Evaluating Highway Pavement Maintenance Management Practices in Egypt

Hany Abd Elshakour Mohamed[1], Suad Hosny Enany[2], Asmaa Kamal Eldin Mohammed[3]

Abstract: The roads network is one of the most important assets in all countries. Nowadays, there is a big boom in roads construction in Egypt. Pavement conditions of roads during the operation phase play an important role in the economic, social, and environmental situations in any country. Roads conditions can be enhanced by the implementation of good pavement maintenance management practices (PMMP). The purposes of this research are to identify PMMP that have the potential to improve pavement conditions of the roads network, measure PMMP applied in Egypt, and on that basis, compare between the actual applied PMMP in Egypt and some international best practices to gain lessons that can be used to improve the applied PMMP in Egypt. The search passed through three successive stages. During Phase I, comprehensive review of the available literature was done to identify the PMMP that have the potential to improve pavement conditions. In Phase II, based on designed questionnaire, data were collected from the General Authority for Roads, Bridge and Land Transport (GARBLT) and its districts in Egypt. The qualitative data were analyzed to determine the actual PMMP applied in Egypt. In Phase III, a comparative study was conducted to pinpoint the weaknesses and opportunities in the applied pavement condition data practices in Egypt. Asset owing organizations and interested stakeholders can use the applied methodology to assess the level of implementations of PMMP.

Keywords: Asset, Pavement maintenance management, Performance measure, and Construction industry.

1. INTRODUCTION

The roads network is one of the most important assets in all countries. According to the records of the Egyptian Central Agency for Public Mobilization and Statistics [1], the highway construction and the flexible pavement roads represent 48.51% and 17.34% of the Egyptian construction industry expenditure respectively. The pavement network is exposed to deterioration as a result of many factors, like errors in the pavement structural design, change in climate, increase in traffic loads, using bad materials, weak of subgrade, and bad construction quality. The required fund for roads maintenance in Egypt is about $ 700 million annually [2]. On the other hand, pavement conditions of roads, during the operation phase, play an important role in the economic, social, and environmental situations in any country. Roads conditions can be enhanced by the implementation of good pavement management system (PMS). PMS can be defined as "a set of methods and tools which can support decision-makers in finding cost-effective strategies to provide, evaluate, and maintain pavements in a serviceable condition" [3]. Pavement management system is based on the methods of collecting, storing, and retrieving the decision-making information needed for making maximum use of limited maintenance (and construction) dollars [4]. Many researchers have tried to develop models and frameworks that demonstrate the basic processes of pavement maintenance management. However, each model has its strength and weakness points; therefore, a compiled model should be developed to benefit from the advantages of the available models. The purposes of this research are to identify PMMP that have the potential to improve pavement conditions of the roads network, measure PMMP applied in Egypt, and on that basis, compare between the actual applied PMMP in Egypt and some international best practices to gain lessons that can be used to improve the applied PMMP in Egypt. The research adopted a three-phase exploratory sequential mixed-methods design. During Phase I, comprehensive review of the available literature was done to identify the PMMP that have the potential to improve pavement conditions. In Phase II, and based on designed questionnaires, data were collected from the General Authority for Roads, Bridge and Land Transport (GARBLT) and its districts in Egypt. The qualitative data were analysed to determine the actual PMMP applied in Egypt. In Phase III, a comparative study was conducted to pinpoint the weaknesses and opportunities in the applied PMMP in Egypt.

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2. PAVEMENT MAINTENANCE MANAGEMENT PROCESSES

Any facility constructed can be considered as an asset that needs to be maintained for ensuring its optimal value over its life cycle [5]. Pavement is one of the most important asset elements in highways and roads network. Asset management can be defined as "a decision-making framework that is guided by performance goals" [6]. Asset management system is "a set of interrelated and interacting elements of an organization, whose function is to establish asset management policy, objectives, and the processes, needed to achieve objectives" [7]. Asset maintenance management is a vital knowledge area of asset management. The pavement network represents important asset in Egypt. As stated earlier, the highway construction and the flexible pavement roads represent 48.51% and 17.34% of the expenditure of the Egyptian construction industry respectively [1]. To maintain the services quality provided by pavement for the benefit of customers, pavement maintenance management practices should be applied effectively and efficiency.

In the past few years, many studies have been conducted to develop theoretical and practical frameworks for asset maintenance management. In 1998, the Egyptian code for maintenance of rural and urban roads was released that was updated in 2008. It established the steps of roads maintenance management system. The steps include determining the objectives and reviewing the practical rules and standard specification before monitoring the network condition, identifying network conditions, performing data analysis, determining the priorities, and estimating the required budget. According to the available budget, the priorities are evaluated for setting maintenance plan. During the execution of the maintenance plan stage, the organization should track the quality and the performance of processes, and finally it should document the information [8].

In 2002, a framework for asset management was developed that includes four areas. These areas are policy goals, planning and programming, program delivery, and systems monitoring. All these areas are supported by quality information and analysis [9].

M. A. Hassanain and T.M. Froese et al (2003) [5] developed five processes involved in asset maintenance management. B. Wilkins (2004) [10] developed a model for highway asset management that consists of six phases. In 2014, Asset Management Council in Australia presented a model for asset management that includes the key elements of an asset management system and how they are interrelated [11]. ISO 55000 (2014) [7] provides a common platform and reference point for asset management internationally, across all sectors and industries, and is aimed at all assets, including those in public and private ownership. ISO 5001 [12] specifies the requirements or "what to do" for asset owning organizations but it does not specify the "how to do". The framework has the following components:

- Determining asset management policy, and asset management objectives in the light of stakeholder requirement and organization context.
- Setting AM plans that include the relevant support.
- Implementing the plans.
- Evaluating and improving the performance.

The main processes of the above stated models and frameworks related to asset (maintenance) management are summarized in Table 1. A succinct review of the models and studies related to the asset (maintenance) management process reveals that they vary in their scope and level of detail. Based on this review, a compiled practical model was developed. The compiled model can have dual function, to show the main processes of pavement maintenance management and to evaluate the current applied pavement management practices in Egypt. The basic processes of the compiled model of pavement maintenance management are presented in the following sections.

3. COMPILED PAVEMENT MAINTENANCE MANAGEMENT MODEL

Figure (1) represents the compiled pavement maintenance management model that is sufficiently broad to permit a complete evaluation of the pavement maintenance management practices and commonly used in pavement management studies. The methodology used to form the model is the Plan-Do-Check-Act (PDCA) methodology. The following paragraphs illustrate the processes of the compiled model for pavement maintenance management.

TABLE (1): Main processes of the asset (pavement) maintenance management model

Main processes of Asset (pavement) management model	Developed models					
	Cambridge Systematics. 2002	Hassanain et al. 2003	Wilkins, 2004	Asset Management Council in Australia. 2014	ISO 55001,2014	Egyptian code for maintenance work (2008)
leadership	×	×	×	√	√	×
Plan						
Pavement asset management policy, goals & objectives	√	×	√	√	√	√
• Identifying stakeholders requirement	√	×	√	√	√	×
• Establishing pavement asset management policy	√	×	√	√	√	√
• Defining pavement level of service	×	×	√	×	×	×
• Developing pavement performance measures & targets	√	√	√	√	√	×
Planning and programming	√	√	√	√	√	√
• Plans to achieve goals	√	√	√	√	√	√
• Resource Allocation Decisions	√	√	√	√	×	√
• Contingency planning	×	√	√	√	√	×
Support	×	√	×		√	
• Resources	√	√	×	×	√	√
• Organizational roles and responsibilities	×	√	×	√	√	×
• Training, awareness , and competence	×	×	×	√	√	√
• Communication	×	×	√	√	√	×
• Required data & information	√	√	√	×	√	√
• Documented information	×	√	√	×	√	√
Do						
• Implement the processes	√	√	√	√	√	√
Check						
Performance evaluation	√	√	√	√	√	√
• Monitoring and measuring pavement management system performance	√	√	√	√	√	√
• Gap analysis, evaluating, and reporting	√	√	√	√	√	√
Act						
Improvement	×	√	√	√	√	×
• Corrective action	×	×	×	√	√	×
• Preventive action	×	×	×	√	√	×
× not applied √ applied						

3.1 Leadership

The concept of leadership is a central principle to any management system. Leadership is the promoter for a positive change and pavement management requires a positive change. According to ISO 55001 (2014) [12], top management should demonstrate leadership and commitment with respect to the pavement

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management system by meeting customer and applicable statutory and regulatory requirements, ensuring that the policy and objectives are established for the pavement management system and are compatible with the context and strategic direction of the organization; ensuring that the resources needed for the pavement management system are available; ensuring that the pavement management system achieves its intended results; and promoting improvement.

