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A SIMULATION MODEL FOR FIELD SERVICE WITH CONDITION-BASED MAINTENANCE

Yiqing Lin
Arthur Hsu
Ravi Rajamani

United Technologies Research Center
411 Silver Lane
East Hartford, CT 06108, U.S.A.

ABSTRACT

In this paper, we consider field service in which service providers are responsible for maintaining equipment performance. To do so, preventive maintenance work is usually required in addition to repairs. Field service managers are often faced with the conflicting objectives of maintaining a high level of equipment availability and keeping a low service cost. A condition-based maintenance (CBM) system can be used to achieve both goals by using equipment condition as a guide for taking maintenance actions. We developed a simulation model for field service with an integrated CBM system. A test case based on the field service operation of an elevator service provider has been built in a visual simulation environment to estimate the value of a CBM system.

1 INTRODUCTION

A field service business involves sending service technicians to perform various tasks on geographically dispersed equipment such as elevators, telecommunication equipment and heavy machinery. On-site tasks can be preventive maintenance or repairs in response to equipment failures. In one type of field service business, service providers are only responsible for repairs when equipment fails, while in another type, they are responsible for maintaining overall equipment performance. In the former case, response time to a service call may be an important measure of service quality, while in the latter case, in addition to response time, equipment availability becomes a key measure. To reduce equipment downtime, on-site preventive maintenance is usually performed in addition to repairs and field service managers are often faced with the conflicting objectives of maintaining a high level of equipment availability and holding down costs. In this paper, we consider the latter type of field service in which service providers are responsible for maintaining equipment performance.

The technology of condition-based maintenance (CBM) of equipment aims at developing systems that are capable of monitoring the operation of a complex piece of machinery and providing an accurate characterization of the current system state and an accurate prediction of the remaining life. It has the capability of reducing equipment downtime as well as reducing maintenance cost by using equipment condition as a guide for taking maintenance actions. However, the deployment of a CBM system requires additional cost due to the need to install new condition monitoring equipment such as sensors, computers, communications, etc. In order to justify the cost of implementing a CBM system and help design the system, a tool will be needed to estimate its benefit in terms of reduced maintenance cost and reduced failures. We developed a simulation model that can be used as such a tool.

Studies have been conducted in various aspects of field service. Duffuaa et al. (2001) described a generic conceptual seven-module simulation model for maintenance system in which equipment requires planned and unplanned maintenance. Joo, Levary and Ferris (1997) used simulation to select a preventive maintenance policy for a fleet of police vehicles. Watson et al. (1998) developed a simulation metamodel for response-time planning in field service for Xerox Corporation. In their model, field service is generated using Poisson assumption and different manpower planning strategies are tested. Dear and Sheriff (2000) provided a simulation model that can be used to evaluate resource allocation and dispatching strategies for technicians performing on-site repairs. Szczerbicki and White (1998) described how to use simulation to model condition monitoring.

In this paper, we combine various aspects of field service into one model. We present a discrete-event simulation model for field service with an integrated CBM system. We first developed a model for generic field service. Then using the model, we simulated a field service operation of an elevator service provider in a visual simulation environment. The main purpose of the work is to develop an integrated field service model to estimate the value of condition-based maintenance. However, the model can also be used to estimate the value of other business process decisions such as alternative technician dispatching strategies.

2 A CONCEPTUAL MODEL FOR GENERIC FIELD SERVICE

In this section, we present a conceptual model for field service with three types of service: regular preventive maintenance, condition-based maintenance and unplanned repairs in response to equipment breakdowns. Regular preventive maintenance can have time-based or usage-based visit frequency. Five modules are defined: (1) an equipment module which models equipment usage and condition, (2) a maintenance planner that generates regular preventive maintenance tasks, (3) a CBM planner that generates condition-based maintenance tasks, (4) a scheduler which assigns tasks to technicians and determines the orders to perform tasks, and (5) a field service module that simulates technician field activities.

Figure 1 is a diagram that shows the five modules and their relationships:

