Design and development of a decision support system with visual analytics to improve MRT maintenance operations

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Abstract

— Specialized Software has been developed and designed for planning, control and maintenance of transportation systems to prevent breakdown and ensure customer safety and satisfaction. Trains are at risk of facing mechanical problems that can lead to accidents and service interruptions if maintenance has not been properly observed. Thus, the researchers conducted the study which aims to develop a computer based maintenance system (CBMS) that will provide (1) more accurate preventive maintenance (PM) schedule (2) easy monitoring of available technicians to handle the maintenance and (3) spare parts monitoring to ensure that the items are available when needed. This research presents the design of an application software covering scheduled preventive maintenance for rolling stocks, preparation of ticket request for corrective maintenance, notification of assigned technicians, recording of spare parts to be used and generation of reports relevant to user’s manager’s decision making functions. The authors were able to assess the current maintenance and scheduling processes to determine system requirements and come up with the design that will improve the maintenance system.

Keywords: MRT; CBMS, decision support system, analytics

1. Introduction

The Metro Rail Transit (MRT-3), is one of two light rail transits in the Philippines. It was designed to carry about 23,000 to 48,000 passengers per hour per direction. However, from the year 2010 to 2015, the passengers reached 174.5M with an average daily ridership of 369,838 which deemed MRT-3 as the highest in the number of passengers (PSA, 2015). The growing number affects the train’s performance and service interruptions caused by machine breakdown were experienced by commuters. These service interruptions (SI) are classified into sections, namely: the rolling stock, track, signal, power and overhead system catenary. The situation has worsened from January 2016 to February 2017 as there were 63 breakdowns recorded and 32 breakdowns were caused by rolling stock (electric train units). Moreover, at the given period, though there are scheduled or planned maintenance for specific trains, there were unexpected breakdowns that occurred ahead of the given schedule due to inaccurate scheduling. The present maintenance system lacks the ability to easily monitor the status of each train, to check the availability of spare parts as replacement and to notify the technicians of the next maintenance schedule. This paper will provide the MRT management and users with accurate maintenance schedule and automated processing of service maintenance from request for service to service completion specifically on rolling stock.

2. Literature Review

A. Management Information System and Decision Support System
Management information system (MIS) is an organizational method of providing past, present and projected
information related to internal operations and external intelligence (Shah, 2013). MIS supports the planning, control and operation functions thus making it very effective for strategic decisions made by the organization. Decision making is important for the progress and overall development and performance of transits as well. From a study by Dr. Thiagarajan and Dr. Murugan on the transits in India, decision making is largely dependent on the existence of an information system wherein it can monitor all activities, performance, results and shortfalls of the organization. Decision support systems (DSS) are knowledge-based information systems to capture, handle and analyse information which affects or is intended to affect decision making performed by people in the scope of a professional task appointed by a user (Filip, 2005) DSS embrace various definitions, but it is largely considered that they are built to assist decision processes and help to identify and resolve problems (Bresfelean.2009). DSS symbolizes a specific class of information systems designed to help users which rely on knowledge, in a range of decision-making positions to solve the encountered problems that matter for the organization’s prosperity (Filip 2005).

The implementation of a DSS on the maintenance system of the MRT can prevent mistakes in the scheduling of the trains PM which can result to less interruptions and providing better service and comfort for their passengers. Moreover, the different reports that can be generated by the system like the service interruptions, spare parts and train maintenance monitoring reports will provide effective decision making and feedback on daily operations.

B. Computerized Maintenance Management System (CMMS)

A CMMS is a tool to support maintenance strategy based on an information system and a set of functions that process data to produce indicators to support maintenance activities (Lopes, 2016). According to Cato and Mobley, Donoghue and Prendergast and Zhang, Li, and Huo , usually the CMMS have assigned a set of functions and applications, including: 1. Assets Management: that consists of recording all assets (or equipment) and a historical record of repairs and equipment parts list; 2. Work Orders Management: that allows setting and releasing of work orders to the maintenance technicians. 3. Preventive Maintenance Management: that supports the planning, scheduling and control of activities; 4. Inventory control: giving access to spare parts availability. 5. Report Management: CMMS processes large amounts of data and produces performance indicators.