3.2 Pavement Maintenance Management Policy, Goals and Objectives

According to M. Grant, and J. D'Ignazio et al. (2013) [13], "planning requires evolving strategies for managing, operating, maintaining, and financing the area's transportation system, and selecting investments in such a way as to advance the area's long-term goals". The planning process generally begins with the development of a vision and broad goals that provide a strategic direction for investment and policy decisions in addition to determining support factors, which help them in making plans and achieving it.

The degree to which any management system meets the objectives and stakeholders' expectations is a measure of management effectiveness. Stakeholders are the people, groups, or organizations that could impact or be impacted by the project [14]. The ability to impact the pavement management objectives and processes depends on the stakeholder's type. A structured approach to the identification, prioritization, and engagement of all stakeholders should commence as soon as possible after the management team begins to form [14]. Stakeholder satisfaction should be identified and managed as a management objective. The key to effective stakeholder engagement is a focus on continuous communication with all stakeholders. G. Pendlebury (2013) [15] suggested several ways to identify the requirements of stakeholders namely workshops, focus groups, public opinion surveys, and collaborative working.

ISO 55001 (2014) [12] defined the asset management policy as "a short statement describes the principles on which the organization aims for applying asset management to achieve their objectives". There are three directions for investigation in highway system. These directions are system preservation, system operations, and capacity expansion (Cambridge Systematics 2007).

The goal is a broad statement that describes a desired condition. When establishing its pavement maintenance management objectives, the organization should consider the requirements of relevant stakeholders and of other financial, technical, legal, regulatory and organizational requirements in the asset manag

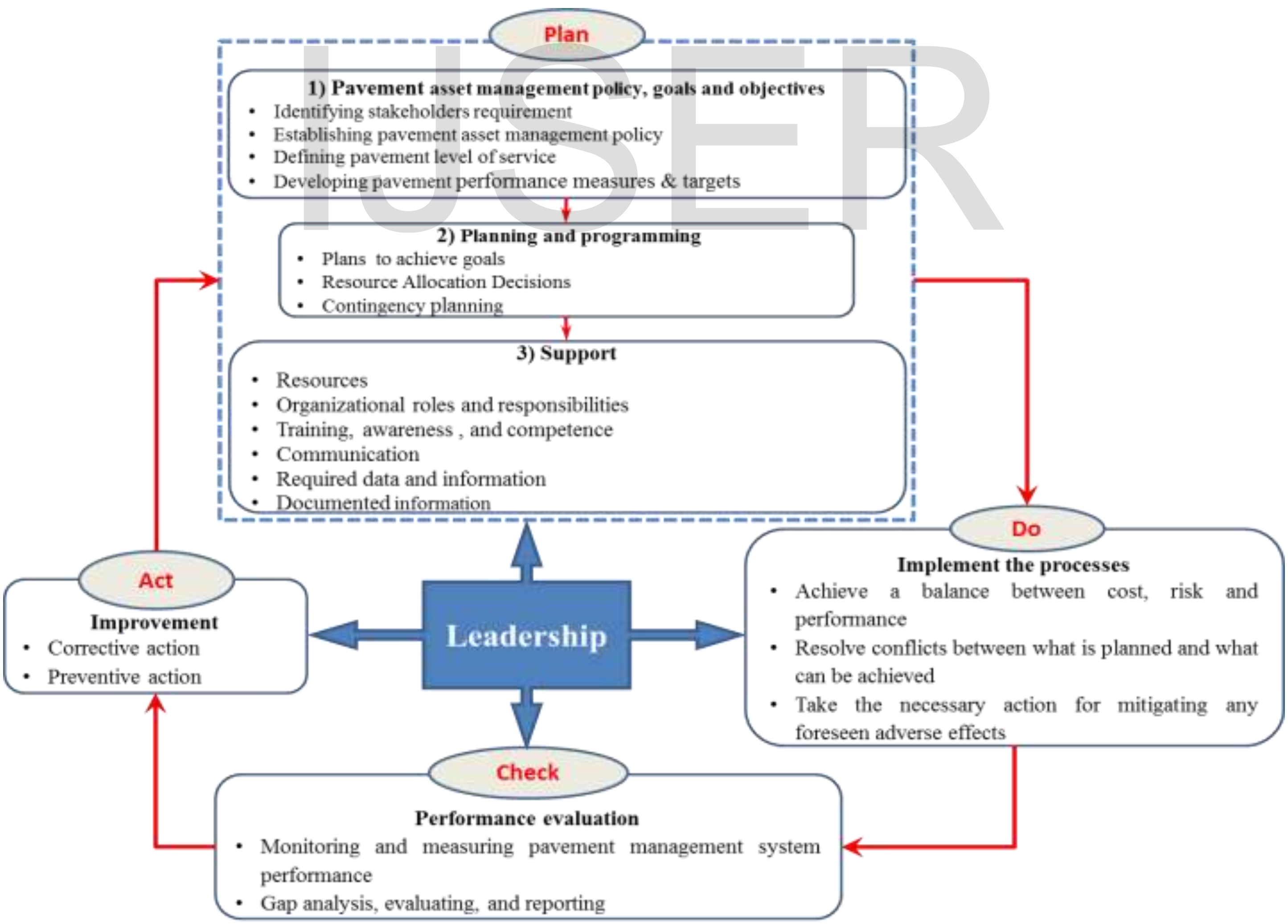

FIGURE **(1):** Compiled pavement maintenance management system ement planning process [12].

To link between policy, goals, and planning and programming decisions, performance measures should be developed [9]. Defining performance measures is a vital step for implementing an asset management approach. It is used to quantify policy, goals and objectives in a practical way [16]. Performance measures can be defined as "indicators of road-related physical condition, quality of maintenance and operation services provided or operational behavior of highway traffic" [17]. The highway organization should engage with the stakeholders the policy and goals that can be measured, assessed, and understood. For this purpose, some organizations use expression of level of service (LOS) [18]. M. J. Markow (2012) [17] defined LOS as translations of performance-measure information to a defined scale that indicates degree of acceptability or degree to which current performance meets expectations. T.M. Adams, and E. Wittwer et al (2014) [19] developed an objective method for setting and implementing LOS targets. LOS may include any of the following parameters: safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost, and availability [20].

3.3 Planning and Programming

An asset management plan serves as a strategic, tactical, and financial document ensuring that infrastructure is managed using sound asset management practices, optimizing available staffing, financial and other resources while meeting acceptable levels of service [21]. Asset management plans include the activities that will be implemented and the resources that will be applied to meet the asset management objectives and consequently the organizational objectives [12]. The pavement management plans include activities such as pavement asset inventory, pavement asset performance measure, gap analysis, scenario planning and analysis, and projects priorities.

The asset inventory is considered the first step in the creation of an asset management program [22]. Pavement inventory data can include road number, road type, functional class, length, divided/undivided road section, pavement type, number of lanes and widths, shoulder type and width, county, and legislative district [23]. It also can include as-built drawings and construction and maintenance records, location reference point survey, and drainage inventory survey [24].