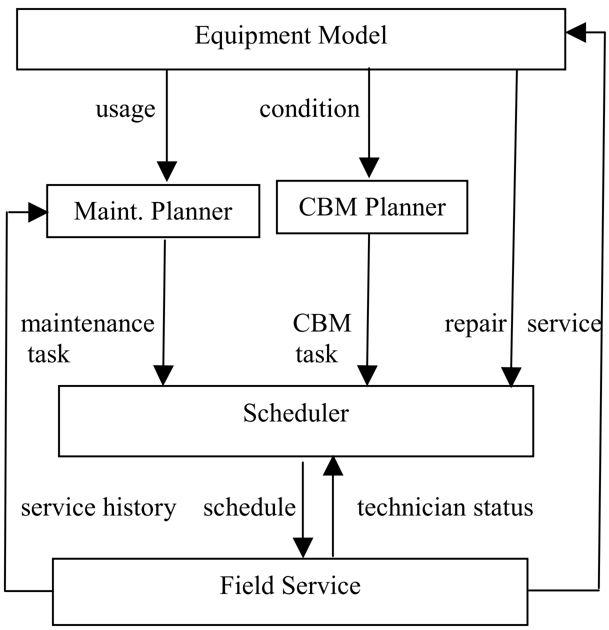

Figure 1: A Generic Field Service Model

(1) *Equipment Model*: The equipment model consists of a usage model that simulates equipment usage and a condition model that simulates equipment condition including failures. When a unit fails, a repair request is generated and sent to the module *Scheduler*. After work is performed on a unit, its condition is updated.

(2) *Maintenance Planner*: This module generates regular preventive maintenance tasks with appropriate due dates for each unit. A maintenance policy may be used to specify regular preventive maintenance tasks and the frequencies those tasks need to be performed based on equipment type, usage environment, service history, etc. Based on service history during the simulation, maintenance tasks can be dynamically updated. To generate usage-based maintenance tasks, usage information from the first module, *Equipment Model*, can be retrieved.

(3) *CBM Planner*: A CBM system module monitors equipment/component conditions and generates condition-based maintenance tasks when necessary. Periodically, it updates its estimate of equipment/component condition based on its true condition. When it detects the condition of the equipment/component is below a threshold, condition-based maintenance work is generated.

(4) *Scheduler*: This module is responsible for assigning tasks to technicians and determining the orders in which the tasks are performed. The input of this module includes all types of service as well as technician status such as availability and current location. The output is a schedule for each technician. The schedule can be generated dynamically, i.e., a new schedule is generated each time a new event occurs, such as when a breakdown repair is requested or after a technician completes a task; or a new schedule can be generated periodically, for example, once a day if there is no unplanned repair.

(5) *Field Service*: The field service module simulates technician activities in the field such as performing maintenance tasks, responding to unplanned repairs, traveling between various equipment locations, taking breaks, and working overtime. Technicians perform field service based on schedules generated in the previous module. After work is completed, the service information is passed to *Equipment Model* to update the corresponding component conditions.

It should be noted that based on the specific field service operation, a simulation model may not need to have all the modules mentioned above and not every module used needs to be modeled in great detail. For example, if in a field service operation, there are only breakdown repairs and no regular preventive maintenance or condition-based maintenance, then modules *Maintenance Planner* and *CBM planner* are not needed. Furthermore, if breakdown repairs do not have a significant impact on equipment conditions (except that they restore equipment to working conditions), then the first module, *Equipment Model*, may only need to generate equipment failures following some probability distribution.

3 MODEL DESCRIPTION AND RESULTS

The purpose of the work is to develop an integrated field service model for elevator to estimate the value of condition-based maintenance. The simulation model is implemented using the discrete-event visual simulation software tool TaylorED.

Elevators are located in buildings and each building may have one or more banks of elevators. The elevator service provider has a list of maintenance tasks for each elevator. These tasks can be general inspections or specific maintenance work on certain components. They may have both time-based visit intervals, such as every 30 days, and usage-based intervals, such as every 30,000 elevator runs. These tasks are performed by technicians during regular working hours unless customers have special service hour requirements.

When an elevator fails to work, a customer will make a service call and a technician will be dispatched to handle the problem. If the call is an emergency, such as when a passenger is trapped, then the technician assigned is expected to drop everything he is doing and go to the job. On the other hand, if the call is a non-emergency, then the technician assigned is supposed to go to the job within a time period based on service level agreement, e.g., within 2 hours of the time the call is made. In this case, the technician usually goes to the job after he finishes his current task. Calls that are made outside regular working hours may be handled by a different crew of technicians.

At the elevator service provider, the number of breakdown repairs is considered a key performance measure for field service quality. One way to reduce the number of breakdown repairs is to implement a CBM system for key elevator components and generate maintenance work on those components based on their condition. The primary objective of this work is to show that a simulation model can be used to estimate the value of a specific condition-based maintenance system.

To estimate the value of the CBM system, two scenarios were developed: one without a CBM system and one with a CBM system. In the case without a CBM system, there are only regular preventive maintenance tasks and unplanned repairs; while in the case with a CBM system, there are also condition-based maintenance tasks that are used to replace some regular preventive maintenance tasks.

The following is a detailed description of our simulation model based on the modules listed in the previous section. In the scenario with a CBM system, all five modules are used, while in the scenario without a CBM system, the module *CBM Planner* is not used.

