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Applying GIS to improve the efficiency of Highway Pavement Maintenance Management System-Case study on Hosanna – Doyogena – Durame Mazoriya

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ABSTRACT

Digitizing the road information can enhance an improved standard to the working environment of people by enabling a flexible and easy database for users. Inventory management of road maintenance with a digitized system supports easy update of information and reduces time spent for extraction of required data. The study assessed road pavement condition and evaluated the road by pavement condition index, and used GIS to produce digital database of road distresses so that it enables to prioritize the sections of road pavement for maintenance based on the outcomes of GIS analyses. Pavement condition index was determined following Ethiopian road authority manual procedure and then, the data was transferred to GIS database. The spatial data was collected from the field by using GPS and then correlated in GIS with pavement condition index using join tool. The road was categorized under very poor pavement condition since the pavement condition index value of all sub-sections is below 35%. The GIS based analysis gave flexible system to prioritize the segments as per the budget available. GIS based PMMS provides very flexible, effective, easy and timely PMMS platform. It also provides maps that can facilitate decision making process for agencies because pavement distress is expressed by position, extent and severity and all these features can be presented in GIS maps better than manual methods.

Keywords: GIS, PCI, PMMS, Spatial Analysis

1. INTRODUCTION

In the modernized world information and data are kept in a digitized database where data of any system can be effectively managed. Road pavement data management similarly, requires that type of database in order to keep information regarding road pavement condition and related. Obviously, road pavement information consist two basic forms of data: spatial and attribute data. In order to digitize information of such a type, it needs a system which supports both types of data. Geographical Information System (GIS) is a powerful application and able to analyze and store all the geospatial data [1]. Digitizing the information can enhance an improved standard to the working environment of people by enabling a flexible and easy database for users. Inventory management of road maintenance with a digitized system supports easy update of information and reduces time spent for extraction of required data.

Road maintenance is a system to maintain or keep pavement surface and its structure in a good condition so that road users cannot be exposed to an unreasonable cost. Road maintenance carries out inventory survey of pavement surface, pavement layers structural strength, shoulders condition, drainage condition and traffic facilities of the road and develops an appropriate engineering measure to reduce the rate of damages or road failures so that it reduces operating costs of vehicles using the road by providing a good road surface, it also provides comfort and security for all the road users.

In order to provide a comfortable, safe and economical road surface highway agency need to balance priorities and make difficult decisions so that pavements will be managed effectively with available public funds [2]. There should be basic steps in order to prioritize road section for maintenance since the available budget is not sufficient to fund all areas at once. This implies that pavement maintenance management system (PMMS) needs a system which can enable an effective decision-making process in consideration of available resources.

Researchers successfully integrated the GIS into PMMS for storing, repossessing, analyzing, and reporting information needed to support PMMS-related decision making. Currently, organizations use mile-post referencing method to distinguish the location (spatial data) of pavement information which is very old and ineffective system as compared to GIS based PMMS. The spatial information of pavement can be easily collected by geo-referencing method and stored in GIS database. Furthermore, the GIS can describe and analyze the topological relationship of the real world using the topological data structure and model. GIS technology is also capable of rapidly repossessing data from a database and can automatically generate customized maps to meet specific needs such as identifying maintenance locations [3].

Acquah & Fosu, (2017) concluded that GIS based PMMS is reliable, precise and can be used for an effective monitoring and evaluation of the road network [4]. Additionally, the system is user friendly, cheap and one need not to be a database expert or an expert in GIS before he/she can operate it. It also helps decision-makers in taking decisions interactively with the aid of visualization of data in GIS without requiring any specialized technical skills.

Researcher stated that in order to enhance the decision-making processes, road agencies should consider the use of GIS for pavement maintenance management because the primary data used in the decision-making process have spatial components [2]. So the use of this technology by PMMS agencies is going to be important in order to get the advantages recommended by the different scholars. Therefore, the literatures review indicates that GIS base PMMS is crucial since it is enables digitized database and also capable to carry out analyses on the geospatial pavement condition rating, and additionally giving visual and graphical display of the results. Thus, GIS-PMMS is a digitized, effective, flexible and user-friendly tool to manage road network so that it is better to implement it in the transportation sector [5].