There are three main factors to evaluate pavement condition namely surface distress condition, structural condition, and functional condition of the existing pavement [25; 26]. Surface distresses is deterioration caused by traffic, environment and aging. Surface distress measurements cover a range of distresses, from potholing and cracking to surface deformations such as rutting [26]. Structural condition evaluation provides information on whether the pavement structure is performing satisfactorily (with minimum deformation and distress) under traffic loading and environmental conditions [26; 27]. Functional evaluation provides information about surface characteristics that directly affect users' safety and comfort, or serviceability [26]. The main characteristics surveyed in a functional evaluation are skid resistance and surface texture in terms of safety, and roughness in terms of serviceability [26]. Table (2) illustrates, for example, the different types of pavement condition data in addition to methods for evaluating it, measuring techniques, and frequency of measure.

TABLE (2): Different types of pavement condition data, evaluating methods, and measuring techniques

Condition data	Evaluating methods	Measuring techniques	Frequency of measure
Distress condition	PCI	visual inspection	- Main roads (1-2 years) - Minor roads (2-5 years)
		surface distress video analysis	
	Rutting depth	manual	
		transverse profiler	
Structural condition	Destructive test (core test)	Marshall	Project level
	Non-destructive test	FWD	
		Deflection beam	
		Other equipment (GPR, DCP, Clegg hammer, etc.)	
Functional condition	Skid resistance (IFI)	Dynamic equipment (skiddometer)	(1-2 year)
		Static equipment (TRL, DF tester)	
	Surface texture: Micro texture	Lab test	
	Surface texture: Macro texture 1. MPD 2. SMTD	Dynamic equipment (WDM texture meter)	
		Static equipment (sand patch method)	
	Roughness (PSR, PSI, or IRI)	Mathematical simulation of car by using roughness measuring equipment	

Where: PCI is pavement condition index, FWD is falling-weight deflectometer, GPR is ground penetration radar, DCP is Dynamic cone penetrometer, IFI is International Friction Index, MPD is mean profile depth, SMTD is sensor measured texture depth, PSR is pavement searvicability rating, PSI is pavement searvicibility index, IRI is international roughoughness index.

Gap analysis is the process that follows pavement inventory and performance measure. Gap analysis used to identify areas of improvement and provide a basis for prioritizing the improvements so that resources are allocated effectively. The organization should develop investment priorities. Typically, there are two options for prioritizing spending on road maintenance:

- Worst first: this is reactive approach focusing maintenance on the stretches of road in the poorest condition. This approach is considered high cost. Because it meets short term public satisfaction but is not forward thinking and results in fewer roads being treated.
- Whole-life cost: focusing maintenance to minimize the total maintenance costs over the lifetime of the asset. This strategy prioritizes some funding for preventative works and recognizes that some assets will remain unrepaired [28; 29].

D. J. Vanier and Z. Lounis (2006) [30] identified a number of prioritization techniques that can be used to compare and rank repair and renewal projects. C. Yang (2013) [31] provided a framework for a decision making system to operate a highway network, to evaluate the impacts of maintenance activities, and to allocate limited budgets and resources in the highway network. This integrated model is composed of a network level traffic flow model, a pavement deterioration model, and an optimization framework.

At the end of planning and programming process, contingency planning should be prepared which consists of plans and procedures for identifying and responding to incidents and emergencies, and maintaining the continuity of critical asset management activities [32].

3.4 Support

Many supports are needed to operate pavement maintenance management processes efficiently and effectively. These supports include resources, roles and responsibilities, training, required data and information, and documented information [12]. Pavement maintenance management should not be used to allocate only money to program areas, projects, and activities but also for the deployment of other resources such as the materials, equipment, subcontractors (outsourcing), tool and staff that required completing the various activities [33]. The organization should care both internal and external resources.

According to IAM (2012) [34], the success of asset management depends mainly on people, and their knowledge, competence, motivation and teamwork. Pavement maintenance management requires change in culture within the organization not only a change in technical procedures [35]. This process requires training courses, education, development, guidance, and other support for each level in the organization. K.A. Zimmerman, and M. Stivers (2007) [36] and G. Pendlebury (2013) [15] recommended that to maintain competency regular training should be considered for staff.

Effective communication within and outside the organization is one of the basic and critical requirements for starting pavement management [9]. Communications describe the possible means by which the information can be sent or received, either through communication activities, such as meetings and presentations, or artifacts, such as emails, social media, project reports, or project documentation [14]. Effective communication builds a bridge between diverse stakeholders who may have different cultural and organizational backgrounds as well as different levels of expertise, perspectives, and interests. A communication management plan should be developed by asset owing organizations.

The data and information requirements to support the assets, asset management system and the achievement of organizational objectives should be defined [12]. This information may include information about construction, inventory, condition, performance, operational, financial, and environmental [37].

The first step in collecting data that should be taken into consideration is linking this data to a location [38]. A location referencing system (LRS) should be used for locating objects along a roadway and for referencing those objects to each other [38]. LRS assist in the integration and visualization of multiple sources of information and data for a specific location [38]. LRS constitutes a set of procedures for determining, storing, retaining, maintaining, and retrieving information about specific points in a transportation network. This system includes one or more location referencing method [39]. A location referencing method refers to a technique used for identifying the specific location of an asset in the field or in the office. There are many types of referencing methods like linear and spatial [39; 38]. Linear referencing methods include route-mile (km) point, route-reference post, link-node, and route-street reference. A spatial referencing method locates transportation features global positioning systems (GPS) to known locations coordinate systems use two or more spatial references [38].

The documented information that will be managed and maintained over the life cycle should be defined and determined [12]. G. Pendlebury (2013) [15] determined a way for making documented information. This way called data management strategy. Data management strategy comprises from seven steps: identify business need, identify data owner, accessibility and date stamping, data collection, frequency of collection and updating, data management, and disposing of data.

3.5 Implementing the Processes

The organizations should implement pavement maintenance management processes and activities contained within the pavement management plan. Implementation should involve an iterative process to achieve a balance between cost, risk and performance, to resolve conflicts between what is planned and what can be achieved, while taking into account the constraints faced by the organization. The consequences associated with both planned and unplanned changes should be reviewed to take the necessary action for mitigating any foreseen adverse effects [40].

3.6 Performance Evaluation

The performance of pavement, pavement management system and pavement management activity should be measured, evaluated on a regular basis for making gap analysis. The evaluation process includes systematic measurement, monitoring, and analysis [40]. In this stage, the organization should collect recent system performance information, which is used to analyze recent and future performance and to revisit and refine program objectives and priorities [41]. Gap analysis is the process that follows pavement inventory and performance measure. Gap analysis used to identify areas of improvement and provide a basis for prioritizing the improvements so that resources are allocated effectively. In most cases, the required fund may exceed available funding. Therefore, the organization needs to rank these projects according to their emergency, importance or cost-benefit [42].

One of the biggest challenges in this process is the difficulty of collecting data [13]. This task needs a lot of coordination. Therefore, the organization must develop a monitoring plan that includes what is being tracked, what data need to be collected, who will collect it, how it will be collected, where it will be stored, and how it will be reported back to the end user [13]. A Geographic Information System (GIS) repository can be used to overcome this challenge.

3.7 Corrective and Preventive Action

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Processes should be implemented to instigate corrective action for eliminating the causes of incidents or nonconformities identified from evaluations of compliance to avoid their recurrence [40]. Processes for introducing preventive action to address the root causes of potential failures or incidents, as a proactive measure, before such incidents occur should be implemented also [40].

4. STUDY METHODOLOGY

The study methodology composed of two stages as shown in figure (2). The first stage is office work that includes literature review, questionnaire design, data analysis and discussion, comparison between best practice and current practice, conclusion and recommendation. The second stage is fieldwork that includes data collection of the current practice of pavement maintenance management in Egypt.

4.1 Questionnaire Design

This section covers the design of the questionnaire required for the survey work. The questionnaire was divided into three parts. Part 1 contained questions related to participant's personal information (e.g., name, position, experience, and district name); Part 2 included questions related to the process of pavement data collection (measuring, monitoring, and maintaining pavement condition data.). It covered the types of data collected to manage the pavement, the frequency of collecting these data, the methods of data collection, the types of location referencing system, and the pavement data quality management. Part 3 included questions related to the main processes and elements of pavement management, it aims to know the practices related to pavement inventory, pavement management policy, pavement performance measures, resource allocation decision, gap analysis, and pavement management supports.