3.1 Equipment Model

A usage model and a condition model are included in this module. For the condition model, we assume that each elevator has four major components which we will refer to as C1, C2, C3 and C4. The condition of each component is measured in terms of its remaining life, such as 2000 hours and 10,000 runs. The component fails when either the time-based or usage-based remaining life reaches zero. An elevator breaks down if any of its components fails. The expected duration of the required repair and whether it is an emergency will be generated following some distributions.

A component condition is updated after work is performed on it. We divide technician work into 3 types: major work, inspection and breakdown repairs. After performing major work and breakdown repairs, the remaining life of the component(s) on which work is performed will be updated. An inspection, however, first checks if a component(s) is in order. If it is in order, then nothing is done; otherwise, some minor work will be performed, which will bring the component to a normal condition. A low-threshold on the condition is used to measure if a component is in order. Probability distributions of each component's lifetime as well as its remaining life after each type of work are given as input data. We use a Weibull distribution in our test case.

For the usage model, the input data include regular working hour and overtime hour usage rates for each elevator. Based on these data, equipment usage is generated following a Poisson distribution. The parameters of the distribution differ among different equipment units. The equipment usage is needed for usage-based remaining life and usage-based maintenance tasks. We need to distinguish the usage between regular hours and overtime hours to accurately model the time of equipment breakdowns, since unplanned repairs that occur within and outside regular working hours may be handled by a different crew of technicians.

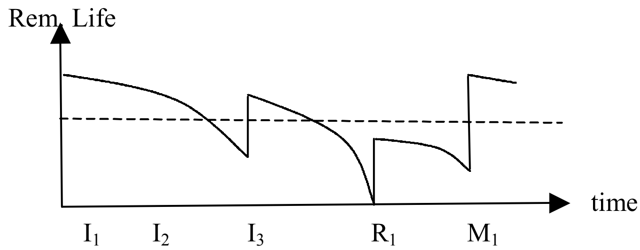

Figure 2: An Example of Component Remaining Life

Figure 2 shows the remaining life of a component during a certain period of time, where I, R and M denote inspection, breakdown repair, and major work respectively. The dotted line shows the threshold for whether work is necessary during an inspection. From the diagram, we can see that the remaining life of the component decreases over time and that a maintenance or repair action does not necessarily restore the elevator to perfect condition. Furthermore, inspections I_1 and I_2 do not change the component condition since at the time of the inspection, the component remaining life is above the given threshold.

3.2 Maintenance Planner

The list of regular preventive maintenance tasks for each elevator from the service provider is used as input data. Each task list includes the expected duration and visit intervals for the tasks. During a simulation run, this module updates task due dates after a task is performed.

3.3 Condition-Based Maintenance

In the scenario with a CBM system, a set of performance measurements on the operation of components C1, C2 and C3 are used to generate condition-based maintenance tasks for those components. A performance measurement (e.g., the time to open a door) is based on the condition of the component (e.g., door rollers). Maintenance tasks for component C4, which has no condition-based estimate, are still generated by the previous module.

Periodically, performance measurements are generated based on the current conditions of components C1, C2 and C3. The data are then analyzed using a data processing algorithm. If the result indicates that the condition of a component is below a certain threshold, a condition-based maintenance task on the component is generated. The task is treated as major work with an appropriate due date. The expected duration of a task is based on its workload, e.g., perform work on one or two components. At the same time, the regular time- and usage-based maintenance on those three components is removed from elevators' maintenance task lists.

3.4 Scheduler

In our simulation, we implemented a simple scheduling algorithm to assign technicians to tasks and to determine the order in which the tasks are performed. Before a simulation run, as input data, each elevator is assigned a primary technician who is responsible for all types of work on this unit. During the simulation, each technician performs tasks according to his schedule. The schedule is dynamically generated. Specifically, a new task will be generated for a technician each time a new event related to this technician occurs, such as when he finishes his current task, when an elevator for which he is the primary technician breaks down, or when the technician needs to take a break.

For planned maintenance task scheduling, a combination of earliest due date rule (EDD) and a clustering algorithm is used. At the beginning of a day, when there are no tasks on a technician's schedule, among all the tasks that he is responsible for, a task with the earliest due date is chosen as the first task to be performed. After the technician finishes a task, if there are no other tasks on his schedule (such as breakdown repairs) and the current task is not the last one of a day, a clustering algorithm will be run to check if there are any other tasks for the same elevator or if there are any tasks for other elevators in the same bank of the building that have due dates close to the current day, e.g., within 7 days. If so, one such task is appended to the technician's schedule. If no such task exists, then the EDD rule is used to choose the next task. The clustering algorithm is used to reduce the number of visits to an elevator, and more importantly, to reduce the total travel time.

For breakdown repair scheduling, the elevator's primary technician is first identified and the repair task will be added to the technician's schedule. If it is a non-emergency repair, it is appended after the current task the technician is working on and after all other breakdown repairs on his schedule. If it is an emergency repair, the current task will be preempted if it is not a repair and if it will take more than 5 minutes to finish. The remaining part of a preempted task will be inserted into the technician's schedule after all existing breakdown repairs.