Current practice of PMMS in Ethiopia indicates that the location of pavement information is collected based on mile-post, even if mile-post are not available in many sections alongside the road, the system also lacks digitized database, inaccurate prioritization mechanism, poor decision-making system and totally ineffective PMMS [6].

There is lack of defined pavement maintenance selection techniques to select cost effective and specific maintenance options at project level, organizational maintenance prioritizing methods to optimize the available scarce resource and absence of quality control and quality assurance system while performing data collection and maintenance were identified as the weakness of road agencies regarding PMMS [7]. There is lack of adequate central data collection system, this has resulted in the maintenance operation not to be efficient and effective [8]. The results of this research help to properly manage maintenance of road pavement throughout the life of the asset by providing easy, accurate, timely and cost-effective PMMS. This can maximize the benefit to the users of the road by cost, time, safety and comfort.

The conventional methods of location referencing and Road Pavement management were not suitable for comprehensive digitization of pavement information [9]. The practice indicates that, pavement is divided into sections of equal length and then, condition survey is carried out under each section so that based on the severity and extent of defects on the road surface, pavement rating is carried out for each section. Each section covers up to half km [10]. Further, the inability of associating road defects with their location makes the data system inflexible. GIS based PMMS helps to create flexible pavement information database which will be used to carry out quick and accurate data analysis in addition to enabling the clear visualization of pavement mapping with their distress extent and severity.

Integrating PMMS and GIS will help to reduce the effort needed than in conventional methods, to collect and analyze the data periodically by reducing the repeated works [11]. So, PMMS agencies need to enhance their PMMS with GIS tools.

2. METHOD AND MATERIAL

2.1. Study Area

Hosanna is a town in southern Ethiopia, and the administrative center of the Hadiya Zone. Located in Sothern Nations, Nationalities, and Region, Hosanna has a latitude and longitude of 7^o 33′N 37^o 51′E with an elevation of 2177 meters above sea level. Durame Mazoriya (also known as Lesho Mazoriya) is located at a coordinate of latitude and longitude 7^o 11′N 37^o 42′E. The highway between these two locations with an approximate length of 53 km is will be considered under this study as shown in Figure 1.

2.2. Materials and Software

Garmin 72H GPS: to collect the latitude and longitude measurement of each and every defect location.

Digital Camera: Digital camera is used to capture pavement distress at each location of the road so that it helps in decision making process.