4.2 Data Collection

The study focuses on the highway pavement maintenance management practices applied in Egypt. The agency, which is responsible for managing the highway network in Egypt, is GARBLT. It is worth mentioning that GARBLT consists of fourteen districts in addition to the central administration located in Nasr City. Face to face interviews were conducted with the engineers working at the central a ministration and different GARBLT districts. The districts are East Delta, Central Delta, and West Delta, the central, north of Sinai, south of Sinai, El-Beheira, Bani-Sweif, and Assiut. The period of data collection was from June 2017 until March 2018.

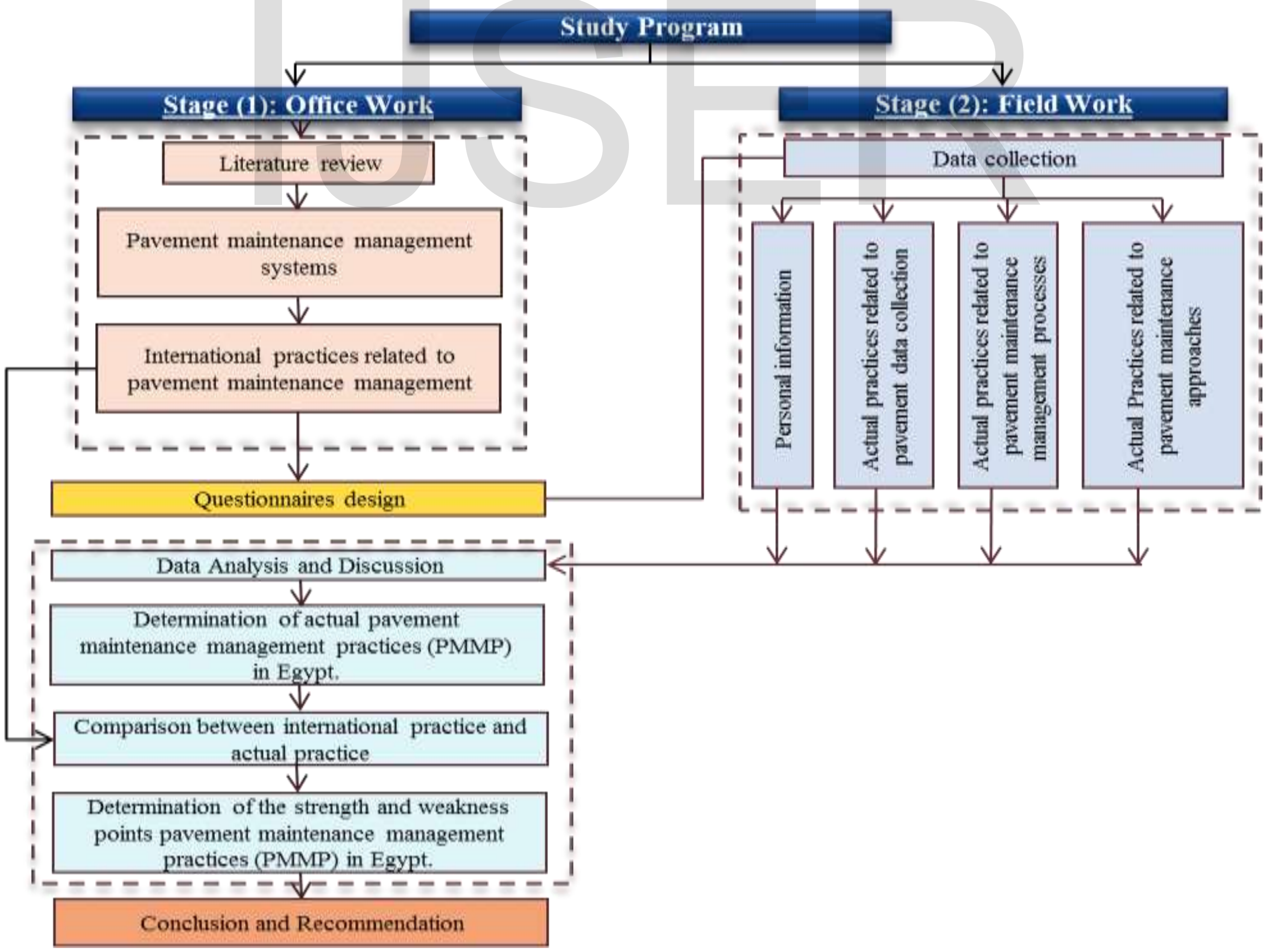

Figure (2): Study methodology flow chart

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5. DATA ANALYSIS AND DISCUSSION

This section presents the analysis of the data collected. The purposes of the analysis are to: 1) identify the actual PMMP that are applied in Egypt, 2) compare it with the international practices determined from literature review. At the end of the analysis, the points of strength and weakness in the pavement maintnance management in Egypt were determined.

5.1 Participants Experience

The experience years of GARBLT participants ranged from 1 to more than 30 years; they were divided into five categories. The participants' positions are engineers, maintenance engineers, maintenance managers, and heads of central administration. Table (3) shows the number of participants in each part of the questionnaire.

Table (3): Number of participants according to experience years

Range of experience years	Number of participants	
	Pavement data collection	Pavement Maintenance management processes
1-5 years	2	3
6-10 years	4	3
11-20 years	2	3
21-30 years	2	2
>30 years	9	9
Total	19	20

5.2 Analysis of Pavement Data Collection Practices

Pavement data collection is considered one of the most important components in pavement maintenance management system. The type of pavement data collection may differ according to their purpose and methods. This part concentrated on the analysis of collected pavement data related to measuring, monitoring, and maintaining pavement conditions. The participants were asked about when they began collecting data for pavement maintenance activities. Most of the participants showed that they began data collection for more than twenty years. Two of the respondents explained that the data collection bagan ten years ago. The reason for this difference may be due to the number of experience years of respondents.

5.2.1 Types of pavement data collection

Inventory, condition, traffic, incident, pavement construction, maintenance, and rehabilitation history are examples of the data that should be collected to effectively manage the pavement maintenance. The pavement condition data is critical to produce informed decisions [39]. Types of pavement condition data that should be collected include surface distress, smoothness/roughness, frictional properties, and structural capacity data. Figures (3 and 4) show the types of pavement condition data collected to manage the maintenance of pavement at network and project level in Egypt.

Figure (3) indicates that GARBLT collects surface distress data at network level. For the smoothness/roughness data, the majority of respondents (89.5%) showed that GARBLT didn't collect this data type, one person only said that they collect it. It is worth mention that GARBLT has only one device for measuring the smoothness/roughnesss of pavement surface called ROMDAS. It means that GARBLT does not have enough resources to collect this type of data at network level.

At the project level, the majority of respondents (89.5%) emphasized that GARBLT collects data on the surface distress and structural capacity to management the maintenance of the pavement (Figure (4)). 10.5% of participants didn't response this question. Most of participants said that GARBLT dependes mainly on the surface distresses data at both network and project level but they collect structural capacity data only at project level if cracks appear on the roadway.

The surface distresses cover many types of defect range from potholing and cracking to surface deformations such as rutting. The participants were asked about which distress types are collected, they showed that GARBLT collects nineteen distress types. These defects are alligator cracks, block cracks, longitudinal and transverse cracks, patching, potholes, shoving, rutting, bleeding or flushing, raveling and weathering, polished aggregate, bumps and sags, corrugation, edge cracks, railway crossing, lane shoulder drop, slippage cracks, swell, landing, and transverse/thermal cracks.

