Assessing the Pavement Quality of National Roads in Sudan

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Abstract: Roads play a vital role in the sustainable economic development for many countries in the world. The quality of road pavement is considered to be one of the most important indicator of economic competitiveness. Therefore, it is very important for Sudan government and road authorities to maintain road networks with appropriate levels of quality and safety standards. The research conducted a field survey in four major national roads to collect data on surface distresses, determine the level of road quality, and identify the most important factors leading to road deterioration. The results obtained showed that 49.5% of the roads are in good condition, 24.4% are in fair condition, and 16.1% are in poor condition and the major distresses observed on roads' surfaces are cracking and potholes failures. It was found that the main reasons for road deterioration are traffic overloading and climatic changes. Finally, recommendations are provided to help the government and road authorities in Sudan to improve the quality of road network.

Keywords: *Consistency Factor, Nomographs, Swelling Potential, Swelling Pressure.*

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1. INTRODUCTION

The transport sector is considered as the artery of economic activity, because it links production areas with consumption areas and export which has great impacts on human life. Roads play an important role in the development and prosperity of the transport sector. They are used by various means of transport, such as trucks, buses, and other vehicles used to transport goods and passengers inside and outside the country through the border ports of neighboring countries. In Sudan, the national roads suffer from excessive truck loads, especially trailers, and poor maintenance, which negatively affect the performance of these vital roads and cause damage and defects that result in shortening the road's life and increasing the costs of its maintenance and rehabilitation.

The rapid deterioration of the national roads due to the heavy traffic loads and the defects on the road surface such as cracks, localized potholes, rutting and other defects, which impede traffic and cause many problems for road users, vehicle drivers and passengers. This negatively affects the road quality standards in Sudan.

This field study aims to evaluate the pavement quality of national roads, identify the causes of road deterioration after a short period of construction or rehabilitation, in order to improve the performance of these vital roads and focus on the importance of design and construction standards to raise the quality of roads in Sudan.

2. LITREATURE REVIEW

2.1 Sudan national roads

The wide area of Sudan is covered by the national road network that connects the states of Sudan. The technical report issued by the National Roads and Bridges Authority [1] showed that the total length of the network is about 30,000 km, of which only 20% are paved. The network is divided into two groups as shown in Figure 1.

a) East - west roads are perpendicular to Nile River with a main road that starts from the east of Kassala in eastern Sudan, the Eritrean border, passes through Khartoum and ends at the western border between Sudan and Chad.

b) North - south roads are parallel to Nile River with a main road that starts from the city of Wadi Halfa in northern Sudan, the Egyptian border, passes through Khartoum and ends at the Jabalin area in southern Sudan, the border with South Sudan.

The most important national roads in Sudan as shown in Figure 1 are:
1) Tahadi Road that connects Khartoum - Atbara - Port Sudan
2) Khartoum - Medani - Gedaref - Kassala - Port Sudan Road
3) Sheryan Alshamal Road connects Omdurman – Dongola.
4) The western ingaz road connects Khartoum - Rabak - Kosti - Al Rahad - Al Abyad - Al Nahud - Al Fasher – Nyala
5) Rabak Road - Kosti - Al Jabalin
6) Karima - Al Salim - Halfa Road
7) Dongola - Arqin Road

2.2 Road challenges and problems

Roads in many countries of the world, especially Sudan, face several difficulties and challenges, such as rapid deterioration, frequent defects, traffic congestion, especially in large cities and capitals, and traffic accidents that lead to injuries, body harm and death.

Road deterioration

Road deterioration is the process by which defects and distresses on the pavement surface develop which is caused by traffic loads and environmental conditions. Road deterioration greatly affects the level of service and safety on the road. After the construction phase and the road opens to traffic, the road deteriorates with age as a result of use, and therefore it must be maintained to ensure safety,

efficiency and durability requirements are met. Newly constructed roads usually deteriorate slowly in the first ten to fifteen years of their life, and then deteriorate much more rapidly unless maintenance is carried out in a timely manner [2].

In Sudan, technical reports have stated that recently constructed roads rapidly deteriorated after they have been opened to traffic. Many causes contributed to these deteriorations, such as traffic overloads, climate changes, poor drainage and low quality of paving materials. The most common road defects are cracks, potholes and ruts, depressions, and damaged edges. These problems affect the level of road service and safety, as they may lead to premature failure and traffic hazards. Before embarking on maintenance strategies, engineers must consider the causes of road deterioration.