Measurement instruments: Meter, Rod

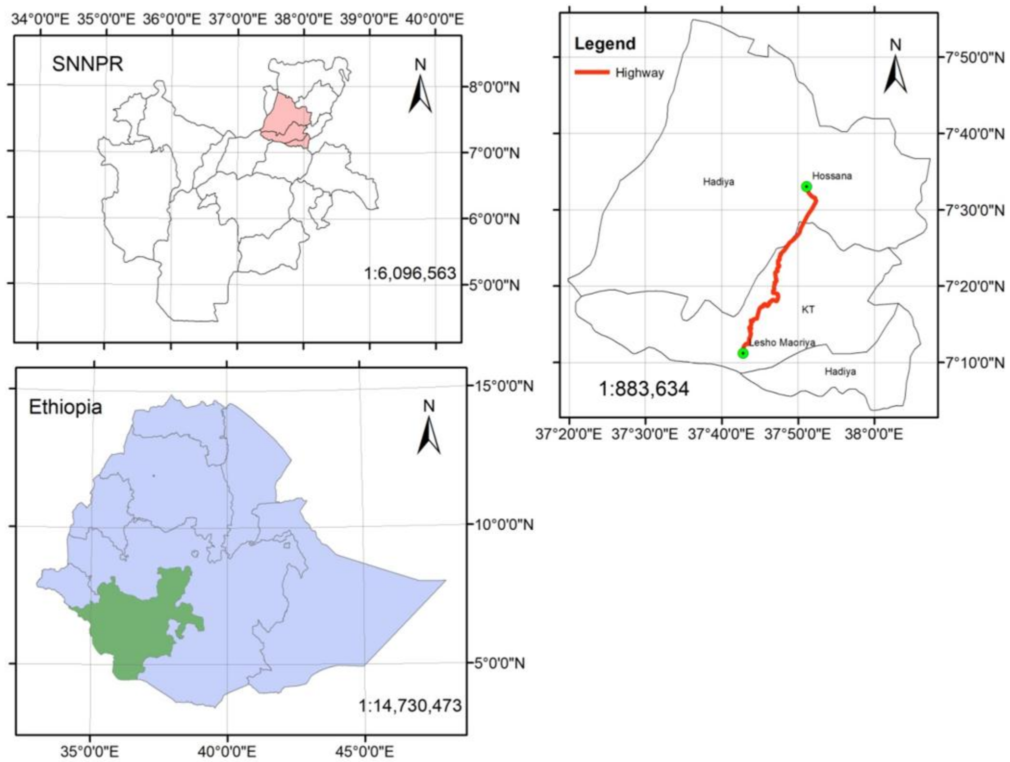
Analysis software: Microsoft Excel, Microsoft Word, ArcMap10.3.

2.3. Pavement condition survey and referencing

A conditional survey will be conducted to measure the severity, type and extent of road surface defects. Alongside with the collection of road surface defects, geographic location of each defect (X and Y coordinates) will be captured with Garmin GPS.

2.4. Pavement Evaluation and Rating

Pavement Surface Evaluation and Rating will be performed along the sections of the road.



Figue 1. Study area map

Procedures to the Calculation of Condition Index (CI) as Per ERA's PMS [13].

The CI is used as follows in ERA's PMS:

- An average network CI is calculated representing the average condition of the unpaved road network for a specific year. This average network CI is weighted by length.
- The CI is furthermore grouped into five condition categories that are used to categorize the condition of the paved or unpaved road network into very good, good, fair, poor and very poor categories. The categories adopted are: Very Good = 86% to 100%, Good = 71% to 85%, Fair = 51% to 70%, Poor = 36% to 50% and Very Poor = 0% to 35%.

2.5. Data Processing and Analyses

The collected data which includes the defect type, defect location and extent were inserted into Excel, rearranged as appropriate and then transferred into ArcGIS Software (10.3 Version) for further analyses and presentation of results. Spatial statistical was used to analyze, evaluate, interpreted and visualize the pavement defects in a GIS so that prioritization of road locations for maintenance done.

3. RESULTS AND DISCUSSION

Asphalt pavement surface may fail due to different reasons; thus, the failure may have varying severity and extent along the road length. Understanding the severity and extent level is very crucial in order to take actions or measures on this failure or defects. To do this, it is needed to carryout assessment on the road surface along the road length using appropriate methods available. ERA (2013) provides the sample field data collecting format as shown in table 1. The form is designed to be as flexible as possible since the nature of paved road deterioration varies depending on factors such as the type of construction, climate and traffic levels. There are, however, a number of defects that tend to be common to all road pavements [10]. The format was edited by the researcher in order to assess the type of distresses common in the study area.

The assessment was made by walking along the highway and recording each distress types with severity, extent and position.

The highway has a total length of 53km and the assessment was made by each 500m which can be 100 sections on the total sections. For each section the latitude and longitude coordinates were measured using GARMIN 72H GPS. To be suitable for GIS use each block was assigned with object ID in order to describe the location or position of distresses.

After all the existing flexible asphalt surface defects were assessed, it was rated using PCI calculation method following the procedures of ERA manual as shown in Table 1.