A follow-up question about the type of index that can be used to judge the pavement condition was asked. The participants declared that GARBLT uses an index that is called Pavement Condition Index (PCI). PCI is calculated only on the basis of the different distress types that are collected by visual inspections. Each distress is classified according to its type, severity, and quantity. GARBLT manual assists the engineers to perform this classification. For each distress type, and based on its severity, a

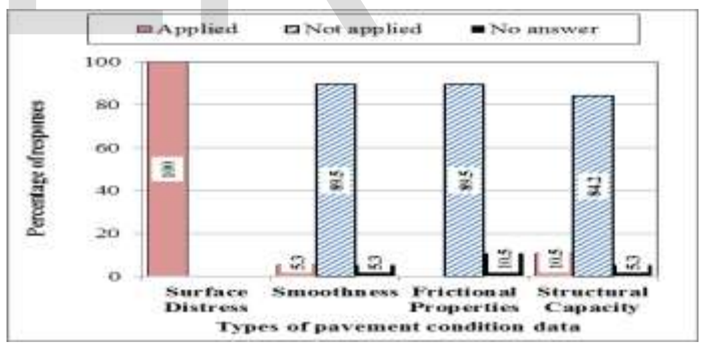

Figure (3): Types of pavement condition data collected at network level

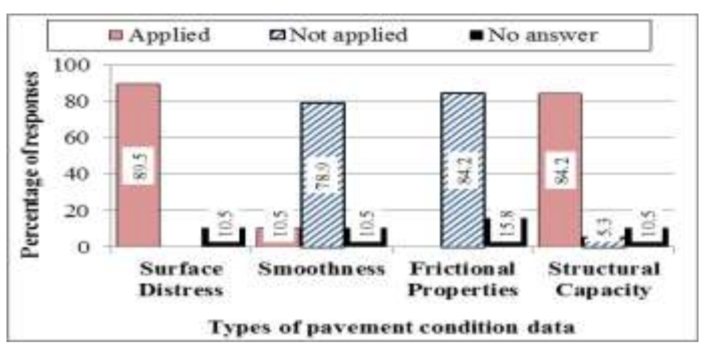

Figure (4): Types of pavement condition data collected at project level

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deduct value is calculated from the appropriate deduct curve. The individual deduct values are totaled, adjusted to account for the interaction of multiple distresses, and subtracted from the "perfect" PCI of 100 to give the actual PCI. The deduct value can be computed by a computer program used by GARBLT called HPMA (Highway Pavement Management Application).

5.2.2 Frequency of pavement condition data collection

The condition of pavement differs from year to year because pavement is constantly exposingd to deterioration. Therefor any highway agency must measure the pavement condition in a repetitive manner. The participants were asked about the frequency of pavement condition data collection. The majority of participants 92% showed that the data was collected once a year. Regartding the frequency of collecting structural capacity, the participants indicated that the structural capacity is measured only for the sections of the roadway that will be maintained and that are included in the annual project plan. These answers confirm that the structural capacity data is collected only at project level.

5.2.3 Methods of pavement data collection

Many methods can be used to collect pavement condition data. These methods can be traditional methods, e.g. windshield survey, and walking survey, and advanced methods, e.g. automated and semi-automated data collection from pavement evaluation vehicles [39; 43]. Windshield survey is evaluating the pavement surface from the moving vehicle. In walking survey, the inspector must walk on road section to record the defects [43]. An automated distress survey is a method, where the images of distress and sensor data collected in the field are entered directly to the computer to interpret, reduce, and analyze them [43; 44]. Semi- automated likes the automated survey but the processing of the data is done manually by people who interpret the images to identify distress information [39; 44].
The participants were asked about the methods used to collect distress data at both network and project level. Their answers showed that GARBLT dependes mainly on the windshield survey followed by walking survey. Walking survey method is rarely used in the cases when the road section has many defects.

5.2.4 The location referencing

The pavement condition data needs to be linked with a good location reference. Poor location data causes difficulty in overlapping different pavement indicators (e.g., roughness and cracking), linking condition with traffic, developing time-series for performance prediction, etc. [39]. By asking the engineers of GARBLT about the type of location referencing used, they indicated that GARBLT depends on the linear referencing method for supporting the process of pavement condition data collection. The linear referencing method is presented in geographical information system (GIS) within HPMA. The problems that face GARBLT engineers in defining the location referencing are:

- GIS needs to be updated because it contains outdated information
- The measurement locations may be wrongly determined. This may be due to lack of spatial resolution.
- The using of linear system may hinder GARBLT to create centralized database.

5.2.5 Pavement data quality management

Adequate quality and quantity of pavement condition data are a very important resource to achieve effective pavement maintenance management. Adopting a comprehensive data quality management approach, which includes methods, techniques, tools, and model problem solutions is the most efficient way for achieving high-quality services. The activities that may be applied in the quality management process of distress data collection include: distress definition; training; systematic data collection process management; systematic data handing and processing; timely, effective quality control system, effective quality acceptance check system, identification and implementation of corrective actions, report development, and delivery of results to the owner agency [39].
Developing a quality management plan for collecting pavement condition data will aid in achieving accurate, reliable, and complete condition data and will address steps to take when facing data quality issues. Without a documented plan, agencies are less likely to apply quality management activities consistently from year to year and assess the effectiveness of the techniques used [38].
Figures (5, 6) show that the majority of respondents declared that they apply a formal quality management plan to collect data but there is no formal quality data acceptance plan. The reason for that may be because GARBLT's manual that is considered a key part of data quality management does not demonstrate the activities to be followed to judge the quality of data collected.
The districts engineers stated that after conducting the visual inspection and recording the defects on the pre-prepared format, the results are sent to the Central administration, where currently provided data are compared with the existing time-

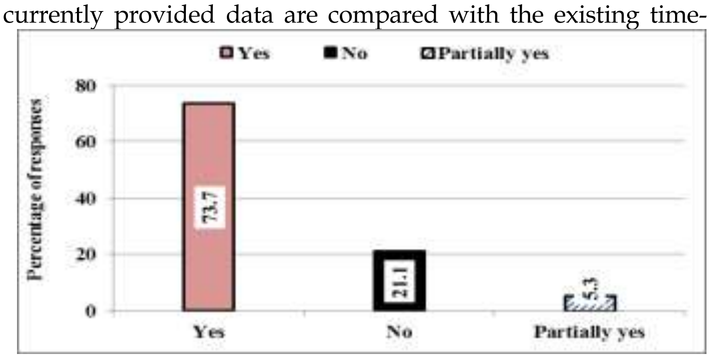

Figure (5): Use of formal pavement data collection quality management plan

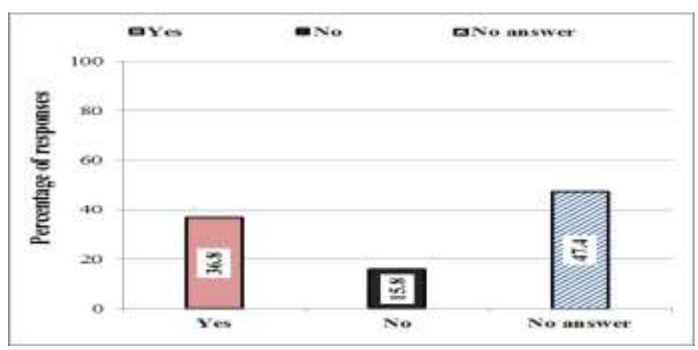

Figure (6): Use of formal quality data acceptance plan

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series data to check the accuracy of the currently provided data. Moreover, the respondents emphasized that the accuracy of collected pavement data depends mainly on the experience of data collectors and the tools used to collect the data. The manual methods used to collect pavement condition data leads to low quality of data, long collect time, and large number of data collectors. If automated devices for data collection are used, the data will be more accurate and less time and effort will be consumed.

5.2.6 Types of pavement maintenance

The types of pavement maintenance includes: preventive, corrected immediately and corrective according to available resources. Figure (7) shows that in Egypt based on the respondents' replies, the corrected immediately and the corrective maintenance based on available resources are the most applied maintenance types. GARBLT implements the corrected maintenance immediately as a routine maintenance in two cases: 1) the appearance of any pothole or crack; 2) during cleaning work and repairing the shoulders. On the other hand, the corrective maintenance needs to be planned firstly. Regarding preventive maintenance, the expert engineers indicated that GARBLT established a company for making preventive maintenance since 2017. The preventive maintenance is considered in experimental phase.

