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Review on the Expert Systems for Airport Pavements Maintenance Management

Nooruldeen Mohammed Kareem
M.Sc. Student in Civil Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq
st.noor.aldeen@ced.nahrainuniv.edu.iq

Asma Thamir Ibraheem
Faculty Member in Civil Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq
Asma.th.ibraheem@nahrainuniv.edu.iq

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Abstract

Airport networks are one of a country's most valuable assets, especially as air travel has become more prevalent as a form of transportation. To maintain the maintenance and rehabilitation program, the aviation agency must make significant time and financial commitments. For the proper functioning of airports and to keep the pavements in good shape, airport pavements need to be continuously improved, repaired, and maintained.

Expert systems, sometimes referred to as knowledge-based systems, are computerized advising programs that replicate the thinking and judgment processes of human experts when resolving specific problems in a limited field. These systems, among the areas of artificial intelligence (AI),those are being researched the most actively and offer a number of benefits over traditional computer programs or human knowledge. Expert systems ability to separate the domain knowledge and the inference, modify the symbolic information, express process and knowledge openly, and replicate human competence and judgment through the application of heuristics and collected human experience.

They have several benefits over human expertise, including permanence, ease of transfer, ease of documentation, consistency, and affordability; in contrast, human expertise is unstable, costly, difficult to transfer, and difficult to document.

The types of pavements found at airports, bearing capacity measurement techniques, the idea behind the software used to assess pavement condition, and a summary are all covered in this paper fundamental background information.

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1. Introduction

The International airport network is mostly organized into the following parts as shown in Figure (1):

1. Runway
2. Taxiway
3. Aprons
4. Hangars
5. Streets and parks

The pavement of each part is either flexible or rigid; sometimes a combination of flexible and rigid pavement is used at most in the runway in some countries.

When deciding which maintenance and rehabilitation therapies to use and apply, a section should be seen as the smallest management unit. Pavement structure, traffic, previous construction, and pavement quality are among the elements taken into account when splitting branches into parts (Ismail, 2009).

Figure 1: Airport Pavement System.

Airport infrastructures are in fact productive businesses that may bring in money and draw in private investment. They must, however, address the demands of expanding territorial growth and mobility. Transportation authorities and airport operators require increasingly dependable pavement management techniques and equipment to ensure a consistent level of service. Non-destructive assessments are crucial in this situation for gathering data and information on the conditions of asphalt concrete and, as a result, for determining the order of priority for interventions in management systems. Due to the increased intensity of the load, the Heavy Weight Deflectometer (HWD) is more frequently used than the Falling Weight Deflectometer (FWD) to assess a runway's structural integrity without causing damage.

In network-level management, inquiries concerning short- and long-term budget requirements, the general state of the network (both present and future) and needs to be taken into account at the project level are addressed. To prioritize maintenance and rehabilitation (M&R) techniques and optimize funding, a network level evaluation may be used to inform management choices for a complete pavement network, such as local consideration, might comprise all the pavements on an airport and, for state consideration, all the pavements in the state airport system. In addition to being an automatic method for saving data on certain pavements, pavement management plan (PMP) is a software has the capacity to create pre-defined reports as well as unique ones. These reports can help the user make decisions on scheduling inspections, rehabbing pavements, budgeting, regular maintenance projects, current pavement problems, and projected future conditions. (O'Donnell, 2014).

2. Expert System for Airport Maintenance Management

Airport operators are required to keep the airport runway, taxiway, and apron pavements in acceptable condition while staying within a certain budget in order to guarantee the safe and effective operation of aircraft.

The development of cost-effective maintenance and rehabilitation methods is made possible by tracking the progression of pavement distresses over time. APMMS's (Airport Pavement Maintenance Management Systems) primary objective is essential to choose the most economical way of maintenance and repair for a high return on investment (Lima and Santos, 2019). The selection of workable rehabilitation solutions necessitates extensive understanding of the assets' conditions, the efficacy of remedial measures, and the effects of the action on system performance.

