Business Process Management Journal

Simulation Modeling for Manpower Planning in Electrical Maintenance Service Facility

Sanjay Choudhari, Hasmukh Gajjar,

Simulation Modeling for Manpower Planning in Electrical Maintenance Service Facility

Abstract

Purpose - The study presents the simulation model for manpower planning in electrical maintenance service facility and evaluates different scenarios to improve resource utilization while meeting the desired service level.

Design/methodology/approach - The process systematically maps entire system of electrical fault rectification, identifies probability distributions of demand of electrical maintenance requests and its process times using historical data. The simulation software ARENA was used to model the entire system and various possible improvements were evaluated to assess performance of maintenance service facility.

Findings - The simulation results obtained for the proposed changes in the system indicated the potential improvement in resource utilization while meeting the average waiting time expectations of customers.

Practical implications - The proposed simulation model can help maintenance people to decide the optimum number of resources to meet the agreed performance level that is expected by various stakeholders.

Originality/value - The paper considers the computer simulation in modeling complex real life system for understanding the resource requirement of electrical fault maintenance facility to improve resource utilization while meeting the desired service level.

Keywords - Discrete event simulation; electrical maintenance; manpower planning; waiting time; resource utilization; Arena simulation.

Paper type - Research paper

Simulation Modeling for Manpower Planning in Electrical Maintenance Service Facility

1. Introduction

Maintenance plays a crucial role in retaining and restoring the availability of equipment or system. Modeling of the maintenance system is considered to be complex process due to characteristics specific to system (Duffuaa and Andijani, 1999; Duffuaa et al., 2001). The characteristics that make system complex include interaction of maintenance system with other systems of organization in multifaceted manner, difficulty in quantifying maintenance output and uncertainty in many inherent elements of the system. The some of the uncertain elements are nature of fault arrival, type of the fault and the time required to rectify the fault. These complexity makes simulation a viable alternative for appropriate representation and analysis of maintenance system (Duffuaa and Andijani, 1999; Alabdulkarim et al., 2014; Alrabghi and Tiwari, 2015).

Several researchers have systematically attempted modelling different activities of maintenance processes in order to monitor and improve the performance of the organization. These studies include (1) evaluation of maintenance strategies (Swanson, 2001; Alrabghi and Tiwari, 2015) i.e. corrective maintenance (CM), preventive maintenance (PM) and condition based maintenance (CBM), (2) determining maintenance resources i.e. maintenance staff, spare parts (Luczak and Mjema, 1999; Ntuen and Park, 1999; Chang et al., 2007; Alabdulkarim et al., 2014) (3) measuring the performance of maintenance system (Parida and Kumar, 2006) and (4) maintenance planning and scheduling (Greenwood and Gupta, 2000; Sloan and Shanthikumar, 2000).

Manpower planning and scheduling is critical for the service organization where the demand for the resources are uncertain (Mjema, 2002). The uncertainty in the service request impacts the service level performance demanded by the customer and also efficiency of resource usage. A well thought maintenance manpower planning and scheduling in such situation is key to effective maintenance (Duffuaa et al., 2001). Manpower planning problem are applicable in all the maintenance systems which may vary in term of characteristics, context and importance of performance outputs. Few attempts have been made to address the maintenance manpower planning problems focusing different issues of maintenance system. Duffuaa et al. (2001) propose general conceptual model for simulating maintenance system including manpower resources. The studies of Duffuaa and Andijani (1999), Luczak and Mjema (1999) and Ntuen and Park (1999) with specific focus on manpower are conceptual and identify the factors that may influence maintenance system performance. Some studies (Luczak and Mjema, 1999; Chang et al., 2007, Alabdulkarim et al., 2014) focus on impact of manpower planning on manufacturing system outputs while some (Duffuaa and Andijani, 1999; Yan et al., 2004) are sector specific such as airline maintenance. Further, some conceptual studies (Luczak and Mjema, 1999; Ntuen and Park, 1999; Chang et al., 2007) simulate the maintenance manpower but lack the real life situation.