C. Mean Time Before Failure (MTBF) and Mean Time To Repair (MTTR)

The mean time before failure (MTBF) is the average time after repair following a failure to the next failure. It refers to the expected time between two successive failures when the product or system is repairable. This is the main factor of preventive maintenance schedule and it determines the estimate date of next maintenance. The mean time to repair (MTTR) is the average time to repair a failed train It is the total corrective maintenance time over the total corrective maintenance actions during a specified period. Knowing the MTTR can determine the length of time to repair the interruption. MTTR is also a factor for the prioritizing maintenance (Kumar, 2006). In a study conducted by the Miami-Dade Transit, the scheduled maintenance program is designed to maintain car reliability by detecting the potential defects to facilitate correction prior to failure. Trend analysis was used to track the actual failures and the failure rate of the equipment was determined (Miami Dade Transit, 2002). To produce a more accurate scheduling for MRT preventive maintenance, the MTBF of each train has been automatically calculated.

D. Visual Analytics

Visualization techniques take advantage of the human perception system and allow analysts to more easily derive insights about data. For instance instead of exhaustively looking into tables to identify data characteristics, an analyst is able to see, explore, and understand a large amount of information by using visualization techniques (R.A. Leite, 2018). In this study, line chart, bar graph and pie chart are the types of visualization presentation used. These charts/ graphs can be generated in the Report Generation Module.

E. Knowledge Management

Knowledge sharing improves richness of communications and very useful in creating value (Figueiredo, M.S.N, 2016). Effective practice of knowledge sharing contributes to increase productivity (Magnus, J. M.2005). Sharing of ideas enhances knowledge and experience in making decision and problem solving (Cabrera, A, 2006). One of the functionalities considered in the design of the automated maintenance system is providing a knowledge library which can be used while processing and updating the ticket request. During initial investigation of the findings, the technicians may refer to historical data that may guide them on succeeding maintenance activities.
2. Methods

2.1 Business Process Analysis

Understanding the current processes is one of the important steps in the development of the CBMS, thus, the scope, the flow of the current maintenance processes and issues on the current processes were identified.

Corrective Maintenance (CM) during Service Interruption

The current corrective maintenance of the MRT-3 starts once a service interruption has occurred during, before or after the train’s egress from the station or the depot area. The train driver will report the interruption to the control center using a two-way radio. Once the control center receives the call, the supervisor will identify if there are available technicians for the corrective maintenance. If there is no available technician, the train driver will decide whether to proceed to the depot station or wait for further help. If there are available technicians, the technician will then request for clearance from the control center to be able to proceed with the corrective actions. The control center will issue out the clearance, giving the technicians approval to carry out the maintenance. If they reach to a conclusion about the interruption, the defective cars will be sent to the yardmaster. The yardmaster should know everything that happens to the trains and has the authority over the train operations. Once directed, they will identify whether the rolling stock is heavily damaged or not. If it is, they will proceed to the heavy maintenance section (HMS) technician for repair; if not, they will proceed to the emergency repair unit (ERU) technician for repair. There would be a final checking to see if the rolling stock is repaired; otherwise, they would need to go back and redo the repairs. Once repaired, it would be reported to the supervisor followed by a report to the yardmaster for the train to be released for operations. The train would be directed to the depot for inspection. All written reports about the interruption and accomplishments will then be submitted for file keeping.

Preventive Maintenance (PM)

The MRT-3’s current preventive maintenance revolves around the following schedules: (1) 3-week: occurs every 15 days, takes an average time of 3.5 hours per train and is done between 12AM to 3:30AM; (2) 2-month: has an average duration of 2 days per train; (3) 6-month: occurs every 2 cycles after the 2-month maintenance and is usually done in the evening with about 5 manpower needed and an average of 3 to 4 days of work; (4) 18-month: occurs every 2 cycles after the 6-month maintenance with an average of 3 to 4 days of work; (5) 2-year: also called as the semi-overhauling of trains. This has an average of 5 to 7 days of work; (6) 8-year: also called as the general overhauling of trains, this should be completed at a maximum of one month working time. The technician would determine which rolling stocks are to be scheduled for maintenance. If there is any, it will be reported to the supervisor. Once the supervisor received the report and determined the maintenance activities to be done, the preventive maintenance unit (PMU) shall proceed to the scheduled activities. When all scheduled activities are completed this would be reported back to the technician and will process and compile all written reports about the maintenance. This would then be turned-over to the yardmaster for release.

Issues on the present maintenance system has been identified which trigger the development of the automated system. These are as follows: (a) difficulty in managing of data recorded in the spreadsheets (b) inaccuracy of maintenance schedules resulting to unplanned maintenance.