Traffic jam

The issue of traffic congestion is one of the major problems facing crowded cities, which results from several linked factors, such as the concentration of various activities and businesses in the city center [3], rural displacement, an increase in demand for public transport and the necessary infrastructure, with the increasing growth of movement and mobility, the increase in the tendency to own cars, the inability of roads and parking places to accommodate the means of transport due to the lack of capacity, and consequently this leads to bottlenecks that slow traffic, lower safety rate, increased transportation costs, damage to goods due to delay, In addition to the anxiety that results in a psychological deviation that affects behavior of humans and society.

Traffic accidents

The increase in traffic with an increase in the rate of ownership and use of private cars, which is matched by a decrease in the rate of use of public transport, as well as increased speeds, recklessness and lack of traffic awareness, resulting in traffic accidents, and it is one of the most serious transportation problems that lead to loss of many lives every year, and as a result of the large number accidents have become an economic burden that weighs on the national economy of countries with high accidents [4].

2.3 Previous studies

In view of the important role that the road network and its quality play in influencing the national economy, the study has reviewed many previous studies, in Sudan and abroad, similar to the subject of this study.

Ali et al. [5] developed a maintenance management system by collecting and analyzing information and determining the pavement condition. The researchers used the PAVER system to evaluate the performance of roads in central Sudan, taking advantage of the information about 676 km length of roads that provided by the Roads and Bridges Authority. The pavement condition index (PCI) was adopted to find out the causes of pavement defects. The results showed that 52.3% of the defects were due to environmental factors, and 21.7% were due to traffic overloads, while 26% were due to other reasons. The study showed by comparing the results with those obtained by the Micro PAVER method are significantly different.

A field study carried out by Margani [6] aimed at applying the evaluation methodology and contributing to make the best decision regarding maintenance cost. The study used a field survey to collect data and apply the pavement condition index (PCI) to assess the pavement condition and maintenance priorities of the road network in Sudan. The study covered roads with a length of 2782 km and used 15 employees for surveying and collecting data. The study concluded that 17.4% of the roads are in poor condition, 20.6% in good condition, 22.9% in good condition, 39.1% in very good to excellent condition, and the average pavement condition 57% which is a fairly acceptable result. The study recommended implementing a comprehensive road survey every two years to develop databases as well as providing automated scanning equipment.

The study by Mohamed [7] implemented the Micro PAVER program and used the PMMS pavement maintenance system. A number of roads in central Sudan were surveyed for twenty sectors with a total length of 617 km. The study found that 12 sectors are in good condition and 7 sectors need maintenance and rehabilitation. One sector needs to be rebuilt, whereas 53% of paving defects due to climate factors, 21% related to traffic overloads, and 26% for other factors.

In another study by Kadhim & Mahdi [8], the relationship between current serviceability (PSR) in road testing, which depends on users' opinions, was highlighted by means of a questionnaire to assess the road pavement condition, as well as by road condition survey where road users view their demand for comfort, safety and security on the road. These opinions were compared with the results of the PCI paving condition, and the researchers chose three different methods in the city of Diwaniyah in Iraq, to conduct the survey, and 50 samples were subjected to each direction of the survey. The PCI value was extracted and the results showed the PSR value for the three methods from (2.2 and 3.1 out of 5) while its values PCI score from (34.8% to 39.2%), which is very low. The researchers revealed that the roads are affected by excessive loads, temperatures, and design and implementation errors.

A study conducted to evaluate the effect of weight gain on paving life was carried out by Wang et al [9], using the automated experimental approach of the Pavement-ME, Pavement Design and Analysis Program to predict paving life for different motion load scenarios. Field performance data collected from truck weighing stations were analyzed and paving life was estimated. Different distribution patterns were observed between overweight movement and normal weights movement in terms of truck and load classes, and the relationship was linear between overweight and the percentage of pavement age deterioration. In general, the study concluded that 1% increase in overloaded truck causes 1.8% decrease in paving life.

Latifi's study [10] investigated the effect of increasing truck weight on pavement flexibility. The study followed the field survey approach to collect data from records and traffic counts used to confirm truck traffic levels as well as issued permits. The pavement was subjected to a visual scan to evaluate paving conditions. The

study aimed to describe the pavement damage and deterioration caused by trucks in Wisconsin, using the AASHTO WARE MEPDG and Micro PAVER program to obtain statistical data for a period of six years from 2007 with 96,000 truck permits. Data analysis were carried out to assess the quality of the pavement in order to identify the percentage of pavement deterioration. The pavement condition was low and truck loads led to a high percentage of damage on the road.