Some of these aspects could be solved deterministically and the others must be solved heuristically. Only a small number of pavement engineering professionals have access to the heuristic information, and they utilize their expertise, discretion, and experience to create interferences and make design and investment decisions. These specialists are seldom available in local organizations, and it is challenging to transfer their essential expertise to less experienced engineers in order to diagnose pavement damage and determine the appropriate solutions. They may lose their expertise and experience since they are retiring. For the benefit of inexperienced engineers, it is therefore vital to capture as much of the expertise, experience, and thought process of airport pavement engineering professionals as feasible (Ismail, 2009). There are 4 key types of maintenance management strategies including run-to-failure maintenance, preventive maintenance, predictive maintenance, and reliability-centered maintenance. (Salamone, 2014).

3. Pavement Maintenance Management System (PMMS)

By preventing surface structural degradation, (PMMS) aims to maintain pavement condition in the upper (PCR) range of (60-90) while reducing the cost of restoration (Sarsam, 2015). The development of the economy and social activities for the nation are influenced by transportation, which also serves as a connection between businesses, industries, and consumers. The allocation of funds for pavement maintenance work, conflicts in the process of decision-making between

technical and administrative issues, and a lack of an efficient decision-making tool generally govern how the transportation network is reserved.

The lifespan of a pavement is directly related to maintenance. The pavement maintenance management system (PMMS) is a methodical approach for evaluating the state of the pavement in a specific region. A cost-effectiveness study of various maintenance and restoration options is also carried out by the system. Last but not least, the system prioritizes and suggests pavement restoration and maintenance to get the most out of a given budget. The system keeps account of workers, supplies, equipment, and costs for tasks carried out when doing maintenance. The approach also promotes the efficient use of people, tools, and resources. Each street section is inspected visually or automatically in the field, and the results are rated and stored into a database. A software program or expert opinion is used to assess the data, provide recommendations, and forecast future circumstances.

(Saad, 2016) created a degradation curve for each section using input, and based on the condition, surface type, functional categorization, and available budget, it assigns the most cost-effective maintenance approach. The study looks carefully at the PMMS and how it may help extend the estimated service life of the pavement as long as feasible at a reasonable cost by applying the correct treatment to the right pavement at the right time as shown in the Figure (2).

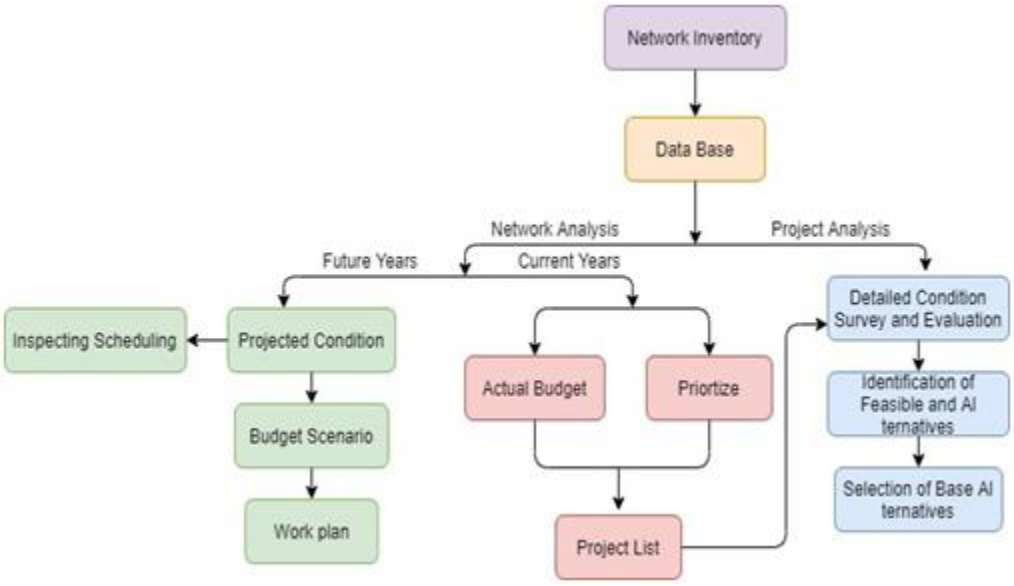

Figure 2: Flowchart the components of pavement maintenance system.

