A Road Maintenance Management Tool for Rural Roads in Kenya

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ABSTRACT
Road maintenance programs generally are divided into three categories: routine maintenance; periodic maintenance; and the rehabilitation of roads, slab culverts, and bridges. Although the budgets for these maintenance activities are planned prudently, based on the engineer’s estimate, changes usually occur in the work plans after the maintenance work starts. The road maintenance activities are broken down into packages, and each package is awarded to the lowest bidding contractor. Progress made on the contract is recorded on a monthly basis, and the reports are generated on a monthly, quarterly, or yearly basis for each region or for an entire country. To perform these works more efficiently, software known as the Road Maintenance Management System (RMMS) was designed and implemented in 47 regions of the Kenya Rural Road Authority (KeRRA), Africa. The software is capable of tracking the change orders in every activity in the work plan and recording the construction progress in detail. As a main objective, this paper discusses the framework of the RMMS system. This paper also identifies five main road maintenance activities that experienced a high number of change orders for road maintenance projects of Kenya.

Key words: Road Maintenance Management System (RMMS), Cost, Time, Change Orders, Road Maintenance Activities

INTRODUCTION
In 2009, the Roads2000 Nyanza Project developed an application named the Road Maintenance Management System Version 3.2 (RMMS) to assist all the road maintenance works taking place in the Nyanza province in Kenya. Later, this software was extended to cover all the road authorities, including the KeRRA, the Kenya Urban Road Authority (KURA), the Kenya National Highway Authority (KeNHA), and the Kenya Wildlife Service (KWS).

The roads in Kenya are categorized into seven classes, based upon their
functionality:

1) Class A - International Trunk Roads;
2) Class B - National Trunk Roads;
3) Class C - Primary Roads;
4) Class D - Secondary Roads;
5) Class E - Minor Roads;
6) Class SPR - Government, Sugar, Wheat, Rural Access, and Tea Roads; and
7) Class U - Unclassified Roads [Kenya Road Board (KRB), 2013].

The data on the website maintained by KRB show that out of the total road network of 160,886 km, 61,936 km are classified roads and 98,950 km are unclassified roads. Similarly, out of the total road network, 11,189 km are paved roads and 149,689 km are unpaved roads. To improve the road network, the Strategic Plan 2005-2010 was executed successfully and another Strategic Plan for 2012-2017 is ongoing at present.

Riverson et al. (1992) stated the importance of rural road strategies for the maintenance and rehabilitation of rural roads in sub-Saharan Africa. Efforts progress in the development of the rural road network in Kenya, and maintenance works are ongoing for 47 regions of the KeRRA. However, because the maintenance activities were conducted aggressively nationwide, the monitoring process became complex. As a result, RMMS was devised to sort out the problems. Specifically, during road maintenance activities, change orders became a big concern. Although road authorities put great effort in reducing the change orders, the central server system recorded many change orders in road maintenance works. Sometimes, these change orders were sources of conflict between the owner and the contractor.

OBJECTIVES

The RMMS application tracks all contract packages and monitors progress of the road activities. The framework adopted in this application is user friendly, and its analysis should prove to be beneficial to personnel working in the field of road maintenance systems. This study explores all the change orders recorded in RMMS for various packages from these regions. Further, this study identifies the most frequently affected maintenance activities, which is important information in order to control change orders in future maintenance works. The main objectives of this study are as follows:

1) Explore the framework of the road maintenance management system implemented in Kenyan rural roads and understand the process of tracking the change orders in the system.
2) Identify the road maintenance activities that had a high amount of change orders.

LITERATURE REVIEW

Ozbek et al. (2010) proposed a framework to measure the overall efficiency of the road maintenance programs, taking into consideration environmental and operational factors. Implementation of this framework would help road maintenance managers to evaluate more effectively the achievements, improvements, and changes made on existing roads as well as the results of decisions made. When determining the efficiency of the maintenance works, the authors used the Data Envelopment
Analysis (DEA) approach to incorporate controllable factors, such as maintenance costs and traffic, and uncontrollable factors, such as climate effects.

Kubota and Mikami (2013) discussed four-dimensional data, including three-dimensional data for spatial locations, and temporal data, such as time, to store the historical data of the road conditions for proper road maintenance and rehabilitation. The authors proposed a four-dimensional management information system that could record all the information generated during the ‘road life cycle’ and could be implemented for road construction and maintenance works. The paper described the system architecture, the ‘spatial data infrastructure,’ the ‘road data models,’ user interfaces, the database system, and the library model required to develop this system.