Many of the above approaches are developed for manufacturing system where maintenance is integral and supportive part of production. Especially in maintenance strategies, lot of emphasis is given to PM and CBM in order to improve the productivity of plant. However, in some instances, the maintenance system is established to work as independent service provider for providing maintenance services at different (i.e. external) customer's sites especially to meet need of corrective maintenance (CM). Majema (2002) argues that maintenance system usually possesses characteristics of a service company. These situations pose more complexity as compared to the maintenance of manufacturing system due to varying distances between the customer's locations and the maintenance service provider (Alabdulkarim et al., 2014). Parida and Kuma (2006) identify various measures to be considered for evaluating performance of maintenance system. Many of these measures used in several studies are related to cost, output of manufacturing system, equipment availability. Further, the appropriateness of specific performance measures may change from one maintenance system to another. Further, their study suggests to link the customer measures to realize the complete maintenance effectiveness. Optimizing the maintenance system by evaluating downtime cost, production loss, minimize total cost which are more relevant and easy to measure for manufacturing system may not be sometime appropriate for service maintenance system where customer is external to system (Al-Zubaidi and Christer, 1997). In such situation, delay in providing expected service is considered to have direct impact on customer satisfaction (Brignall and Ballantine, 1996; Fitzsimmons and Fitzsimmons, 2006).

The planning and scheduling manpower for service maintenance system plays important role to provide services at different locations for effective outcome. The manpower has direct impact on scheduling and outcome of maintenance service but not many researchers incorporated them in the simulation model (pp. 172, Alrabghi and Tiwari, 2015). This paper considers the electrical maintenance department that provides maintenance services to various hostels of a large educational institute. This department rectifies the various types of electrical faults (minor to major type) occurring in various hostels. Aim of the department is to quickly rectify the electrical fault and provide desired service level to their customers i.e. residents of hostels. However, electrical maintenance department is facing a challenge in terms of deciding appropriate staff in each shift in order to meet stochastic demand of maintenance requests. This paper considers the stochastic nature of complaint arrival and processing times to rectify faults and attempts to decide appropriate staffing level while meeting the desired customer service level. This problem cannot be solved using existing Operations Research techniques due to stochastic demand and processing times for different types of complaints and complex processing routines. This paper analyzes the trade-off between utilization of maintenance crew and waiting time of customers. Electrical maintenance department was looking forward to improve the utilization of maintenance crew without sacrificing the acceptable waiting time of customers (i.e. complaints). Using simulation, the study models the electrical fault rectification process and evaluates the effect of various possible changes (as an alternative scenarios) in the current process on average waiting time and resource utilization. The objective of this study is to propose appropriate staffing policy in electrical maintenance department using simulation model to meet the following specific requirements.

- Resource utilization: To ensure that resources are used to their capacity.
- Minimize the average waiting time of complaints: To meet desired service level of customer.

The paper is structured in six sections. Section 2 briefly reviews the relevant literature pertinent to the study. The problem context, operation of electrical maintenance facility, and various steps in the fault rectification process are introduced in section 3. In the section 4, research methodology used in study including process, data collection, model development and various alternative scenarios is discussed in detail. Section 5 presents the findings of simulation model. Finally, Section 6 concludes the study.

2. Literature review

Maintenance department possesses characteristics of a service company (Mjema, 2002). Typical features of a service company include the variation in the demand of service from month to month and sometimes also from day to day (Aggarwal, 1982). In addition, the change from one demand level to another demand level can be within very short time interval (Mjema, 2002).