Systems for managing pavement maintenance (PMMS) are becoming used around the world, not just in applications for airports but also for highways. Following discussions with several outside businesses, it is clear that introducing PMMS might be challenging due to the prevalent maintenance mentality used by many airport managers. Additionally, it has to be known that the PMMS entry won't be available right away.

In order to assess the existing and future pavement state, PMMS often employs the pavement categorization system, also known as the pavement status indicator (PCI). To evaluate the best cost-effective maintenance options for the airport, various budget and maintenance scenarios may be conducted for the anticipated future walkway (Papaleo, 1998).

3.1. Selecting the PMMS

The following is a list of actions that can be supported in the PMMS choosing and actions that will be used to create the system (Papaleo, 1998):

1- Establish a review team
2- Select PMMS requirements
3- Check the PMMS available
4- PMMS
5- Establish a development team
6- Program training and PCI procedures

Instead of relying just on technical expertise and governance, employing the PMMS sidewalk maintenance system has a number of advantages. Among them are the following (Papaleo, 1998):

1- Offers a methodical and impartial strategy for managing walkways
2- enables you to easily simulate several budget and maintenance scenarios
3- The engineer explains how the existing pavement works and how the future pavement will progress.
4- Offers a database for historical sidewalk and construction information
5- Make the most of the maintenance funds that are available in a timely and efficient manner.

4. Pavement Maintenance Concepts

According to Roberts and Suhbier (1971), maintaining a transportation route entail keeping route facilities as close as practicable to their original states and operating them to deliver adequate service and safe transportation.

According to Oglesby and Hicks (1982), maintenance is the observation and preservation of each type of transportation route in as close to its original state as when it was built or as it has since been improved, as well as the operation of the facilities and services that go along the route in order to offer satisfactory and safe transportation. According to AASHTO (1987), maintenance is a strategy to seek repairs and return a system of roads and its components to their intended or acceptable configuration.

According to (Kelly, 1984; Finch and Gilbert, 1986; Banerjee and Flynn, 1987; O'Flaherty, 1988; Sheu and Krajewski, 1994; Kelly et al., 1997; Lofsten, 1998) there are really two distinct approaches to sustaining current utilities:

1- Breakdowns and the need for urgent repairs are reduced by the PM (Preplanned and Scheduled adjustment Maintenance) strategy.
2- On the other hand, the CM (Corrective Maintenance) approach focuses on the steps taken to repair or otherwise return facilities to a state of operation following a failure.

A normal maintenance program, a periodic maintenance program, special maintenance operations, and a transportation route strengthening are other ways to arrange and categorize maintenance tasks (Oglesby and Hicks, 1982).

According to Al – Zubaydi (1989), there are two crucial areas need to be the emphasis of road maintenance:

1- Maintaining the structural integrity of the road by preserving the asphalt layers, base and subbase layers, and shoulders in good shape, nearly identical to when the road was initially built.
2- Road maintenance services, such as repairing (traffic signs, safety fences, wire fences, phone lighting poles, roadside, etc.) in a way that provides a reliable and affordable mode of transportation.

5. Maintenance Classification

According to Al-Zawiny (2000), maintenance may be categorized based on the activities that are included in it, the type of activity, or the goal of the activity, as illustrated in figure (3).

The priority of municipal transportation departments has shifted from building new roads to maintaining and protecting the current pavement surfaces (Johnson,2000).

Three different pavement maintenance activities have emerged as a result of the change which are emergency maintenance, emergency repair, and preventive maintenance A thorough pavement care program requires all kinds of maintenance.

A pavement may not need corrective maintenance if preventative maintenance is prioritized. The proper repair must be made on the right road at the right time as part of preventive maintenance. Corrective and preventative maintenance were the categories used by Jaber (2007) to group maintenance.