Chan et al. (1994) studied implementation of genetic algorithms in road maintenance programs. They discussed the PAVENET model, which was described as an application capable of dealing with problems related to budget planning and programming of road maintenance activities. The paper presented genetic algorithms as an optimization technique to sort out the planning decision problems in the road network. This model was developed to help the maintenance program engineers in Singapore select the section of road to be repaired, schedule maintenance work, and identify the kind of maintenance activity to be carried out in that particular section.

Vassallo and Izquierdo (2002) demonstrated that the benefit of using finance systems for road maintenance could be estimated by using a simulation model. The authors stated that the simulation model could help convince road users about the advantages of proper road maintenance programs. They concluded that to make the benefit ratio higher, the productivity of road maintenance also should be higher.

According to Wambeke et al. (2011), “Variation almost always exists in the construction work process and it inevitably can have a significant impact on labor productivity.” The authors studied the causes of construction variation. They found that the “turnover time by engineers when there is question about drawings,” “rework,” and “obtaining required work permit” were the main causes of these variations.

Shrestha et al. (2013) analyzed change orders in 191 modernization projects and 98 new school projects constructed by the Clark County School District (CCSD) in the State of Nevada in the U.S. The authors found that there was no significant difference between the total change orders in these two types of projects. The types of change orders found in these projects were due to change orders due to “unforeseen conditions,” “requirement levied by government agencies,” “value added design deficiencies,” “no-value added design deficiencies,” and “owner requests.”

The size of the project significantly influenced the frequency of change orders, according to Anastasopoulos et al. (2010). The authors found that “resurfacing and traffic maintenance projects” had fewer change orders, and there were no involvements of uncertain conditions, such as earthworks or sub-soil treatments. They found that the longer the duration of the project, the more frequent the change orders.

SYSTEM FRAMEWORK

To achieve the objectives of this study, the researchers received the necessary data from the KeRRA office. The details required for understanding the framework of the road maintenance management system in Kenya was gained by reviewing the
software documentation and user manuals. The study procedures in exploring and analyzing the data are described in the following sections.

**Exploring framework and functionalities of the RMMS**

The database system of this application was designed to maximize the flexibility in the system. Initially, the system was developed only for the KeRRA regional offices; later, it was extended to other authorities, including KRB, KeNHA and KURA. The system was developed based on a two-tier concept, the first involving the database and the second involving the interfaces of the application.

The database system utilizes many tables for storing required information for road maintenance works. Basic tables were for the road networks, road sections, region list, province list, road activity list, and unit cost of road activities. Other tables were needed to form work plans, packaging and contracting operations, and to monitor progress. The RMMS application was designed to interact with these tables to store, retrieve, and update data for road maintenance activities.

**System components**

The various components incorporated in the system are shown in Figure 1. Mainly, the system consists of:

a) A ‘logon’ system for the database security;

b) A rate analysis component to determine the unit cost of the road activity, based on detailed calculation with all basic steps required;

c) Components to store contract details from the date of the starting the contract, details about the winning contractor, and the progress achieved in the project site; and

d) A GIS mapping component for displaying the road networks, work plans, and progress in the form of a map to visualize the progress on contracts.

![Figure 1. Components in the RMMS system](image-url)
Database concept

The central server can operate on a wide area network (WAN) or a local area network (LAN). The database system adopted by this application is shown in Figure 2. For this application, the idea was to work independently in local regional offices and upload data to the central system for approval from the respective officer in the main office. Once the central database system received data from all of the regional offices, the aggregate report for the entire nation could be generated easily. The centralization of the database system removed the lengthy steps involved in merging data from several regional offices to generate regional reports.

![Figure 2. Database concept in the RMMS system](image)

For consistency in work done in different regions, the central office maintains the activity codes and distributes them to regional offices. The code is generated based on:

a) The item code for the work type, for example, earthworks, site clearance, and other major items;
b) The sub-item code for sub-division in the main item; and
c) The activity serial number in the sub-division.

For example, the activity code ‘08-60-018’ tells that the activity is a road drainage and structure work (Item ‘08’), the supply and installation of concrete pipe culverts haunched in concrete (Sub Item ‘60’), and has a serial number ‘018’.

In order to save maintenance activities in the database system for different work plans, a unique identity number (ID) is assigned for each work plan prepared for a selected road section. A work plan consisting of several road maintenance activities
is saved, based on its unique ID along with financial year of execution; funding sources; schedule of work; work category, whether routine maintenance, periodic maintenance, or rehabilitation; and the region where the maintenance work will take place.

Similarly the packaged ID is generated based on the province code, the region code, and a serial number. For example, the Package ID ‘2140887’ is the number obtained from a combination of province code ‘2’, the unique number ‘14’ as the region code, and the four-digit serial number. All the activities associated with the package are saved along with this package ID. In order to save change orders for packages, the activity is saved along with the same package ID, but in a separate column with the change quantity.