Customer waiting is regarded as one of the most critical aspects of service quality. A customer waiting in line for service is potentially a lost customer (Sheu et al., 2003). According to Zhao et al. (2014), the waiting experiences are typically considered to have negative influence on customers' overall satisfaction with the products and services, so the importance of proper management of customer waiting time is of significant interest to most organizations. Managers have made efforts not only to reduce actual waiting time, but also to explore new ways of improving customer satisfaction with a given waiting time. The way in which the service process is designed determines, to a large extent, the wait that customers experience. Any reductions in customer waiting time by better management of process design can certainly help lower both customer dissatisfaction and defection (Davis and Heineke, 1998; Taylor, 1994).

Duffuaa et al. (2001) describes the maintenance as a complex process that is triggered by equipment failure or planned repair. This process requires planning, scheduling, control and the deployment of maintenance resources to perform necessary maintenance activities. Maintenance has a major impact on delivery, quality and cost. It plays a key role in the long-term profitability of an organization in the private or public sectors.

Industrial enterprises are faced with increasing costs of their maintenance departments. The costs of maintenance represent 15% to 40% of the goods produced depending on the type of the industry (Mobley 1990). According to Luczak and Mjema (1999), it is important to pinpoint the predominant cost center that is the maintenance personnel in order to reduce the increasing costs of maintenance. Therefore, the determination of personnel capacity requirement in maintenance plays an important role in the reduction of operating costs within the whole production system.

Maintenance staffing management is an interesting and important problem in manufacturing system. Maintenance labor could contribute as high as 80% of the total maintenance cost. Therefore, accurate estimation of labor force becomes crucial (Chang et al., 2007). They further state that the questions of the maintenance workforce planning include how to decide the appropriate staffing level corresponding to the dynamic workforce load over time, and how to maintain absolute levels of staffing despite the constantly changing maintenance demands. Accordingly, they mention that the maintenance workforce planning has to satisfy long-term maintenance request on one hand, and also respond to the demand changes quickly to maximize the throughput of a production system on the other hand.

Few authors in literature have used simulation tool to model the maintenance manpower planning. Duffuaa and Andijani, (1999) outlines the elements of an integrated simulation model for the maintenance system at an airline company in the case of SAUDIA. The model consisted of several modules that were linked through the interaction of the maintenance activities. Yan et al. (2004) studies the airline maintenance manpower supply planning problem where they consider technicians with multiple maintenance certificates, three flexible strategies and the related operating constraint to develop a set of models that can help an airline find an effective maintenance manpower supply plan. Ntuen and Park (1999) develop a simulation model to estimate the level of maintenance crew size required in a maintained reliability system (MRS) due to its stochastic nature. They found that number of unplanned repairs affects the crew size in a typical production system and predicting such unplanned repairs with precision is difficult. Al-Zubaidi and Christer (1997) develop a building maintenance manpower simulation model within the case context of a specific hospital complex to investigate the potential gain to be realized using different manpower management and operational procedures. Allowance was made for daily variation in demand for maintenance, sickness and holiday pattern, and the characteristic of different trades.

The workload in the maintenance department is characterized by high fluctuation in demand for the maintenance personnel. The arrival of the maintenance work order is stochastic such that it is difficult to plan the personnel requirement by certainty (Mjema, 2002). Such complex systems lend themselves to the use of simulation for proper modeling and analysis. Moreover, the numerous factors mentioned do not build a direct relationship with regard to the determination of the capacity requirement (Mjema, 2002). Therefore, it is not possible to use mathematical analysis to investigate the effects of these factors on the capacity requirement.

It is concluded from the above literature review that maintenance manpower planning problem is not widely studied. However, maintenance manpower contributes significantly to the total maintenance cost. The manpower planning is difficult due to complexity of the maintenance system. The maintenance system can be considered as service system where-in focus should also be on increasing customer satisfaction by improving service level while minimizing the waiting time of the customers. However, applying optimization or mathematical models in maintenance system is difficult due to stochastic nature of request arrival and repair times. Hence, simulation was widely used in the literature to study to arrive at suitable maintenance manpower staffing.