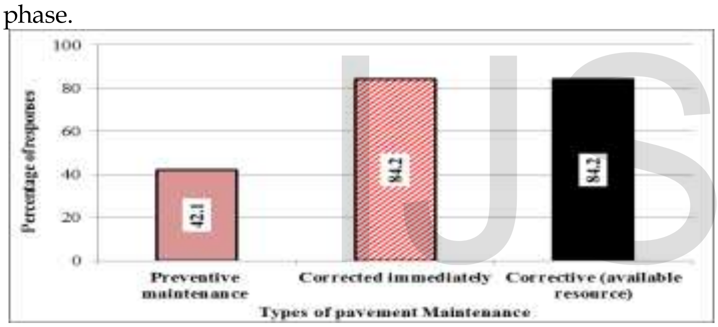

Figure (7): Types of pavement maintenance

6. COMPARATIVE STUDY

A comparison was made between the results that are conducted from the responses of the questionnaire participants from GARBLT in Egypt and the international best practices presented in USA and England. The purpose of this comparison is to pinpoint the opportunities and weaknesses in the applied PMMP in Egypt as shown in table (4).

The National Cooperative Highway Research Program in USA made study survey about the quality management practices of pavement condition data collection. The survey covered fifty five agencies; the data analysis indicated that the surface distress data, smoothness/roughness, friction properties, and structural capacity are very important to manage the pavement at project and network levels [39]. GARBLT, USA and England are collecting the surface distress data for all networks.

The international roughness index (IRI) became the standard international scale for roughness measurement [37]. The following points indicate the important of collecting smoothness/roughness data for GARBLT in Egypt:

- Smoothness/roughness data is the best indicator that reflects the user's perception of the overall condition of a pavement section.
- Smoothness/roughness has impact on ride quality, operation cost (e.g., fuel consumption, tire wear, and vehicle durability), and vehicle dynamics.
- IRI is considered one of the most important pavement performance indicators in both network and project levels [46].
- Egyptian code for highway maintenance advised with necessary of making functional evaluation (international roughness index and friction properties) for pavement network beside the surface distress method to determine the priorities of maintenance [8].

Regarding Smoothness/roughness collected data for both network and project levels in GARBLT are comparecd with USA.

For pavement condition data at project level, G. Flintsch, and K. K. McGhee (2009) found that 71.4% of the agencies collect structural capacity data, 66.1% of them collect smoothness/roughness data, 58.9% of them collect surface distress data, and 55.4% of them collect surface friction data for project level [39]. This means that structural capacity very important at project level compaired with network level. Structural capacity helps in determining the type of treatment for the segments. The second important data is smoothness/roughness is followed by surface distress and friction data. The agencies that have started to collect structural capacity data at the network level with a lower sampling rate compared with sampling rate at project level is due to cost-effective for providing useful information [39]. Table 4 shows there isn't significant differences between GARBLT, USA, and England in surface distress and structural capacity data while GARBLT neglected the friction properties data in both metwork and project levels.

For the frequency of pavement condition data collection, most agencies in USA and GARBLT collect the surface distress data once a year, while England ranges between six months and two years according to number of road lanes.This frequency is considered good practice because the regular inspection is required in asset management. For the smoothness/roughness and friction properties data they haven't frequencies in GARBLT but in USA there are only nineteen agencies collect it and most of them collect it every 2-3 years. However, in England the friction properties data are surveyed of one third of the network each year, over a three year the network is surveyed. GARBLT collected the structural capacity data for the project level only, but in USA and England most agiencies collect it annulally for both project and network levels.

Windshield survey, walking survey, semi- automated, and automated are four common methods used to collect the surface distress data [39]. The survey illustrated that the 35 of 76 transportation agencies in USA use automated or semi-automated method to collect data, 27 agency use windshield method and 14 agency use waking method. While in England, the results indicate the widespread trend toward automated and semi-automated surveys [48]. Howerver, GARBLT still uses windshield survey as a main method in addition to walking survey in rarely cases. The major problems of the windshield survey method applied in GARBLT are:

- Labor-intensive, slow, and subject to errors [44].
- Lack of consistency due to the possibility of different classifi-

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cation of distress and its quantity from one engineer to another
- The only way to check apparent anomalies in the data after the data has been summarized and corrected is to return to the field.
- Lack of safety for field crews.
- Trade-off between vehicle speed and data accuracy [49].

Table (4): Comparison between pavement data collection practices in GARBLT, USA, and England

Element	**Egypt** GARBLT	**USA** (G. Flintsch, and K. K. McGhee, 2009) [39]	**England** (NCGSB, 2019; CEPA, 2018) [47; 48]
Pavement condition data using at network level: • Surface Distress • Smoothness/Roughness • Frictional Properties • Structural Capacity	• 100% • 5.3% • 0% • 10.5%	• 98.2% (54 agency) • 94.6% (53 agency) • 33.9% (19 agency) • 16.1% (9 agency)	• 100% (Cracking, rutting depth) • 100% (longitudinal profile variance) • 100% (the average Sensor Measured Texture Depth SMTD) • 100% (measure pavement layer types and thickness by GPR [47], measure the structural capacity by TSD [48])
Pavement condition data using at project level: • Surface Distress • Smoothness/ Roughness • Frictional Properties • Structural Capacity	• 89.5% • 10.5% • 0% • 84.2%	• 58.9% (32 agency) • 66.1% (36 agency) • 55.4% (30 agency) • 71.4% (39 agency)	• 100% (Cracking, rutting depth) • 100% (longitudinal profile variance) • 100% (the average Sensor Measured Texture Depth SMTD) • 100% (measure pavement layer types and thickness by GPR [47], measure the structural capacity by TSD [48])
Frequency of data collection: • Surface Distress • Smoothness/ Roughness • Frictional Properties • Structural Capacity	• 89.5% Once a year • 0% • 0% • Project level only	• 58.2% (32 agency) once a year, 30.9% (17 agency) 2-3 years • 60% (33 agency) once a year,29.1 (16 agency) 2-3 years • 3.6% (2 agency) once a year,20% (11 agency) 2-3 years, 3.6% (2 agency) >4 years • 5.5% (3 agency) 2-3 years, 1.8% (1 agency) >4 years, 9.1% (5 agency) varies based on previous condition	• Every six months on one lane, annually on two lanes, annually on three lanes of four lanes roads and the slip roads are covered over a two year period by TRACS • The same as Surface Distress frequency (TRACS) • skidding resistance data carry out surveys of one third of the network each year, over a three year the network is surveyed (SCRIM) • Annually (GRP installed on TSD) [48]
Data collection methods (Network): • Windshield survey • Walking survey • Automated • Semi- Automated	• 78.9% • 89.5% • 0% • 0%	• 49% (27 agency) • 25.5% (14 agency) • 20% (11 agency) • 43.6% (24 agency)	• 0% • 0% • 100% • 100%
Data collection methods (Project): • Windshield survey • Walking survey • Automated • Semi- Automated	• 47.4% • 84.2% • 0% • 0%	• 49% (27 agency) • 25.5% (14 agency) • 20% (11 agency) • 43.6% (24 agency)	• 0% • 100% • 100% • 100%
Location referencing system: • Geographic Positioning System (GPS) • Mile points and milepost • Link-node	• 5.3% • 47.4% • 73.7%	• 46.4% (25 agency) • 85.7% (47 agency) • 26.8% (15 agency)	• 100% (GPS combined with distance measurement equipment)
Formal pavement data collection quality plan	• 73.7% Yes • 21.1% No • 5.3% Not sure	• 35% Yes • 27% Under developed • 27% No • 11% Not sure	• 100% (All surveys are subject to a detailed quality assurance regime)

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Table (4): Comparison between pavement data collection practices in GARBLT, USA, and England (Continued)

