GISs)

Geographic information systems were used to help create an integrated system for maintenance. The study sample was located in the Arab Republic of Egypt, Qena Governorate, and it consisted of two roads, the first of which is the Qena to Qaft agricultural road east of the Nile, which extends between two circles of latitude 5″ 59-25°, 20″ 9-26° north, and between longitudes 38″ 48-32°, 42″ 44-32° east, extending from the south, from the Qaft–Qusayr road crossing point to the Al-Bayadiya crossing point in the north, for a distance of 21 km. The second of these two roads is the Qena to Al-Mahrousa agricultural road west of the Nile, which extends between two latitudes 36″ 1-26°, 33″ 8-26° N, and between longitudes 49-45 - 32°, 48″ 41-32° east, extending from the south, from the village of Mahrousa to the Dandara crossing point in the north, for a distance of 15.5 km. Figure (3) presents the roads in the studied area.

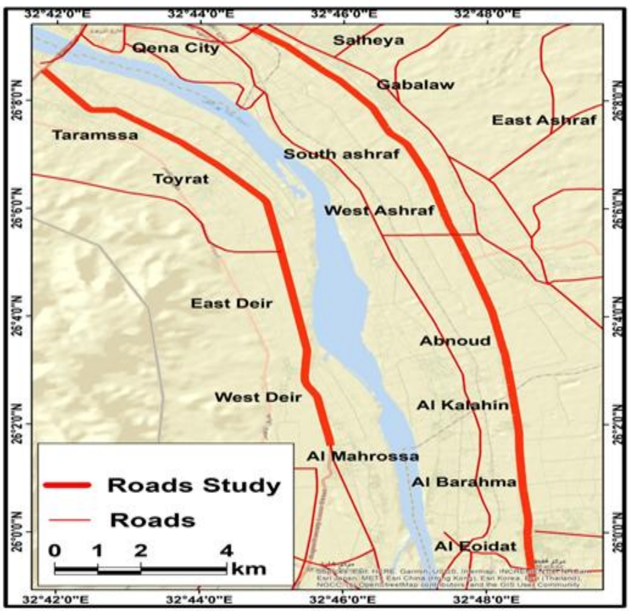

Figure 3. Roads chosen for the study sample

The steps for working on the geographic information system programs were as follows:

- Scanning available topographic maps of various scales, and using these to draw and classify the studied roads. The maps were geographically defined in the ARC MAP program by means of the georeferencing list.
- Creation of a geodatabase in the ARC Catalog program, related to the roads to be studied, which includes a group of classes (the first of which is the closed-feature polygon class) and includes the course of the River Nile. The second is the line-feature class, represented in the roads, and the third is the point-feature class, e.g., city sites, through which analyses were made of the studied methods.
- Drawing the phenomena in all layers and modifying/ adjusting them by means of a list. Data for each layer were entered into the attribute table.
- Analysis of the data, linking the data together (with the help of ARC Map, ARC Catalogue and ARC Toolbox lists) and producing the final maps.
- Various other auxiliary programs were used as well as the ARC Map program for the purposes of drawing roads, updating drawings based on topographic maps, locating sites and saving them in different formats, e.g., Google Earth, which contains satellite images with a resolution of more than 90 cm.

7. Results and Discussions

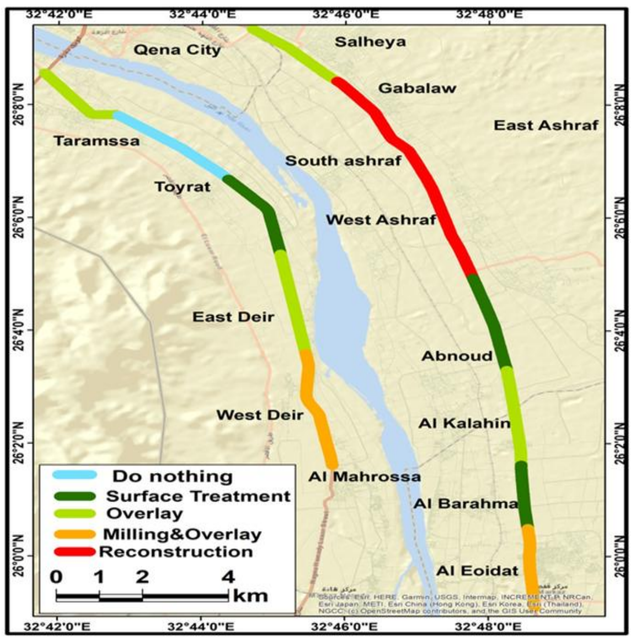

Figure 4. Final map and actual need for maintenance (and the level of maintenance required)

Our data analysis revealed that the Qena–Qeft road needs five levels of maintenance, and the Qena–Al-Mahrousa road needs four levels of maintenance. Figure (4) presents the results of using GISs to present the final map and to determine the actual need for maintenance and the level of maintenance required. Having read this kind of map, decision-makers can determine the areas that need maintenance, and the extent of maintenance work required, and with the help of engineering maintenance experts, the costs of such maintenance can be calculated. Likewise, administrators can specify maintenance priorities, the appropriate methods to be used when immediate maintenance must be done, or cases that can be postponed.

8. Conclusions

- The link established in this study between the road maintenance system and geographic information systems has enabled us to create a useful database that decision-makers can use when making recommendations about necessary action to be taken during selection of maintenance methods, based on the information obtained in this study.
- Road owners need to update information on roads and road condition in order for decisions based on the results of the road maintenance system to yield accurate and efficient results and avoid unnecessary maintenance expenses.
- Increased use of geographic information systems will help improve methods for managing owned assets such as public facilities and roads in particular.

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