This research considers a manpower planning of electrical maintenance activities of various hostels of a large institute and aim to reduce the waiting time of the customers and plans the staffing differently during peak season and non-peak season. This section has briefly reviewed the literature specific to maintenance manpower planning. The next section describes the operation of electrical maintenance service facility (EMSF).

3. Operation of electrical maintenance service facility (EMSF)

Electrical maintenance service facility (EMSF) is an entity that repairs all the electrical faults occur in the 14 hostels spread over approximately 500 acres campus of a large educational institute. Institute insists on 24 x 7 availability of electricians in EMSF to attend any emergency occurs from electrical faults. The EMSF has recruited electricians and helpers and works as continuous operation system. Even when there are hardly any complaints from the hostel during night, EMSF needs to assign a pair of electrician and helper in the night shift. The entire process of rectifying the electrical fault encompasses the following operations as represented in Figure 1:

Insert Figure 1 here

Arrival of complaints: In the event of electrical fault, concerned person from hostel registers a complaint to EMSF over telephone. The details of a complaint generally recorded in main complaint book by EMSF staff are complaint number, date, time of arrival, hostel number, room number or location where the fault occurred and type of fault. The EMSF staff also records these details in respective hostel service book. The pair of electrician and helper carries the hostel service book during their visit to respective hostel to resolve the fault. The number of complaint from the same hostel are pooled together during visit. However, in general, they attend all the complaints on first come first serve (FCFS) basis. Some complaints that affect the large community of hostel such as power failure etc. are given the top priority.

Assignment of electricians: As soon as available, the pair of electrician and helper are assigned to respective hostel on first cum first serve (FCFS) basis. The **Table 1** shows the scheduling of electricians and helpers in four different shifts. Further, EMSF has additionally one pair of electrician and helper to manage weekly-off of all the employees. The assignment of employees to specific shift and weekly-offs are decided on mutual discussion among employees. During each visit, the pair of electrician and helper goes walking to hostel with electrical tool box, spare parts and respective hostel service book. Once the complaint is resolved, they return to EMSF and visit the next assigned hostel.

Insert Table 1 here

Fault detection and rectification: Once the pair of electrician and helper reaches the appropriate location of hostel where fault occurred, they identify the reason of fault and repair and/or replace new part if required. The duration of time spent on each fault is the function of the type of fault and complication involved in the electrical problem. Once the fault is rectified, electrician notes down the date, time and time spent to attend the complaint in the hotel service book and subsequently in main complaint register. It is to be noted that time required to repair varies significantly from 5 minutes to 1 hour based on the characteristics of complaints.

The hostel community judge the performance of EMSF based on the time they generally need to wait before pair of electrician and helper attend the fault. Nevertheless, institute emphasizes the resource availability for EMSF facility as this facility is outsourced to a service provider on contract basis. Institute needs to prepare annual plan which includes resource planning, shift scheduling and framing a cost contract for EMSF and other similar departments. The management requires the convincing facts on justifying these decisions and associated budget. However, as discussed, the entire process of handling and rectifying the fault includes very complex process due to stochastic nature of the arrival and service processes which cannot be handled by any quantitative techniques. Further, management is not interested in experimenting various options in real life and interfere the system like EMSF as it has direct impact on large community. This makes simulation very applicable tool to experiment various options as these options can be evaluated within short time without interfering the real system. Institute also wishes to setup uniform resources across the year as it is very difficult to vary resources even for handling seasonality without sacrificing service. However, management is open for short term options which need not really change resource level for handling any seasonality.

4. Research methodology

Considering electrical maintenance fault rectification as a service process, EMSF is a particular case of service operations. As service provided by EMSF is perishable in nature, the performance of EMSF system depends mostly on the level of uncertainty involved in arrivals of complaints from hostels. In such system, rough cut capacity analysis must make sure that service capacity is at least equal or more than demand. This analysis before getting into simulation model can provide rough estimate of minimum resource capacity to meet demand from the service facility. However, it is difficult to predict the optimum service capacity due to uncertainty and randomness in arrival patterns. As service capacity is perishable in nature, there are number of instances where server (electricians) is idle while other time there is a long queue of customers (complaints) waiting in line.