Element	Egypt GARBLT	USA (G. Flintsch, and K. K. McGhee, 2009) [39]	England (NCGSB, 2019; CEPA, 2018) [47; 48]
Types of training and certification for data collector:			
• On-the-job training	• 73.7%	• 54.5% (30 agency)	
• In-house training programs	• 94.7%	• 30.9% (17 agency)	
• Local colleges and universities	• 5.3%	• 1.8 % (1 agency)	
• Professional training programs	• 0%	• 3.6% (2 agency)	• 100%
• Formal certification for data collector:	• 25%	• 15% (8 agency)	• 100%
Level of education:			
• Less than high school	• 0%	• 0%	
• High school	• 0%	• 25.5% (14 agency)	
• Associates degree	• 0%	• 29.1% (16 agency)	
• Bachelor's degree	• 100%	• 9.1% (5 agency)	
• Master's degree/ PhD	• 0%	• 1.8% (1 agency)	
Years of experience:			
• 0-6 years	• Varied according to available engineers in each districts	• 20% (11 agency)	
• 6-10 years		• 27.3% (15 agency)	
• >10 years		• 16.4% (9 agencies)	

TRACS = Traffic Speed Condition Survey, SCRIM = Sideway-force Coefficient Routine Investigation Machine, TSD = Traffic Speed Deflectometer, GPR = Ground Penetration Radar.

It is recommended to employ automated methods in GARBLT for recording, storage, reduction, and processing of pavement data to minimize the errors and standardize the survey process. The advantage of automated methods is reducing errors resulted from transferring data from field paper forms to computer systems for analysis. Other advantages are faster, safety for survey crews, and more objective surveys [44]. The associated studies illustrated that automated pavement condition surveys have the capability of accurately and efficiently collecting pavement condition data.

The location referencing systems are: Geographic Positioning System (GPS), Mile points and milepost, and Link-node. The link node and milepost are characterized by easy section identification and are familiar to most users and operators. The disadvantages are that markers may move (e.g., as a result of realignments), and potentially changing the size and location of individual pavement segments. These changes may cause inconsistencies from year to year [39]. This disadvantages lead to confusion with historical condition data, the track of condition become hard, and difficulty of data integration. Other problem related to this method is that the locations of the signs do not always go along with the actual location of the mile referenced when measuring using a DMI [50]. DOT in USA found that milepost linear reference does not meet the requirements of accuracy or data integration because of the above mentioned problems in addition to missing or non-existent of posts [51]. The use of spatial location referencing based on GPS is becoming more prevalent as the technology becomes more affordable and accurate [39]. The location in GPS is known in terms of coordinates, so the relocation of milepost or road realignment will not affect the true location of the distressed area. The usage of GPS facilitates the coordination process, and data integration [39; 50].

The GPS location referencing system is applied in England, as well as in USA and Egypt. G. Flintsch, and K. K. McGhee (2009) [39] illustrated that most of agencies in USA use milepost or link node in addition to GPS. In Egypt, this study found that GARBLT use mainly link node and milepost in data collection stage and the GIS (Geographic Information System) wasn't updated for many years, it's recommended to uses GPS in addition to LRS (Linear Referencing System) to overcome all the problems.

Most agencies in USA have a formal quality management plan or under development. But in Egypt, GARBLT has manual handbook for distress identification and trains their engineers on visual inspection in addition to comparing the data collected with the time-series data. All the mentioned activities are considered good quality practices.

Regarding the training on visual inspection, In USA, G. Flintsch, and K. K. McGhee (2009) advised the agencies by continual training in addition to rates the pavement distress raters every time and gives them a certification[39]. However in England, the assessment of visual condition was limited to unclassified roads since 2007. In April 2007, The UK Roads Board recommends that anyone who undertakes a new Visual Survey Inspector accreditation scheme should be accredited to the current nationally accepted standard [47]. But in Egypt, GARBLT needs to improve the training courses and examines data collection personnel and certified them. GARBLT depends only on time-series data to verify the collected data. This practice isn't enough because the time-series data may be wrong also. One of the methods that can be used for data verification is control sites to address the issue of inconsistency; 2-10% of the entire networks are carefully selected to ensure that they represent the population or entire network fully [44].

The bachelor's degree in the engineering is the required level of education for pavement data collection personnel with experience from 0 to 10 years in in Egypt. While in USA, the level of education for pavement data collection personnel are high school or associates degree. The pavement condition data collec-

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tion is principally composed of experienced technicians (69% have more than 6 years and 26% more than 10 years of experience). They hold associate degrees (44%) or high-school diplomas (39%), with only a small percentage having bachelor's and graduate degrees [39]. Thus, it is good practice that GARBLT depends on more qualified person for making the visual inspection.

7. PAVEMENT MAINTENANCE MANAGEMENT PRACTICES

This section illustrate the PMMP processes which includes pavement inventory, pavement management policy, pavement performance measures, resource allocation decision, gap analysis, and pavement management supports in term of asset management team, training, and communication. In addition to, highlight the important role of applying and developing highway PMMP in Egypt.

7.1 Pavement inventory

There are two types of pavement inventory systems in GARBLT, manual and electronic documention using HPMA. This is a good practice because the inventory data is the first step in developing any asset management system.

7.2 Pavement management policy

GARBLT have a written policy to manage pavement, but it need to publish it as shown in figure (8). GARBLT's written policy can be summarized in three points namely:

- Construct the national highway network is the main policy with enhancing pavement network safety.
- Maintain the efficiency and condition of the pavement network according to the available resources.
- Monitor the pavement condition periodically toward a safe, economical, and comfortable road.

The participants indicated that GARBLT depends mainly on the visual inspection for determining the condition of road sections. This task is conducted in parallel with the enumeration of the traffic volume on the roads through the counters to identify the roads that need expansions or maintenance. GARBLT has two plans, one for maintenance and the other for investment. The investment plan includes road expansions and construction of new roads according to the financial appropriations. The available fund which comes from GARBLT resources and Ministry of Finance is divided to 85% and 15% for highway maintenance and the traffic safety insurance works, while the investment project fund is coming from the Ministry of Investment.

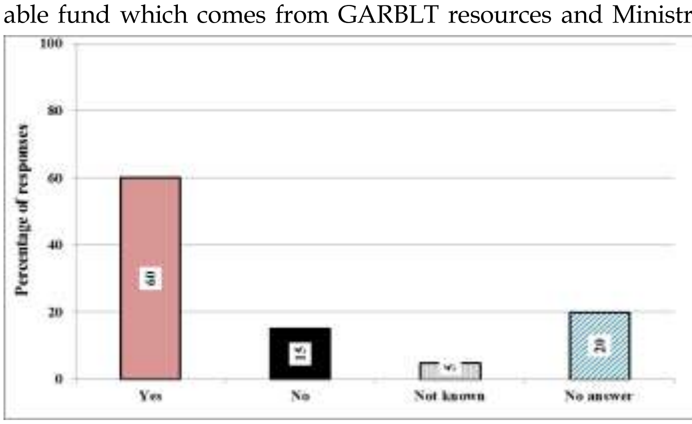

Figure (8): Knowledge of written pavement management policy

7.3 Pavement performance measures

Performance measures are used to monitor progress towards policy, goals and objectives. Performance targets are specific performance measure values intended to be achieved [16]. 75% of GARBLT participants indicated that there is a target performance for pavement network as indicated in figure (9) and the PCI value for the roads network is targeted to be bigger than or equal to 70%. The target value can be uniform or various according to the region, importance of road, and the traffic volume as shown in figure (10).

GARBLT uses only PCI as clear performance measure and doesn't use any other clear measures. C. Systematics and T. T. Institute et al. (2006) [54] advised transportation agencies to create measures regarding "preservation, accessibility, mobility, operations and maintenance, safety, environmental impacts, economic development, social impacts, security, delivery".