2.1 Design of the proposed Business Processes

The users of this system will be the technicians and the administrators. System functionalities are as follows: (1) Automatic generation of Preventive Maintenance Schedule based on historical data including MTBF and MTTR; (2) Display maintenance schedules and notify the user of an incoming preventive maintenance and/or an interruption needed to be addressed; (3) Enable the users to view past data to determine the interruption’s cause, time and place and possible solutions to the interruption if available; (4) The system should be able to request for a service interruption ticket to perform a corrective maintenance (CM); (4) Automatically assign technician to handle the preventive/ corrective maintenance; (5) The system should be able to generate reports that will help the administrators in strategic decision making functions. These reports maybe exported to .pdf, .xls or .docs format.
As the technician logs in, the system will show the list of confirmed PM scheduled for the trains. The technician will get his assignment, should conduct inspection and testing of trains. If all parts and the train have passed the testing the technician will proceed to update the status of the train and spare part to working, deeming it fit for service. Otherwise, the technician would need to request for corrective maintenance.

The proposed corrective maintenance system will accept input from the technician who would be categorized as the user and will be authorized to access the system. Should the technician have a schedule on the day or have any pending maintenance to attend to, the system will notify them as soon as they gain access. If there is an interruption that occurred, the train driver will notify the technician for inspection. If the train needs corrective action, he will prepare a ticket request. Upon preparation of the ticket request, the technician may search for past interruption similar to the interruption currently being experienced. If past records exist similar to the current interruption, it would be displayed by the system. This would provide the technician with a solution that can fix the interruption faster. Should there be changes to an existing data or if there is no existing data at all, the system will proceed to add it to the database as a new entry. Once the ticket is submitted for pending approval, the system will display it in the dashboard as a pending ticket. The administrator or a representative from the control center will confirm the ticket request to acknowledge the interruption. The administrator may opt to include the number of men to be assigned but, by default, the system will automatically provide the number of technicians needed depending on the severity and will also assign the technicians available to do the task. Once the train is fit for service, the technician will record the findings and solution implemented to submit the completed ticket.

### 2.2 Results

#### 2.2.1 CBMS Modules and User Interface

The computer based maintenance system has 9 modules namely: (1) administration, (2) dashboard, (3) ticket request, (4) service, (5) spare parts monitoring, (6) scheduling, (7) train monitoring, (8) user administration and (9) report generation.

**Administration Module**

The administration module is used for authentication of each user. There are access restrictions depending on the type of the user. One can only view the application and send ticket requests while the other is allowed to review, manage and send ticket requests. Figure 1 shows the Log-In screen.

![Log-In Screen](image)

**Figure 1: Log-In Screen**

**Dashboards Module**

This module contains data on service interruptions that has occurred and service interruption ticket requests that needs to be confirmed. Prioritization will be observed according to the severity of the damaged machine. A list of spare parts will also be displayed as well as the available quantity and the re-order quantity to notify if there is a need to be replenished. Figure 2 shows the screenshot of pending CM request. Pending PM request can also be displayed by this module from the Maintenance tab (Figure 3).
Ticket Request Module

Initially, the technician would need to request a ticket and for its confirmation before proceeding to the maintenance. When the maintenance is completed, he will input the initial breakdown and spare parts used, will input the findings and solution done. The technician may search for a similar breakdown that has occurred in the past and will be automatically populate the field for easier work, but they may also edit the data for each field. Figures 4 and 5 are the sample screenshots.

Service Module

This module covers confirmation of ticket request by the supervisor which allows the technician to proceed with the maintenance activities. Once the service has been completed, the request will be updated and solutions and recommendations will be encoded in the system. Figures 6 and 7 show sample screenshots.
Spare parts monitoring Module

This module provides inquiry on the availability and stocks of spare parts that will be used for preventive and corrective maintenance. Given the re-order level of each spare part, stock-outs maybe prevented. Figure 8 shows screenshot.

Figure 8. Screenshots for Spare parts monitoring

Scheduling Module

This module will show the scheduled preventive maintenance for each train and it will be adjusted automatically according to the mean time before failure (MTBF). There will be limitations per day and any succeeding train scheduled for preventive maintenance that cannot be accommodated will be moved to another schedule while considering its severity. The technician would need to complete a checklist and determine if train is fit for service to complete the preventive maintenance. Figure 9 shows the sample screenshot.