The given situation includes several hostels along with the different types of complaints with random arrivals. The nature of complaints also varies based on the characteristics of faults and so the time required to rectify them. The number of resources vary during a day due to overlap of shift timings. The arrival pattern also varies across the day as more complaints are received during a day shift as compared to night shift. The location and the distances of hostels from EMSF varies, leading to variable time to reach and attend the complaints at different hostels by electricians. The situation includes non-deterministic elements such as inter-arrival times, arrival from different hostels, types of fault, resources walking time to various hostels, service time for various faults. The situation presented in the paper seems to be complex to model and difficult to analyze using other techniques like queuing model than simulation. Simulation provides a better scope of modelling such real life complex system while experimenting alternative scenarios (what if analysis) and evaluates the performance of system (Duffuaa and Andijani, 1999; Law and Kelton, 2003; Alabdulkarim et al., 2014; Alrabghi and Tiwari, 2015).

The simulation model has been developed for the EMSF operations to optimize the various performance measures such as waiting time of customer, utilization of service capacity etc. The various steps performed in this simulation study are as per the methodological approach proposed by Banks et al. (2001).

4.1 Input data collection

The necessary information for the model was collected from electrical maintenance service facility (EMSF) by interacting with supervisor, electricians and helpers who are well aware of complete operations of EMFS system and electrical fault rectification process. The aim was to get familiarize with complete process, to understand the required data point at different steps of the process and possible sources of data collection. The main complaint book and hostel service books were identified as key sources of data.

Arrival data of complaint was collected from main complaint book for each complaint. It includes date of complaint, time of complaint, type of faults and hostel number as shown in **Table 2**. The number of complaints received by EMSF is seasonal with its peak demand falling in two months (i.e. in July and August when academic session begins). Hence, data of both the periods (referred as peak and normal) was collected and analyzed separately to identify the suitable distribution. The data of fifteen days was collected for both the periods. In order to determine the arrival distribution, the inter-arrival time between two complaints were calculated for all the complaints sequentially from first to last complaint. This times were then used and analyzed to identify the appropriate statistical distribution that satisfies characteristics of identified distribution (Banks et al., 2001; Law and Kelton, 2003). The Input Analyser in the Arena simulation software was used for fitting the appropriate distribution. The distribution of peak and normal period are shown in **Table 2** along with the proportion of these complaints from various hostels. The proportion of complaints shows the percentage of complaints for a respective hostel from total number of complaints received in EMSF.

Insert Table 2 here

The service time is the actual time spent by a pair of electrician and helper for rectifying the electrical fault. This time was available for each complaint from hostel service books. Based on the fault analysis, it was observed that complaints varies based on service time, characteristics of faults, priorities and frequency. Finally, based on frequency of complaints, the complaints are classified into four categories as shown in **Table 3.** Respective service time distributions along with their proportions are identified using Input Analyzer. The service distribution for each complaint type was determined using the data of time spent on each complaint type. In the simulation model, the complaint created was further classified into complaint type using the distribution given in Table 3. The 'hostel major' type of complaint is given the first priority and other types of complaints are attended on FCFS basis. Additionally, the walking time to various hostel by pair of electrician and helper were also estimated based on the distance of each hostel from EMSF. These were found to be uniformly distributed.

Insert Table 3 here

4.2 Simulation software for model

A discrete event simulation model was developed for EMSF system in the ARENA. The model was prepared using available libraries and entities for mapping different EMSF processes. The advantage of simulation software was its ability to provide flexibility in various scenarios analysis, computational time efficiency without intervening the ongoing real system and interactive graphical user interface (Alrabghi and Tiwari, 2015). A step by step effort was made to understand the process of incorporating the EMSF real behavior in simulation software.