In another study conducted by Kraus and Fernando [11], to examine the effect of frequent excess truck movements on buried facilities. The study was conducted in Texas, USA. The study showed that increasing traffic of loaded trucks leads to acceleration of deterioration of the infrastructure, which affects the facilities buried under the pavement, especially if these facilities are old. In this study, the researchers evaluated the potential damage to the buried pipes exposed to the loads, and the results indicated that the pipe deformation in terms of reducing the vertical diameter was less than 5% of the pipe diameter, which is the maximum permissible value, as well as the occurrence of damage to the buried concrete pipes.

Addling and Gupta [12] in their research to find out the causes of pavement deterioration before conducting maintenance strategies, the results showed that the causes of deterioration are the sudden increase in traffic load as well as the temperature that ranges from 50 degrees Celsius to less than zero throughout the year, and the variation in foundation soil and poor drainage of rainwater, as well as the temperature of bitumen, increase or decrease, and these reasons were put forward to find out the appropriate remedial methods, to reduce pavement deterioration and increase its life.

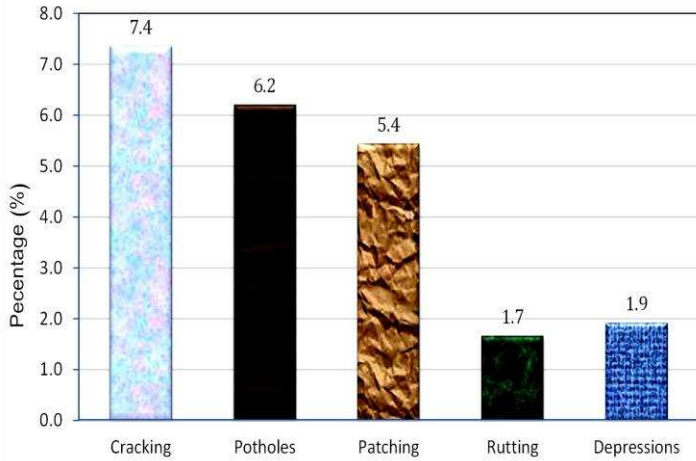

Fig.1. Map of the national road network in Sudan

Fig. 2. The distresses types and percentages of distresses on the surveyed roads

3. STUDY METHODOLOGY

The methodology on which the study relied included reviewing the data and information available on aspects of road maintenance practice in Sudan and the budgets provided to meet current and future maintenance requirements. A field survey was conducted on pavement status of the selected national roads in Sudan. Four national roads were selected from the road network (R1 to R4) to conduct the field survey. The choice of these roads is based on the representation of the different regions and cities of Sudan. The total length of the selected roads is about 1455 km and the roads' names and lengths are shown in Table 1. Relevant documents and reports on road design, construction and maintenance were reviewed. Data and information on how to fund road maintenance and the adequacy of funding to meet current and future maintenance requirements were also collected to help assessing road quality in Sudan.

3.1 Field Survey

In this study, a field survey is conducted on the selected roads to evaluate their current status. The type and severity of defects were inspected visually for each road section. External indicators of pavement problems resulting from loading, environmental factors, and design and construction deficiencies were noted. The levels of severity were observed during the field survey. Inspection was performed by driving the vehicle at normal speed in a road segment during normal traffic flow. Drive quality was used to determine the severity of distresses and defects such as cracks, local potholes, ruts, depressions and patching. The quantities of defects on the road surface are either measured in linear meters or square meters. Each defect observed was quantified and data recorded by walking on pavement or road shoulders.

4.1 RESULTS AND DISCUSSION

The data and information collected from the field survey were analyzed statistically using excel sheets. It is known that the length of paved national roads about 6000 km (20% of the total length). In this field study, the roads covered with a total length of 1455 km, which represents about 24% of the total length of paved roads. The results are presented, analyzed and discussed below.

4.1 Road failure

In field survey, the most common roads' failures recorded include Cracking, rutting, potholes, raveling, depressions, patching and edge failure. For each distress, the area covered were determined

And by comparing it with the total area of pavement sections, the distress percentage can be calculated. The types and percentages of roads' distresses are plotted in Fig. 2. In this figure, it can be observed that cracking, potholes and raveling have high percentages, 7.4%, 6.2%, and 5.4% respectively. On the other hand, rutting and depressions are minor distresses with low percentages, 1.7% and 1.9% respectively.