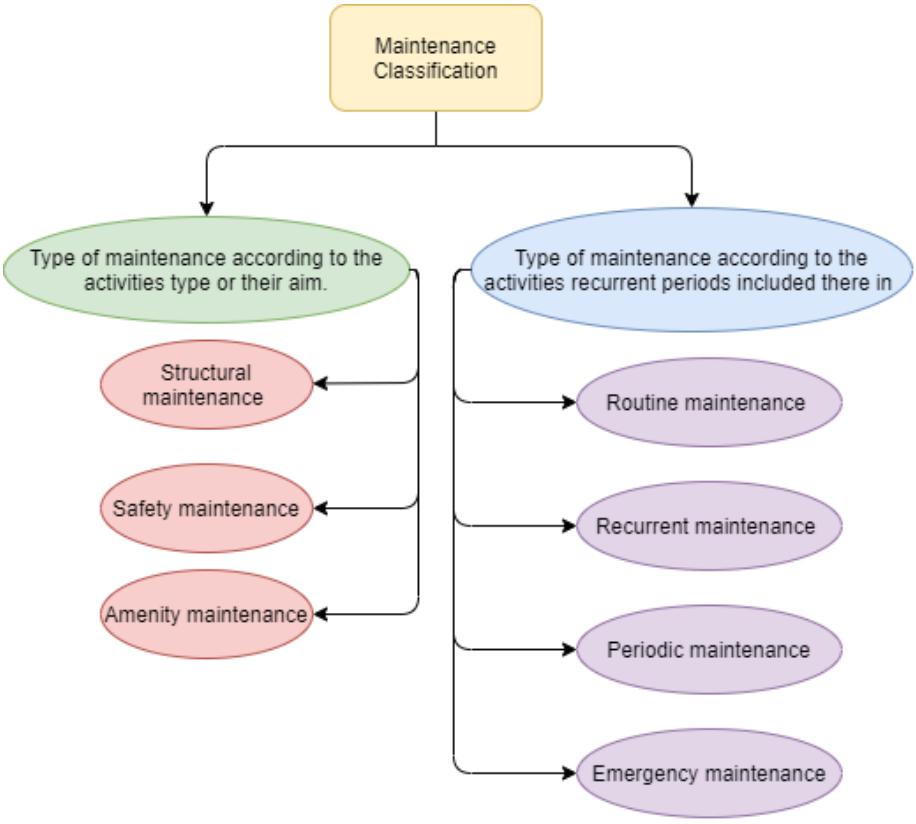

Figure 3: Maintenance classification diagram.

6.Maintenance Importance and its Economic Advantages

Robinson (1986) reported that when the road gets older due to its use by vehicles, gradual deterioration appears. Generally, the deterioration average depends on many factors including weather condition, paving quality, underlying soil strength, traffic volume, and axial loads for the trade vehicles allowed to be used on the road. Figure (4), which is a typical performance curve, clarifies the relation between the road condition and its age.

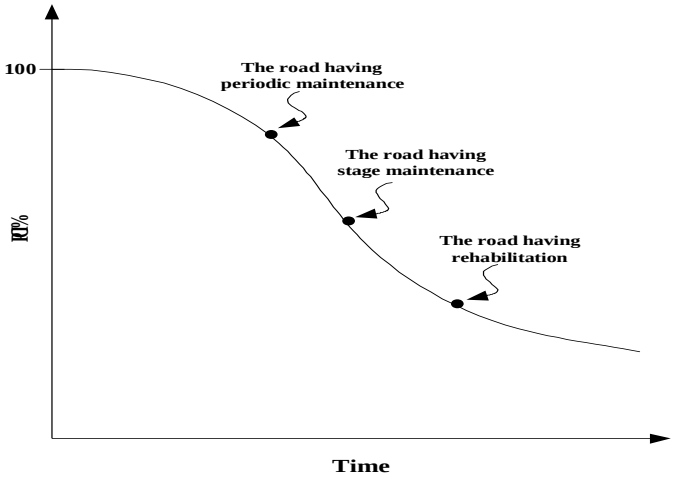

Figure 4: Typical Performance Curve, (Robinson, 1986).

Also, he reported that the neglecting of routine maintenance, such as neglecting the small cracks on the paving surface, will cause gaps through which water penetrates into base layer or the layer below the base one.