4.3 Performance of EMSF simulation modeling

There are numerous measures available for analyzing service system performance as discussed in the literature (Parida and Kuma, 2006). Based on the observations and resulting interaction with the stakeholders, the two major important performance measures were identified as following:

i) Average waiting time in the queue for complaints: T_q
ii) Utilization of servers (i.e. electricians): ρ

The waiting time of each complaint is the duration of time (in minutes) between arrival and resolving the complaint while average utilization of electrician is the ratio of total time spent by an electrician attending complaints to length of shift (i.e. total working hours). The average value of both the measures was computed by running the simulation for 15 days.

4.4 Simulation model development

The various modules related to complaint creation, electrician creation, complaint resolution, complaint and electrician exits were prepared in the Arena. The integrated graphical interface of the modules are shown in **Figure 2**. The detail description of major modules are provided below:

Insert Figure 2 here

Complaint creation and distribution logic: This part of the model generates the complaints as per arrival distribution as given in Table 2. As soon as a complaint is generated, it is assigned to the 14 hostels depending upon proportions given in Table 2. The assigned complaint then moves to the respective hostel sub-logic model. There are fourteen such hostel sub-logic units depicted in Figure 2. The detail of the module and graphical interface of the Arena are provided in Figure 3. Generally, the hostel community registers the complaint between 8 am to 12 am at EMSF even if the fault occurs in other time duration except major fault such as power failure. The proportion of such faults are two percentages.

Insert Figure 3 here

Electrician creation and assignment logic: The electrician is generated in EMSF department as per respective shift timings and schedule provided in Table 1. There are total four shifts including general shift. The electrician exits the entire system after eight hours or immediately after attending complaint in hand in case eight hours shift is over. As soon as complaint are generated and subsequently assigned to the specific hostel by complaint creation logic, an electrician is assigned to that hostel. The electrician then walks to the assigned hostel with FCFS basis with first priority given to Hotel Major type of complaint. Empirical distribution of walking time to and from the respective hostels was also used and modeled in the Arena. The electrician remains in the EMSF when there is no pending complaint in the system till completion of 8 hours. The module of this complete process is shown in Figure 4. As an important feature of the Arena, report captures and determines the averages with statistical confidence interval of all the details of electrician such as time spent on walking, fault repair, total time spent etc. in EMSF integrated system.

Insert Figure 4 here

Hostel sub-model logic: There are fourteen hostels on the campus and hostels have similar hostel sub-model logic for handling the complaints. The representation of such hostel sub-logic module are provided in Figure 5. As described earlier, once the complaint is assigned to respective hostel from complaint assignment module, it reaches hostel sub-model logic. Each complaint is then categorized into hostel major, hostel minor, room major or room minor type as per the proportion given in Table 3 and waits till the electrician arrives. Immediately after this, the electrician is assigned to the complaint. The electrician checks the priority and rectifies the fault as per the priority and FCFS rule. The complaint exits the system after resolving the fault. However, complaints assigned to the respective hostel remains pending till the time the electrician attends to them. Latter, electrician walks back to the EMSF department. The time required to rectify the various complaint types were determined using the probability distribution of service time for each type of complaint as shown in Table 3. The Arena report collects the data of time spent by complaint from the time of its creation to time of its resolution. The report determines the average time of waiting with associated confidence interval for the complaints.

Insert Figure 5 here

4.5 Model verification and validation

Verification deals with determining whether the conceptual simulation model has been correctly translated into computer program (Law and Kelton, 2003; Kleijnen, 1995). Verification was established by evaluating input and output parameters of each sub-model (i.e. complaint arrival, electrician arrival, hostel sub-model etc.) with step by step addition as an individual module and as integrated system of all modules. Validation is the process of determining whether a simulation model is accurate representation of the system (Law and Kelton, 2003; Kleijnen, 1995). After developing the simulation model, output data were compared with some sample of existing real life system for validation. Some preliminary results of output and animation of simulation was also shown to EMSF personnel to confirm its validity.