3.5 Field Service Model

Technician activities during regular working hours, such as performing service and traveling, are modeled. Handling of overtime breakdown repairs is not modeled except that the number of such repairs is recorded. During the simulation, random service time and travel time are generated based on expected task duration and expected travel time respectively. Expected travel time is computed based on building locations and travel speeds between buildings.

Besides traveling between buildings, there are three types of setup time when a technician is on site: time spent after a technician arrives at the site and before he starts to perform maintenance work (e.g., time spent on finding a parking place, talking to a customer), time to travel between different elevators within a building, and time spent after the technician finishes his last task in a building and before he starts to travel to the next site. The setup time is given as input data.

For each technician, there is a technician availability table that specifies the unavailable time slots for that technician during the simulation. In our model, we assume that each technician is available 8am-12pm and 1-5pm from Monday to Friday. Usually, a technician takes a lunch break after he finishes the first task that ends at or after noon. However, if the expected completion time of the task is after 12:30pm, then the technician will take a break at noon and resume his work after the break. Similarly, at the end of a day, if a task cannot be finished by 5:30pm, then the technician will leave work at 5pm and perform the remaining part of the work the next working day. Otherwise, he will finish the task and all work that is performed after 5pm is considered as overtime. On the other hand, when a technician finishes a task and his expected arrival time at the next site will be after 5pm, he will end the day's work at the current location and the time between now and 5pm will be considered as idle time.

3.6 Results

A test case was built for a set of 90 buildings and 197 elevators of a field office. To run the simulation, the following data are required:

- For each building, its location, on-site setup time, travel time to all other buildings and a list of banks and elevators inside the building
- For each elevator, its usage distribution, a list of maintenance tasks with their visit intervals and expected durations, and its primary technician
- Technician availability
- Probability distributions of maintenance service time, repair service time, travel time, and percentage of emergency repairs
- Probability distributions of feature value, component lifetime, remaining life after each type of service.

To assess the value of a CBM system, we used fourteen metrics. The most important measures are:

- Number of unplanned breakdown repairs
- Number of maintenance tasks for components with a CBM system
- Average maintenance and unplanned repair hours per elevator.

The first measure is used to reflect service quality and the other two measures are used to estimate maintenance cost. We believe that a CBM system has the potential of improving these measures. It can help reduce unexpected equipment failures as well as eliminate unnecessary preventive maintenance work.

Fifteen simulation runs were conducted for both scenarios with and without a CBM system. In each run, we simulated the field service operation for three years. The simulation runs of the scenario without a CBM system showed that our model does reflect current operational metrics for field offices with similar geographic density and equipment types as the office used in the test case. The results indicated that the CBM system significantly reduced the number of breakdown repairs at the expense of slightly increasing the number of maintenance tasks for components with a CBM system. Specifically, the number of breakdown repairs was reduced by approximately 42%, while the number of maintenance tasks for those components was increased by about 14%. Overall, the total amount of work per elevator (both maintenance and unplanned repairs) was reduced by 12%.

4 CONCLUSION

Field service is a complex system consisting of several subsystems that interact with each other. Two major subsystems are equipment and field activity. While equipment is the driving force for various field activities, field activities may also have a significant impact on equipment conditions. Therefore, in order to accurately assess a business process in one subsystem, a comprehensive model is needed to take into account all key elements of field service.

A simulation model with integrated equipment condition and field activity was developed to evaluate the benefits of a CBM system and some preliminary results were obtained. Besides estimating the value of a CBM system, the model can be used to estimate the value of other business processes. For example, it can be used to assess the effect of an alternative technician scheduling system on field productivity and equipment condition. It can also be used to assess alternative maintenance policies.

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AUTHOR BIOGRAPHIES

YIQING LIN is a Research Engineer in Operations Optimization group at United Technologies Research Center. She received her Ph.D. in Operations Research from Columbia University in 2001. Her research interests are in network optimization, supply chain management and simulation modeling. Her email address is <liny@utrc.utc.com>.

ARTHUR HSU is a Principal Research Engineer at United Technologies Research Center in East Hartford, Connecticut. He received his Ph.D. in Industrial Engineering and Management Sciences from Northwestern University in 1995. His research interests are in supply chain management, field service operations, stochastic modeling and network optimization. His email address is <art_hsu@hotmail.com>.

RAVI RAJAMANI is a Principal Research Engineer at the United Technologies Research Center in East Hartford, CT. He received his Ph.D. from the University of Minnesota in 1990. His research interests are in simulation modeling and supply chain management; monitoring & diagnostics and condition based maintenance; and design and analysis of control systems. His email address is <rajamar@utrc.utc.com>.