3.1. Integrating accident Database with GIS

Features of pavements defects/distresses position

In order to create distress database platform in GIS the distress position should be measured in terms of digitized methods. One of the digitized

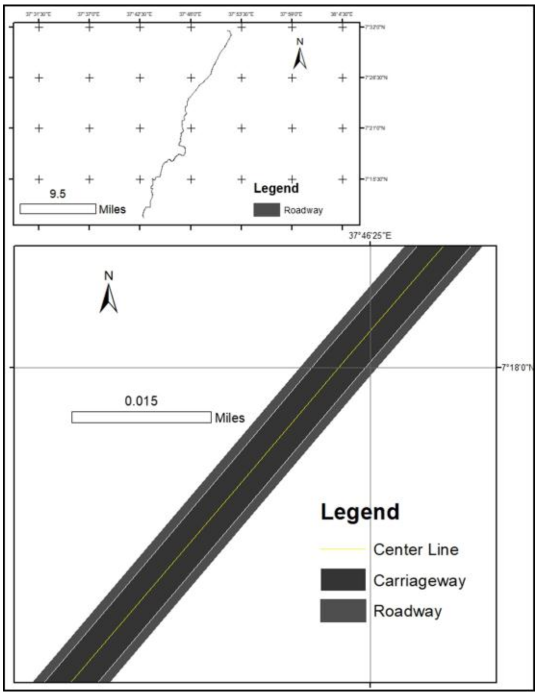


Figure 2. Study area map

methods to determine the position of those features is by using geographical positioning system (GPS). In this research each block position was measured using GPS. Since the block has start and end point, the longitude and latitude of start and end points were measured using GPS instrument. Object ID* is used to join spatial table and attribute table. It is common feature for both spatial table and attribute table. The join analysis in GIS requires feature to be based on to associate two tables and for that purpose object ID* is used. The results of block locations were presented.