Due to these unique IDs, centralization of the database system can be achieved without any problem. For purposes of security, only authorized users are allowed to access the database of the system. Therefore, the system begins with an option for selecting the proper database system, either the local database or the central server system. Normally, most users prefer to work locally in their own personal file and finish whatever is required. After that, the users upload all data from local files to the central server. In this way, users could finish all the work without an internet access; later on, they could upload the data to the central server at their convenience. This allows the central office to check and generate nationwide reports of progress made in the road maintenance programs.

Having data on personal files and the same data on the central server provides a kind of backup system. If data loss occurs in the personal files, the central server is available to recover the lost data, and vice versa. In addition, while working with this application, the user can use the ‘Save-As’ command to generate backup files of the personal database file or the ‘Export’ command to create a personal database file from the central server.

System operation details

Figure 3 presents the steps required for KeRRA’s road maintenance program. The KeRRA office prepares the annual budget ceilings, which includes the breakdown costs to be funded by donors, such as the Government of Kenya (GOK) Development Funds, the Swedish International Development Agency (SIDA) funds, and other funding agencies. Based on the budget available, the budget for the road works and administrative overheads are determined. Then, the regional manager prepares work plans for a particular road and uploads data to the central server for approval. Details of the work plan include several road activities and an estimate for the work planned for each activity. Authorized personnel check this work plan for its correctness and approve it; if not approved, they record the reason for denial so that the regional manager has an option to view the reason. The regional manager then must revise the work plan, taking into consideration the comments received; this revised plan is uploaded again to the server for approval.

Once the work plan receives approval, the regional manager is allowed to download the work plan. The regional manager prepares packages for the work plan and generates bill-of-quantity (BOQ) tables for these packages. Referencing to the BOQ, the contractors submit their bids to the regional office. Qualified contractors
are selected, and the contract is awarded to the lowest bidder. At that point, the bid rates provided by the winning contractor are entered into the system. Other details, such as the contract start date, contract end date, and contractor details, are recorded as well. Finally, the original contract amount is generated by the system.

As the Contractor makes progress at the project site, all the progress details are recorded in the form of the quantity achieved, the labor input spent, and the work achieved in terms of kilometer length of the road. Various types of reports required by the KeERRA office can be generated using this RMMS application.

**Figure 3. Workflow concept in the RMMS system**

- Report on engineer’s estimate
- Budget utilization report based on the funding sources
- Road network summary
- Work plan details report
- Work plan progress summary
- Payment certificate generation
- Employment reports
- Change (variation) order report
- Regional work plans, packages, contract progress report
- Display work progress in GIS map tool
This application has a special option to introduce change orders in the contract that are subject to alteration from the original conditions. With this option, users can add or delete the planned quantity for the activity already incorporated into the contract or introduce an entirely new activity that was not in the original contract. Because of this feature, the regional manager can handle change orders easily for the contract in question; they can be issued and incorporated as many times as required.

RESULTS OF CHANGE ORDER ANALYSIS

The details of quantity/cost change orders in different packages were received from the KeRRA in the form of an Excel file, which was scrutinized to extract the desired tables. The Excel file consisted of package IDs, package numbers, package names, contractor names, activity codes, activity descriptions, unit of measurements, planned costs (engineer’s unit cost for the activity), financial years, start chainages, end chainages, bid rates (contractor’s unit cost for the activity), planned quantities (engineer’s estimated quantity of work), and quantity changes (the work quantity added or deleted or new activity quantity). Based on this information, data processing was done to determine the frequency of change orders for different activities.

Almost 10,473 packages were contracted in two financial years: 2011/12 and 2012/13. However, only 339 contract packages (around 3.2% of the total contract packages) had change order details. Table 1 shows the top five road maintenance activities based on the highest frequency of change orders. From 2011 to 2013, ‘gravel patching’ had the highest number of change orders, followed by ‘culvert installation 600 mm with surround’, and ‘heavy grading without watering or compaction’. Change orders in ‘gravel patching’ was due to changes in the surface area of the patching between the time of estimate and construction. Gravel surface patching was estimated based on the current surface condition. In the time lag between the estimate and the construction work, the surface deteriorated, and therefore needed more work to complete the gravel patching. Feedback received from 21 regional managers showed that the change orders in ‘gravel patching’ were due to under-packaging the amount of gravel during the BOQ preparation at the initial stage.