Policy, goals and objectives should be developed in conjunction with both internal and external stakeholders [13]. GARBLT take the opinion of road users and industry firms in the performance of pavement network. Most participants indicated that the users' opinion may be known through tracking the written complaints, electronic complaints, or trouble calls. But GARBLT didn't have proactive approach to know the users opinion.

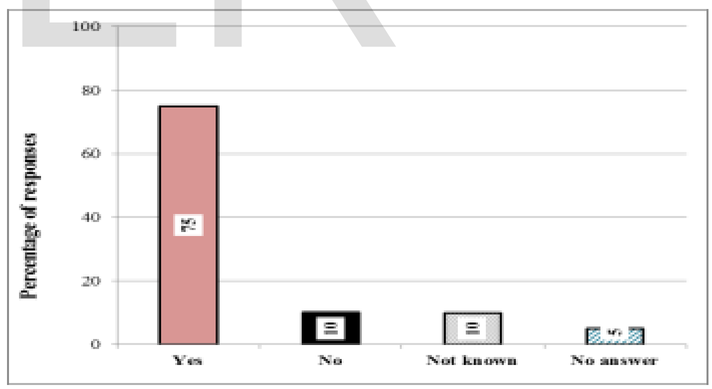

Figure (9): Pavement target performance

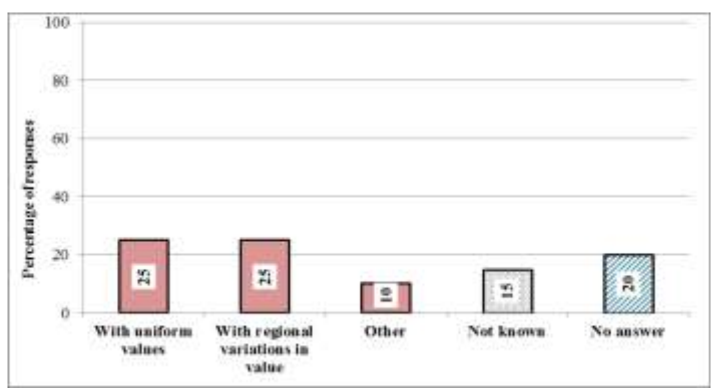

Figure (10): Values of performance measures

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7.4 Pavement management supports

Many supports are needed to operate pavement maintenance management processes efficiently and effectively. These supports can include resources, asset management team roles and responsibilities, training, required data and information, and documented information [12]. Michigan DOT, one of the agencies that represent best practice in applying asset management principles in USA, they found that the key factors which help any asset management program to success are some type of legal mandate, and assembling of a team to promote asset management [53]. To realize the importance of having an asset management team, N. Hawkins, and O. Smadi (2013) made a deep analysis on 43 transportation agencies and found that the agencies which have asset management teams are ahead incorporating asset management principles and practices to resource allocation, project selection, decision support tools, and performance reporting by 12% [55]. In Egypt, GARBLT doesn't have a compotable asset management unit, the asset manage-ment team distributed across the agency depatrtements and its districts where AM activities are connected across multiple divisions.

Training is important support used to improve staff understanding of pavement maintenamce management practicies. In GARBLT, the training can be summarized in the following types:

- Identification of flexible pavement distresses (visual inspection of pavement) (annually).
- Pavement management systems (rarly).
- Introduction to GIS (rarly).
- Methods of geometric and structural design for roads.
- Methods of road maintenance.
- Surveying works

GARBLT use visual inspection for pavement data collection. Therefore, the quality of data depends mainly on the inspectors. The participants indicated that the in-house annual training programs are the main training type in GARBLT followed by the site training but there isn't professional training. The central administration sent a request to their districts to identify the engineers who want to attend the visual inspection course.

The communication of information about PMMP between the organization and its governing bodies, stakeholders, and customers is critical to success [9]. In Egypt, the information is reported through performance accomplish reports within GARBLT and its districts only. In rarely cases, the reports are presented to transportation commission in Parliament. Also, periodic meeting between GARBLT chairman and Heads of districts is conducted each period. It is notable that GARBLT is limited in communicating information within central administration and its districts. It is preferable to communicate the information that justifies investing in the road system to internal and external stakeholders. This process provides different stakeholders with the impetus to feel comfortable that the existing road network has been handled well [53].

7.5 Gap analysis and decision making

The objective of establishing performance measures and targets is to identify the pavement sections that need maintenance. In this context, the engineers were asked if GARBLT makes comparison between target performance and actual performance. The responses indicated that GARBLT make comparison between target PCI and actual PCI by the central administration office. Also they determine the road sections with safety problem and the traffic volume on the roads to make gap analysis and make the most suitable decision. The results of gap analysis should be reported to the different stakeholders by suitable shape and details for each interested group.

Decision making aims to make effective technical and financial decision to get the target objective. After making gap analysis and determining the gaps in the pavement performance, the organization must take a decision to reduce the defined gap. The decision must be made in the light of the specific policies of the organization and in accordance with the decision-making key pavement performance data. The key pavement performance data that drive decision making across GARBLT are safety, physical condition, risk assessment, others (the road importance and the political decision) etc. as shown in Figure (11).

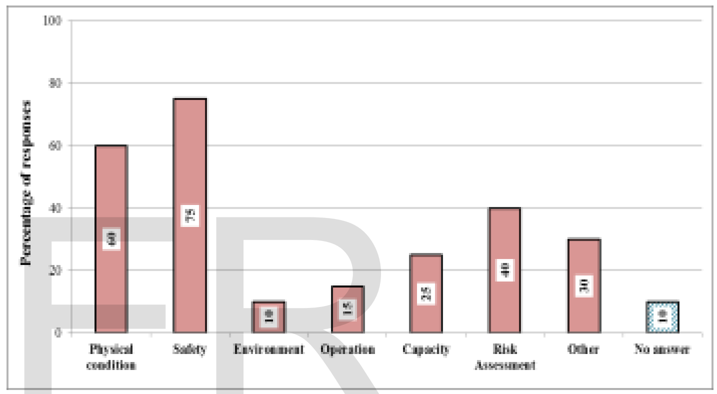

Figure (11): Decision making key pavement performance data

8. CONCLUSION AND RECOMMENDATION

The Construction and maintenance of the national highway network are the top priorties for the government in Egypt. The results of a compartive study to evaluate the actual applied highway Pavement Maintenance Managment Practices (PMMP) in Egypt with USA and England shows:

1. GARBLT has a good practices in pavement inventory, but it need to be updated.
2. GARBLT collects pavement distress data at the network and project levels. This practice is good but it should collect functional evaluation data beside the surface distress data for making effective network level decision.
3. GARBLT collects the surface distress data annually; this practice is identical to the Egyptian code.
4. GARBLT collectes the surface distress data by visual inspection. This method has many problems. So, the study recommends to employ semi automated and automated methods in recording, storage, and processing of pavement data to minimize the errors and standardize the survey process.
5. GARBLT depends on linear referencing methods specially link node in collecting pavement condition. This method is simple but potentially changing the size and location of individual pavement segments due to realignement of the

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network. These changes may cause inconsistencies from year to year and them the track of condition become hard, and difficulty of data integration.

6. GARBLT has a formal quality plan of pavement data collection. It is worth mention that GARBLT has manual about visual inspection of pavement and make visual inspection training each year.
7. GARBLT depends mainly on two types of pavement maintenance namly: corrected immediately and corrective maintenance according to available resources. This study recommends with rapidely applying preventive maintenance. Preventive maintenance proved its effectiveness in many countries; it helps in prolonging the pavement life.
8. GARBLT doesn't have formal asset management departement. It is recommended to establish formal department for asset management.
9. The pavement management policy isn't clear for all stakeholders. The policy needs to be clearer for transparency in making decision.
10. GARBLT depends mainly on physical condition of pavement, safety, and political for making maintenance decision but the target measures not clear. They need to create clear performance measures regarded to accessibility, mobility, operations and maintenance, safety, and so on.
11. Pavement management information needs to be shared with internal and external stakeholder, which is critical for communicating investment needs and adding transparency to the decision-making process and trade-offs.

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