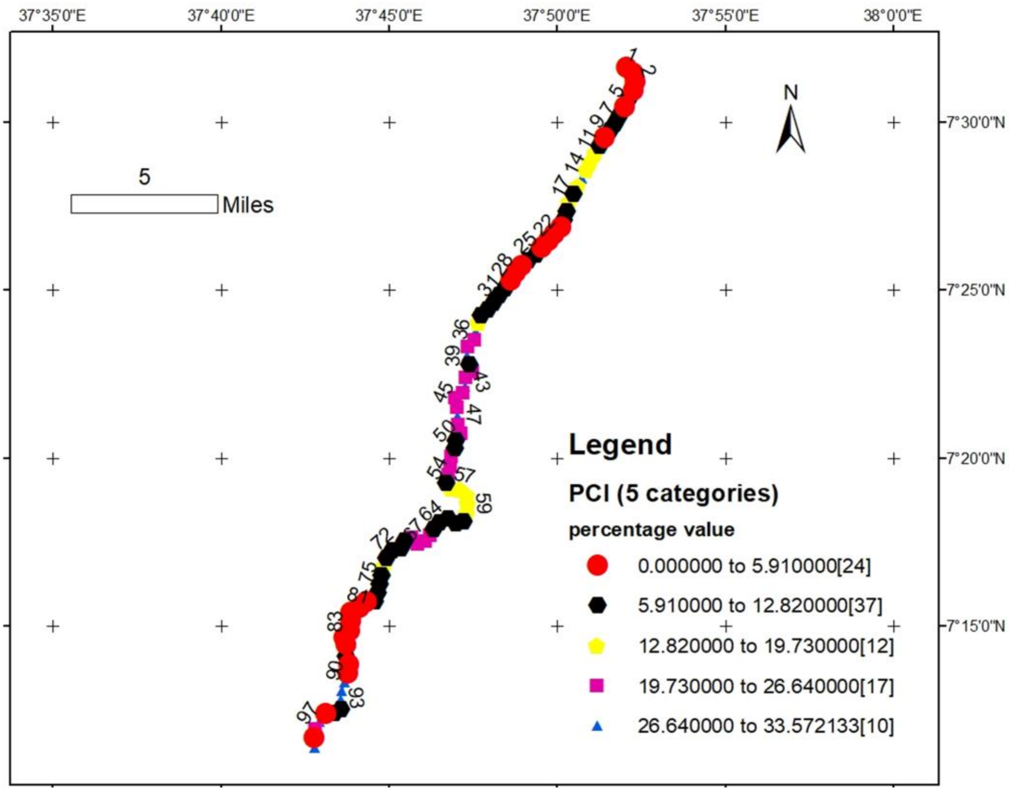
3.2. Digitized Highway data

The center line and edges of study area, which has 50km length, was measured side to side when collecting distress data and is visualized in GIS database as shown in figure 2.

3.3. Sections of road pavement prioritized for maintenance in GIS based

PCI Analysis

ERA uses PCI based prioritization. The PCI values can be overlaid on the top of the digitized road or highway. This visualization facilitates the decision makers to better understand the condition on the whole length of the road network. The PCI value calculated for Hosanna – Doyogena–Durame Mazoriya road indicated that all the roads were at the very poor standard. Since the road agencies have a limited budget, it can be difficult to maintain the whole sections of the road at once because the results from PCI analysis indicated the whole sections of the road with a total of 100 sections or 50km road were categorized as very poor with PCI value of less than 35%. Hence it requires further analysis to identify more affected sections so that with available budget maintenance can be carried out. PCI analysis categorizes sections into five levels as mentioned previously namely: very good, good, fair, poor and very poor. In case the road agencies have limited budget to maintain whole sections of the road at once, it requires analysis that can prioritize the road section in accordance to the budget. This type of analysis helps to rank the road section as per the budget. So, PCI categorization alone cannot be effective to select the most affected sections of the road without the help of other tools which can facilitate the prioritization process. Actually, road have different levels according to this research. So, by applying spatial analysis to PCI values in GIS platform, the sections of the road were ranked till the selected/prioritized/ sections are matched with the available budget. Until the selection meets as per the budget the road sections is repetitively analyzed to



Figue 3. Prioritizing Road sections: analysed and mapped in ArcMap10.3

prioritize the sections. This repetitive process to select sections that can be maintained with available budget is done by adjusting the PCI threshold values.

GIS platform gives database (storage), spatial statistical analysis tools and map displays. GIS based works save time and effort that can be wasted if done manually [11]. Since distress has severity, extent and position, GIS gives a better understanding for features characterized by position. It is not difficult as seen in manual referencing method to reference distress locations in GIS. So, the integrated GIS and PCI analysis gave or further prioritized the sections of the road as shown in figure 3. The analysis tool can perform the prioritization by adjusting PCI threshold into different levels till sections are matched with funding capacity. The final categorization used in this research for the Hosanna – Doyogena–Durame Mazoriya road, sections are prioritized as shown in figure 3: from triangle shape (blue color) to circular shape (red color). Red color shows the first prioritization.

As it was mentioned in previous section, direct PCI categorization prioritized the whole section of the road for maintenance. Based on the spatial analysis in GIS, the first prioritization sections were identified and shown by red color. The road segments (500m) fall under red color was 24. As compared to the PCI analysis directly from ERA which has 100 segments, 24 segments can be less. 24 segments can be maintained with approximately four times less budget. This the way how we can do maintenance of the road segments with available budget. It is better to maintain 24 segments with available budget rather waiting for more budget that can