Figure 9. Screenshot for Scheduling Module

Train Status Monitoring Module

This module displays the status of each train, as well as the next schedule of the preventive maintenance and corresponding spare parts. Please refer to Figure 10.
User Administration Module
This module manages the accounts of users and administrators of the system as shown in Figure 11.

Report Generation Module
This module will provide historical and analytical reports for users and management to be used as basis for daily and strategic decision making.

A. Train logs contains time spent by technician per maintenance activity may be displayed as shown in Figure 12.

<table>
<thead>
<tr>
<th>Train</th>
<th>Description</th>
<th>Technician</th>
<th>Date</th>
<th>Time</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Normal severity</td>
<td>Tech Twenty</td>
<td>2018-05-30</td>
<td>09:05:55</td>
<td>0:10:04:53</td>
</tr>
<tr>
<td>9</td>
<td>Preventive Maintenance</td>
<td>John Doe</td>
<td>2018-05-21</td>
<td>08:49:15</td>
<td>0:10:12:44</td>
</tr>
<tr>
<td>7</td>
<td>Normal severity service interruption</td>
<td>Tech Thirteen</td>
<td>2018-05-24</td>
<td>01:06:10</td>
<td>0:10:00:53</td>
</tr>
<tr>
<td>6</td>
<td>Preventive Maintenance</td>
<td>Erwin Alonso</td>
<td>2018-05-23</td>
<td>12:15:58</td>
<td>0:10:03:33</td>
</tr>
</tbody>
</table>

B. Service interruptions report at a given period shows the details of the corrective maintenance activities done which include the findings and solutions and the time spent per service ticket. Graphs for service interruptions per month, per year and per train can also be generated as well as the most frequent type of interruptions (Figures 13-14).
C. Spare parts utilization displays the percent usage of each spare part at a given period. It can also show the top 5 spare parts used. Please refer to Figure 16 and 17.

8.4 Technician Utilization provides the time spent of each technician in maintenance jobs as shown in Figure 18. This is significant in balance scheduling.
2.2.1 System Testing

The authors had used the iterative method in the development of the CBMS in which testing will be done on repeated cycles until the system is fully functional. Results of the test is shown below:

<table>
<thead>
<tr>
<th>Test Case</th>
<th>First Iteration</th>
<th>Second Iteration</th>
<th>Third Iteration</th>
<th><em>PC to PC</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technician</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Login</td>
<td>2 Passed</td>
<td>2 Passed</td>
<td>2 Passed</td>
<td>2 Passed</td>
</tr>
<tr>
<td></td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Dashboard</td>
<td>16 Passed</td>
<td>17 Passed</td>
<td>18 Passed</td>
<td>13 Passed</td>
</tr>
<tr>
<td>Navigation</td>
<td>1 Failed</td>
<td>1 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Service Navigation</td>
<td>29 Passed</td>
<td>36 Passed</td>
<td>36 Passed</td>
<td>28 Passed</td>
</tr>
<tr>
<td></td>
<td>7 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Spare Parts</td>
<td>4 Passed</td>
<td>13 Passed</td>
<td>16 Passed</td>
<td>14 Passed</td>
</tr>
<tr>
<td>Navigation</td>
<td>12 Failed</td>
<td>3 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Maintenance Schedule</td>
<td>8 Passed</td>
<td>8 Passed</td>
<td>9 Passed</td>
<td>1 Passed</td>
</tr>
<tr>
<td>Navigation</td>
<td>1 Failed</td>
<td>1 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Train Monitoring</td>
<td>2 Passed</td>
<td>2 Passed</td>
<td>2 Passed</td>
<td>2 Passed</td>
</tr>
<tr>
<td></td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
<tr>
<td>Reports Navigation</td>
<td>8 Passed</td>
<td>8 Passed</td>
<td>8 Passed</td>
<td>8 Passed</td>
</tr>
<tr>
<td></td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
<td>0 Failed</td>
</tr>
</tbody>
</table>
Conclusion

The researchers were able to develop a prototype of an automated maintenance system that will facilitate the processing of maintenance transactions and will provide a more accurate maintenance schedule to prevent service interruptions. Furthermore, system output provide operational support specifically on manpower and spare parts utilization. Reports and charts / visual analytics that can be generated will help in the analysis of the transaction trends specifically on breakdowns and service interruptions, thus, preemptive measures will be considered.

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Biographies

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