This matter leads to sink in certain parts of the roads. Subsequently, repeated periodic maintenance is required.

Al-Zubaydi (1989) reported that keeping roads new by maintenance will provide a comfortable and easy driving and reduce the cost borne by road users. Subsequently, a great benefit for the national economy will be achieved by paying attention to maintenance and improving the road to lower the vehicles operating cost. The matter, which led to close a number of factories and plants for several months, as well as, delivering their production to distribution centers.

Additionally, the agricultural areas at that were affected for not being able to get the fertilizers or delivering their products to the markets. Also they reported that the implementing maintenance works is to keep the road open to ensure providing continuous service for residential area, industrial and agricultural facilities surrounding the road. Blocking the road either because of the sand hills or floods in rain seasons will also create series of social and economic consequences.

Richecoure and Heggie (1995) reported that in one of the African countries, 40% of vehicles are unable reach their destinations due to the bad condition of the roads in rain seasons. Atkinson (1997) concluded that the roads after a certain period of time require maintenance works. Improvements and rehabilitation of roads are important to keep them as a longer period as possible in service as shown in Figure (5), which indicates a new circle of the road's life. Al-Zawiny (2000) reported that driving vehicles in damaged and narrow roads will increase the operating cost, because of more fuel consumption.

Statistical studies, in this respect, were published lately in the United States of America indicate that the waste of fuel is about (16.4) billion gallons per year because of using damaged roads. Also, he reported that in the damaged roads will increase the vehicles wheels consumption, as well as the suspension system is consumed in a shorter time. Subsequently, everyone in the United State of America has to pay a hidden tax which is about (136) dollars every year.

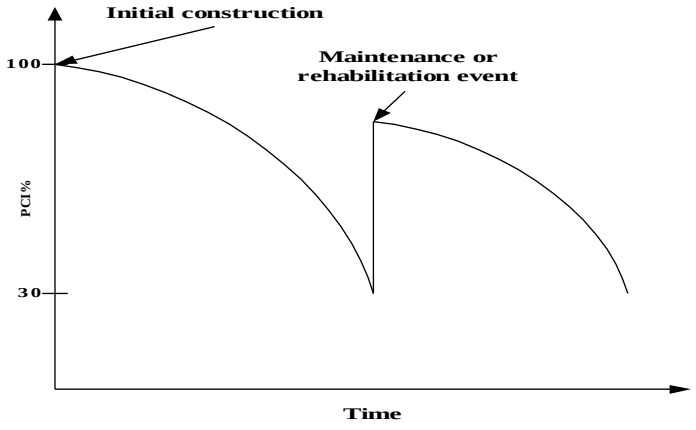

Figure 5: Concept of projecting pavement performance using PCI, (Oglesby and Hicks, 1982).

7. Maintenance Costs

FHWA (1997) reported that the expenditures of (1996) year were $ 46.6 billion for highway construction and $26.7 billion for highway maintenance (57.3% of the construction cost).

The estimated cost of periodic maintenance is ID 10*106 /km of 8 m pavement width. The estimated cost of reconstruction of 1 km lane according to the World Bank is ID 100*106 /km. These estimates are based on the average prices of 1996.

Jrew (1997) reported that despite the increase in funding projects and maintenance works in Iraq, these increases have failed to keep pace with the escalation in prices and costs of maintenance works. This price escalation is the normal outcome since the beginning of the imposed blockade in Iraq in 1990. He carried out several alternative maintenance programs and policies. He indicated that the best maintenance policy of implementing proper and adequate maintenance for the network on annual and regular periods instead of postponing that due to expenditure reduction.