Table 1. Frequency of Change Orders of Road Maintenance Activities

<table>
<thead>
<tr>
<th>Activity Code</th>
<th>Activity Description</th>
<th>Unit</th>
<th>Freq. in FY 2011/12</th>
<th>Freq. in FY 2012/13</th>
<th>Total Freq.</th>
<th>Freq. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-60-003</td>
<td>Gravel patching</td>
<td>M³</td>
<td>77</td>
<td>18</td>
<td>95</td>
<td>28.0</td>
</tr>
<tr>
<td>08-60-025</td>
<td>Culvert installation 600 mm with surround</td>
<td>M</td>
<td>38</td>
<td>8</td>
<td>46</td>
<td>13.5</td>
</tr>
<tr>
<td>10-50-001</td>
<td>Heavy grading without watering or compaction</td>
<td>M³</td>
<td>29</td>
<td>11</td>
<td>40</td>
<td>11.8</td>
</tr>
<tr>
<td>10-50-003</td>
<td>Light grading</td>
<td>M³</td>
<td>34</td>
<td>3</td>
<td>37</td>
<td>10.9</td>
</tr>
<tr>
<td>10-60-001</td>
<td>Provide gravel-wearing course excavation, free haul, spread, water and compact gravel to specifications</td>
<td>M³</td>
<td>21</td>
<td>12</td>
<td>33</td>
<td>9.7</td>
</tr>
</tbody>
</table>
Table 2 shows the change-order cost percentage calculated, based on the bid cost. The results showed that the highest change-order cost percentage was found in ‘heavy grading without watering or compaction’, followed by ‘culvert installation 600 mm with surround’, and ‘light grading’. Even though the frequency of change orders in gravel patching was highest among all the activities, ‘heavy grading without watering and compaction’ as well as ‘culvert installation 600 mm with surround’ had the highest change-order cost percentage. Culverts are means to guide water that crosses the road. As the nature of the water flow is dynamic and difficult to predict exactly, during the installation process, the protection work and work involving water flow guidance varied from the original estimate, causing the change orders.

**Table 2. Change-Order Cost Percentage of Road Maintenance Activities**

<table>
<thead>
<tr>
<th>Activity Code</th>
<th>Activity Description</th>
<th>Unit</th>
<th>FY 2011/12</th>
<th>FY 2012/13</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-50-001</td>
<td>Heavy grading without watering or compaction</td>
<td>M²</td>
<td>112.3</td>
<td>48.6</td>
<td>94.8</td>
</tr>
<tr>
<td>08-60-025</td>
<td>Culvert installation 600 mm with surround</td>
<td>M</td>
<td>75.5</td>
<td>120.7</td>
<td>83.4</td>
</tr>
<tr>
<td>10-50-003</td>
<td>Light grading</td>
<td>M²</td>
<td>80.2</td>
<td>26.7</td>
<td>75.8</td>
</tr>
<tr>
<td>10-60-003</td>
<td>Gravel patching</td>
<td>M³</td>
<td>59.9</td>
<td>46.6</td>
<td>57.4</td>
</tr>
<tr>
<td>10-60-001</td>
<td>Provide gravel-wearing course excavation, free haul, spread, water and compact gravel to specifications</td>
<td>M³</td>
<td>17.7</td>
<td>33.1</td>
<td>23.3</td>
</tr>
</tbody>
</table>

**LIMITATIONS OF THE SOFTWARE**

To prepare a package with multiple work plans, the user had to create multiple packages and merge them while generating output. The developer team could have provided an option to create a package with multiple work plans for flexible packaging work. Based on comments received from users, the software worked slowly while updating data to the central server; sometimes, the users had to upload data several times in order to maintain data consistency.

To sort out this problem, a centralized online working system has to be initiated. The local copy of database shall be provided just for read-only purposes; for new data entries and modifications, the user will need to log into the central system with proper authentication. This option will avoid the multiple copies of the same work, and maintain an active and centralized single database system.

**CONCLUSIONS**

This study revealed that a flexible design in the RMMS database system improved the workability and efficiency of report generation. The system for working either in local personal files – the local server in a particular office unit – or the central server – located at the head office by means of an internet connection – proved to be the most important option for managing huge amounts of data. The centralized
database server provided transparency in the work progress, and was useful for tracking the current situation of ongoing works. Top-management-level personnel had options to query the required summaries from the central server; this helped in the decision-making process regarding the status of the change orders and the work progress.

As entire contract packages for road maintenance began to be stored systematically in the servers, the task of tracking change orders became easier. The records that were saved for road maintenance contract packages implemented successfully in 47 regions of the KeRRA showed that the top three activities that were affected frequently by change orders were ‘gravel patching,’ ‘culvert installation 600 mm diameters with surround,’ and ‘heavy grading without watering or compaction’ works. However when the change order cost data was calculated, the top three activities that had the greatest cost for change orders were ‘heavy grading without watering or compaction,’ ‘culvert installation 600 mm with surround,’ and ‘light grading’.

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REFERENCES