Table 1. Rating the pavement condition index

ID*	ΣFn	ΣFn(max)	C=1/Σ Fn(max)	CIp=100*(1-C*Σ (Fn))	CI=(0.02509*CIp +0.0007568*CIp^2) ^2	PCI Category
1	93.672	134.000	0.007	30.095	2.075	V.P
2	78.343	120.000	0.008	34.714	3.179	V.P
3	60.000	60.000	0.017	0.000	0.000	V.P
4	60.000	60.000	0.017	0.000	0.000	V.P
5	88.653	174.000	0.006	49.050	9.311	V.P
6	60.179	74.000	0.014	18.678	0.537	V.P
7	65.029	120.000	0.008	45.810	7.494	V.P
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
96	72.000	120.000	0.008	40.000	4.904	V.P
97	66.098	210.000	0.005	68.525	27.804	V.P
98	64.611	196.000	0.005	67.035	25.835	V.P
99	60.000	60.000	0.017	0.000	0.000	V.P
100	74.247	250.000	0.004	70.301	30.296	V.P

maintain the 100 segments. As mentioned in chapter three, the Hosanna – Doyogena–Durame Mazoriya road has 100 segment each compromise 500m with segment one in Hosanna and Segment 100 in Durame Mazoriya. The 24 segments can be maintained at first level were shown in figure 3. The specific segments are can be seen from the labels displayed over each section. Accordingly, the object ID (segment number) of the sections prioritized at first level were: 1-4, 6, 10, 21-24, 27-29, 79, 80, 82-86, 89, 90, 96, 99 each section covers 500m. To know the position of each segment in the field for maintenance works: coordinates are used from table that are associated with respective object ID or coordinates can be displayed (labeled) in the map. During data assessment object ID (segment number) and coordinates (position) were recorded associated to each other respectively. After analysis, agencies go to field to maintain the prioritized sections and to identify the start and end position of the segments, the association between object ID and coordinates can be easily used.

For the prioritized section an appropriate maintenance method can be applied to increase the PCI value of the section so that facility will have a better pavement surface for the traffic to drive on [13].

4. CONCLUSION

Road construction is vital for the development of one country, to do so the design and construction of the road is the basic in the implementation. After the construction of the road, from the experience, it is known that the pavement cannot kept in its first condition so that it needs to be maintained well to extend the service level as the same to the initial. Agencies need to develop maintenance and rehabilitation plan together with design and construction phase as much as possible. This planned road maintenance and rehabilitation should be effective in order to kept the pavement surface in its initial condition as much as possible. Road agencies in Ethiopia have poor PMMS because most of the roads are not maintained immediately and well. The reason for this is that road is not maintained in an appropriate and standard way. They focus on quantity rather than quality. Focusing on the quantity and quality require sufficient budget. Agencies lack budget and so that they need to prioritize road section in accordance to the budget they have. But in order to select the most affected segments; agencies need tools that can effectively and easily prioritize the sections. The study showed that the whole length of the road was identified as very poor under PCI analysis requiring immediate maintenance. Since the budget cannot enable agency to maintain the whole length, the more specific prioritization technique was adopted. In this research GIS based PMMS technique was used to select the most affected segments from the whole section by applying spatial analysis. In GIS based classification sections were prioritized in more specific levels. PCI was determined following ERA procedure and was transferred to GIS platform. Spatial data was collected from the field by using GPS and then joined in GIS with PCI values using join tools. Then applying spatial analysis, 24 sections out of 100 were prioritized for immediate maintenance. Agency can maintain the prioritized sections with available budget. The study indicates that, GIS based PMMS provides very flexible, effective, easy and timely PMMS. As shown in figure 3, GIS also provides results maps that can facilitate decision making process for agencies because pavement distress is expressed by position, extent and severity and all these features can be presented in GIS maps better than manual methods. Additionally, the database in GIS is accessible to anyone without requiring further time and budget and without any errors.

5. RECOMMENDATIONS

- Road agencies should plan PMMS at the stage of road construction which will enable agencies to maintain deteriorated pavements immediately with available fund.
- PMMS should integrate GIS as data management tools which can provide easy, timely and flexible analysis platform. Analysis results can be better understood by maps. The data can be accessed easily

by anyone. The data can be collected without error and stored better.

- Road agencies should give training for the PMMS professionals on the data management and analysis tool: GIS based PMMS.

6. ACKNOWLEDGEMENT

NA

7. CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

8. SOURCE/S OF FUNDING

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