Daoud (1997) pointed out that the allocated funds for maintenance of roads in Iraq as a percentage of the total allocated funds for roads during 88, 89, and 90 were 10.4%, 4.8%, and 4.6% respectively. According to The World Bank reports (1999), the maintenance cost as % of the total investment for roads in the Arab Gulf States during the eighties was between 4-10 %. This low level of maintenance resulted into the need for a complete reconstruction or rehabilitation. The estimated cost of reconstruction is about $ 200 billion over a period of ten years up to the year 2000. Also, he reported that due to the blockade imposed on Iraq, the cost of maintenance works has increase by annual rate of approximately 108% during the period 1990-1995. The cost of 50 mm layer of asphalt overlay in Iraq in 1990 was ID 4/m^2 while the cost of the same job in 1995 was ID 160/m^2 and pointed out that the annual cost of the required routine maintenance for pavements in developing countries according to the World Bank reports ranges from $200 to $1000/km. For resurfacing the average cost ranges from $8000 to $1000/km. experiences with existing highways having similar characteristics (Gani,2008).

8.Airport PMMS

Airport PMMS is a collection of tools or techniques that may help decision-makers come up with affordable plans for constructing, assessing, and keeping pavements in usable condition. By anticipating future conditions, PMMS offers a methodical, consistent way to choose maintenance and repair needs and choose the best time to make repairs (Shahin and Kohn 2006).

For airport applications, there were primarily two pavement maintenance management systems in use worldwide:

1- **The Micro PAVER** from the USACERL, or United States Army Corps of Engineers Research Laboratories. (The Micro PAVER system's scope is to manage maintenance tasks within the constraints of resources and maintenance costs. Using computer software integrated with a geographic information system (GIS) program for managing geographic and inventory data, the system primarily relies on systemic methods and procedures for data acquisition, recording, pavement evaluation, maintenance priorities, maintenance needs, and decisions, as well as determining the cost and activities of the future maintenance programs.

2- **The Integrated Airport Pavement Management System from Gibb Consulting** (IAPMS). The US Army Corps of Engineers created an objective, repeatable rating system to determine the state of the pavement, according to published research (2004). This pavement maintenance management system (PMMS), known as the PAVER system, was created to maximize the expenditures allotted for pavement maintenance and rehabilitation (M&R) (Bara'w.Al-Mestarehi, 2012). It is now a validated pavement maintenance management system for airports, cities, and counties.

9. Implementation of Airport PMS

PMMS is discussed for a specific pavement network. There is a systematic action to be followed to implement PMMS at the project level. This procedure all over the world is used with very little difference (Papaleo, 1998):

1- Data collection and definition of the pavement network - in this move, the construction records should be collected for the pier to enter into PMMS. This step can take a very

long time and depend on the availability of existing information. Once you create this, the sidewalk network must be specified in accordance with D5340-93.

2- Evaluation of the state of the pavement - This step includes a visually examination of the pavement to develop procedures and conduct other tests considered to identify the state of the pavement. In general, only PCI survey is made, but can also test the pier test if you wish.
3- Forecasting the sidewalk - this includes the use of PMMS to calculate the current pavement state, as well as predict the status of the future pavement, by using a family of performance forecasting curves
4- Formulation of maintenance policies - each airport has a special set of maintenance and maintenance policies used to determine when maintenance will have to be implemented.
5- Formulation and development of status scenarios - in this move, multiple budget and maintenance scenarios can be run quickly to determine the most cost-effective solutions to the pier while staying within the budget limits (Papaleo, 1998).

10. Development of Expert System for Airport Pavement Maintenance

Expert systems, sometimes referred to as knowledge-based systems, are computerized advising programs that replicate the thinking and judgment processes of human experts when resolving specific problems in a limited field (Sundin et al. 2001). They are among the areas of artificial intelligence (AI) that are being researched the most actively and offer a number of benefits over traditional computer programs or human knowledge. Expert systems ability to separate the domain knowledge and the inference, modify the symbolic information, express process and knowledge openly, and replicate human competence and judgement through the application of heuristics and collected human experience. They have several benefits over human expertise, including permanence, ease of transfer, ease of documentation, consistency, and affordability; in contrast, human expertise is unstable, costly, difficult to transfer, and difficult to document.