4.2 Pavement quality assessment

It is necessary to use a new concept to assess the quality of road pavement based on its condition. The Pavement Condition Index (PCI) was developed to determine a number for each surveyed road according to the pavement condition, average percentage and severity level of observed distresses. The PCI is defined as a numerical indicator that classifies the pavement condition. The proposed scale is assumed to determine the current observed pavement condition on the road. The description of the alignment condition is a function of the PCI value which represents the lowest value of "PCI" from 0 to 25 the "poor" alignment and the highest value of the PCI from 75 to 100 is the "excellent" alignment, as shown in Fig. 3.
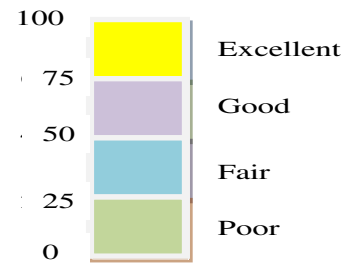

Fig. 3. The Pavement Condition Index (PCI)

For the purpose of easy and proper evaluation of the pavement condition, the proposed "PCI" was considered in the analysis to correlate each road with its surveyed distresses such as cracking, potholes, patching, raveling, and rutting. For each road, there is an estimated PCI value for the total percentage and the level of distress severity that were measured in the field survey as shown in Table 1.

Table 1. The analysis results of the field survey.

Road	Symbol	Length (km)	PCI	Rating
Khartoum - Alkamilin	R1	160	44	Fair
Omdurman - Dongola	R2	500	70	Good
Kassala - Haya - Port Sudan	R3	560	30	Fair
Sennar - Singa - Damazin	R4	235	20	Poor

It is noticed from this table that the lowest value of the PCI is 20% which occurred on Sinnar – Singa – Damazin road (R4), whereas Omdurman – Dongola road (R2) showed the highest value of "PCI", 70% and this may be due to the rehabilitation that was implemented in 2010. Furthermore, the results showed that the two roads (R1 and R3) with a total length of 720 km are in fair condition and represent 49.5% of the surveyed roads, while the road (R2) represents 34.4% in good condition, and (R4) which represents 16.1% road is in poor condition.

4.3 Causes of road deterioration

A variety of factors contribute to pavement deterioration were investigated based on field survey. The study has identified some of

the factors that cause failure. The observations of the field survey showed the causes of deterioration that occurred on the selected roads.

Fig. 4 shows the pavement photo of road (R1) having a rough surface with serious potholes. From this figure, it is observed that the crack occurred on the track of the vehicle wheels, and the potholes appeared in the middle of the road. This road experienced heavy traffic as it is one of the main roads for buses and trucks. Also, there is no side drains observed and uneven pavement surface which resulted in poor surface drainage. The recorded data indicated improper pavement design and construction, the design based on low traffic loads, using low-quality materials in construction, and following inappropriate design procedure. Therefore, insufficient pavement thickness, lack of construction materials and poor drainage may be the causes of these defects.

Fig. 4: damaged surface with large potholes on road R1

Fig. 5 shows the pavement of road (R4) that has severe potholes, cracks and failure in the side edges of the road. The distress area is too large and hinders traffic flow. It appears that the failure may be simply due to a weak subgrade of expansive clay soil, the problem associated with failure of the shoulders is likely linked to a problem in the subgrade soil. There are numerous failures associated with swelling soil in all sections of the road. The lack of adequate surface drainage is another critical factor that leads to problems with expansive soils.

Fig. 5: Dangerous potholes and edge failure of road (R4)

5. CONCLUSION

This research work undertaken to assess the pavement quality of national roads in Sudan and find out the causes of road deterioration in order to provide recommendations for improvement of road quality. The following are the conclusions drawn:

- Identifying the causes of pavement deterioration greatly contributes to the proper selection of effective maintenance techniques, which results in enhancing the road quality and extending its service life.

- The results of the field survey conducted on four main national roads, representing 24% of the paved roads in Sudan, showed that 49.5% of roads are in good condition, 24.4% in fair condition, and only 16.1% in poor condition. Therefore, there is an urgent need to maintain the road network in Sudan.

- The study identified the major distresses as cracking, potholes, and patching and the main reasons for the rapid deterioration of the national roads in Sudan include traffic overloads and climatic impacts. In addition to weak subsoil (expanded clay) and poor drainage system.

- The design standards adopted in Sudan for pavement design are not appropriate for the country conditions and the vehicles in use, therefore the rates of pavement deterioration are higher than would be the case if the design criteria used were in accordance with the requirements of heavy multi-axle vehicles.

- In Sudan, road maintenance is chronically underfunded, in particular the routine and periodic maintenance activities. Therefore, adequate funding is necessary. The level of funding should be linked to the targets that have been set for the maintenance works of the road network.

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