In Iraq, Daoud (1997) created a method for managing highway maintenance. The study took into account the backdrop of the current condition of the highway network as well as the

situation of the State Corporation for Roads and Bridges' maintenance management system. The examination of the current system revealed numerous significant flaws in the system through the review of prior rules and processes. These deficiencies are categorized according to the main basic functions of management: planning, organizing, directing, and control. The developed system is based on fundamental and basic elements of system development. It is also based on the outcome that is obtained from the analysis of the existing maintenance management system of highways in Iraq.The developed system introduced some new and modified components to be adopted by State Corporation for Roads and Bridges in order to upgrade its management system. These components are: new highway inventory system, new pavement performance evaluation procedures, modified estimating and budgeting system of maintenance works, new system for the allocation of the limited resources for maintenance of highways based on priority model, modified organizational structure for the maintenance section of State Corporation for Roads and Bridges, and a design of new and modified control system.

Ajam (1999) created an expert system that has information about the many types, causes, and solutions for distresses that might arise in flexible pavement. The information for this thesis was taken from the two knowledge sources stated before. These are references, data from surveys, and knowledge gleaned from interviews with senior pavement engineers (experts) with extensive experience in flexible pavement engineering, specifically for entry into the "CRYSTAL" expert system builder shell. The system, which is called Flexible Pavement Distresses Diagnostic Expert System "FPDES" is intended to identify the distress clarify its causes and provide the user with practical advises to remedy it. It is believed that "FPDES" represent a useful and practical tool that assist practicing engineers in making quick and clear expert decision at the sites, when a human expert is not available. Saving in cost and efforts will also be appreciable. Future research will be possible through the use of the developed system.

According to FHWA (1999), one of the most frequently carried out highway maintenance activities is patching potholes in asphalt and concrete pavements. The pothole experiment's main goal was to identify the combinations of materials and patching techniques that offer the most affordable repair of potholes on asphalt concrete-surfaced pavements. The following patching techniques were used in combination with the various cold mixes:

1- Throw-and-Roll: Material is thrown into a hole that may be littered with water and debris, compacted by four to eight passes of the truck tires, and then removed from the hole.
2- Edge Seal: Using asphalt tack and sand on the road surface, edge sealing is combined with the throw-and-roll method.
3- Semi-permanent—A hole is cleaned of water and debris, the sides are squared off, and cold patch material is added before being compacted by vibratory or rolling compactors.
4- Spray Injection: A pothole is cleaned of water and debris, new asphalt and aggregate are sprayed into the hole, and then a layer of aggregate is spread over the patch .

According to Johnson (2000), there are many ways in which pavement distresses cause pavement failure. The most typical flexible pavement distresses are bleeding, rutting, ravaging, weathering, and cracking. The pavement portion is probably not a candidate for preventative maintenance treatment and should be scheduled for rehabilitation or rebuilding if the distresses found in the pavement are attributable to structural issues. Treatment that is preventative, remedial, or urgent can alleviate other distresses. An engineering strategy should be used to pick and build the therapy for it to be efficient. For the pavement to perform as intended and for the maintenance program to be successful, it is essential that the suitable maintenance treatment be applied at the appropriate time. Many factors should be considered when determining the value of any pavement maintenance treatment. The decision process should include the following three factors in the following order:

1- Enhanced performance that can be measured in several ways, including comfort, convenience, safety, or life cycle costs. If there are no improvements in any of these customer-related issues, then there is no reason to use the treatment. If one or more of the areas can be enhanced, then the second factor should be taking into consideration.
2- Measuring the benefit of a treatment should include an assessment of the pavement's performance, and not necessarily the performance of the treatment itself. The error often made when comparing maintenance costs is to compare the

cost and life of the treatment with the cost and life of the pavement. This comparison is not valid.

3- Once the cost-effectiveness of the therapy has been established, choose the best building materials and techniques.
4- Mohammed (2001) created the "HMPCES" expert system to manage issues with highway maintenance. This system was designed with standards definition as its primary goal (controlling the activity problems). The research examines issues with flexible pavement, drainage, rood sides, and other issues, and it chooses the best maintenance activity based on the degree of distress in the flexible pavement and the nature of the issue in other situations.
5- The system was created using data from journals, papers, books, manuals, and senior pavement engineers (experts), particularly in rood maintenance. This approach is thought of as a useful tool that aids the engineer in choosing the appropriate and proper maintenance activity for various roadway concerns.

Asian Development Bank (2003) reported that the developing world, roads are deteriorating for want of maintenance. Roads are being lost. The Asian Development Bank (ADB) and other agencies lending money for roads are concerned about this. Inadequate maintenance is the cause of the problem. Maintenance includes all activities needed to keep a country's road network operating indefinitely:

1- Periodic maintenance (resealing, about every five years, to renew the surface)
2- Routine maintenance (improving drainage, patching potholes and cracks, preserving edges)
3- Rehabilitation (overlaying, about every 15 years, to restore smoothness and durability).

When a road network is in good shape and doesn't degrade over time as a whole, it is sustainable. Individual roads do not stay static; paved roads experience an ongoing cycle of deteriorating smoothness until they are rehabilitated, at which point they resume their previous smoothness. The state of the network as a whole does not alter year over year since a network is made up of roads that individually are at all stages in this maintenance cycle. Therefore, a

maintained road network is one that is sustainable. Any of the following causes can be attributed to inadequate maintenance:

1- Money is not allocated (in sufficient amounts).
2- Money is allocated but not spent.
3- Money is not spent efficiently.
4- Money is not spent effectively.

According to Infra Guide (2005), bituminous pavements may be preserved by using thin surface repair procedures. Thin surface repair procedures include applying treatments to the pavement surface since typical paving processes often involve overlays that are at least 40 mm thick. The following seven methods for restoring thin pavements:

1- Thin hot mix overlay (less than 40 mm).
2- Hot-in-place recycling (with the total depth of re-processed and new material of less than 40 mm).
3- Micro-surfacing.
4- Slurry seal.
5- Surface treatment.
6- Restorative seal.
7- Texturization.

The strength of the pavement is not greatly increased by thin surface restoration procedures, but they are advantageous for pavements because they shield the pavement's structure from early degradation and/or enhance or restore the pavement's surface. In the interim, until a permanent solution can be applied, thin pavement surface repair procedures are also well suited. Thin pavement surface repair methods also offer a cost-effective, dust-free wearing surface for low traffic volume roadways.

According to Geiger (2005), preserving the pavement on our current roadways is a proactive strategy. It helps State transportation authorities to cut back on time-consuming, expensive restoration and construction projects as well as the ensuing traffic delays. With prompt preservation, we can provide the traveling public more safety and mobility, less traffic, and

smoother, more durable pavements. Preventive maintenance, modest rehabilitation (non-structural), and certain regular maintenance operations make up the three primary parts of a pavement preservation program. Jaber (2007) created an optimization model that can pick the best group of projects from the network while taking financial constraints and the accomplishment of numerous goals into account. The network's performance was examined under several budgetary situations and with various goals. The study looks at how maintenance choices affect the ecosystem. In other words, the model tries to choose upkeep options that would provide low emission levels. The research has been expanded to include a list of the connections that must be kept up for each activity category. The goal planning approach is used in this study to allocate money for highway repair operations in the best possible way. Seven maintenance activities were considered in this study. Three of them are implemented through contracting and the remaining four are carried out by district local force. Four objectives are considered for simultaneous optimization. These objectives are pavement condition service level, safety and environmental emission. Finally, the study included developing analysis interface program (AIP) to provide maintenance strategies because it is an effective powerful and easy tool.

11. Conclusions

It is well understood by pavement engineers that managing pavements requires a reliable pavement performance indicator. An index of pavement condition (PCI) based PMS that relies solely on visual condition ratings for pavement condition estimation cannot provide the optimum maintenance selection since it lacks structural information. This thesis provides an opportunity to study alternatives to replace or supplement the visually derived PCI. Specifically, the development of expert systems in the area of airport pavement management has been in existence since a few decades ago. It was developed to simulate or reproduce intelligent problem-solving behavior in a computer program. Expert systems show weariness’s in the difficulty to reach points of a agreement a money the experts and the lack of tools procedure to represent the knowledge domain especially in Iraq

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