4.5 Alternative scenarios

There is a tradeoff between efficiency of service system and service level provided to customer. Accordingly, this work experiments alternative scenarios by varying number of shifts and working hours while assuring the desired service level.

Two separate models, one for normal and another for peak demand, were developed by removing the general shift and adding one hour overtime respectively. One cannot talk about possibility of improving performance unless some benchmark is available. Therefore, current performance of the EMSF system is measured for both normal and peak periods for 15 days using 10 replications. The performance measures considered were average waiting time of complaints in the queue (T_q) and average utilization of electricians (ρ). The ARENA model was first developed for normal period using the given data. The model for peak period was developed by changing the arrival distribution of the complaints in the model developed for the normal period. This was possible as the difference in both the periods was only the arrival pattern leading to different form of distribution for complaints.

The EMSF is a non-stop system. Therefore, it is termed as a non-terminating simulation system. In order to get 95% statistical confidence interval for average waiting time of complaints, simulation model was run for 15 days with 10 replications.

5. Simulation Results and Discussion

Simulation model was run by making appropriate changes in different scenarios. The model outputs reflect the performance measures before and after the changes in both normal and peak period of EMSF model. Normal period includes one scenario while peak period considers two scenarios. The only change in peak period scenarios was distribution of arrival rate of complaints.

The decision of analyzing alternative scenarios one after another was to decide the optimum number of resources i.e. proposing the system which serves in both the normal and peak periods by meeting the required service level with appropriate resource utilization. The proposed changes in the form of alternative scenarios were decided by analyzing the current performance of EMSF. **Table 4** shows the simulation results for average waiting time (T_q) with 95% confidence intervals for both normal and peak period for different scenarios. The resource utilization results are also shown for different scenarios in **Table 5**. The results provides the average time (in hours) and percentages details of fault rectification time, walking time of resources from EMSF to and from hostel, total time spent in the shifts.

Insert Table 4 here

The average waiting time (T_q) for complaints is 20.22 minutes (16.5 to 23.94 with CI of 95%) currently in the normal period. In the alternative scenario, the general shift was removed observing very low resource utilization of 20.55%. The results show the average waiting time (T_q) for complaints changes to 31.86 min (27.66 to 36.06 with CI of 95%) with improvement in average resource utilization to 35.85%. The minimum utilization of resources are in the third shift i.e. 6 %. This is a night shift when very few number of complaints are received from customers. The institute makes it compulsory to keep 24 hours availability of resources for meeting services of all the hostels. It is possible to manage system with three shifts during normal period by removing general shift. The performance of alternative scenario meet the customer expected average waiting time of two hours before electrician attends the complaint. Further, the average utilization of resources also improve without scarifying customer service and still meeting the institute norms.

Insert Table 5 here

In the peak period, number of complaints registered in EMSF are significantly higher than normal period. The average waiting time (T_q) for complaints is 45 minutes (41.10 to 48.96 with CI of 95%) and resource utilization of 65% in the present situation of peak period. In order to make potential changes consistent for both normal and peak periods, this work evaluates only three shifts by removing general shift in peak period as well. However, the average waiting time (T_q) increased significantly exceeding 2 hours requirement (109.80 to 126.60 with CI of 95%). Further, the resource utilization increased to 99% in the first two shifts. This reflect the performance measures deterioration than expected level. The peak period time lasts for 2.5 months immediately after students' admission. Therefore, the overtime of 1 hour was added for the peak period as an alternative scenario to adjust performance at desired level. In alternative scenario, the average waiting time for complaints using three shifts and additional one hour overtime is 88.80 minutes (84.00 to 93.60 with CI of 95%) with resource utilization of 74%.

It is seen from the **Table 5** that walking time for electricians is more than 50% of value added time spent in fault rectification time. For example, time spent in walking during peak period is more than 25% of total time spent by electrician in EMSF department. Any effort towards reducing such non-value added but necessary activity can significantly improve average waiting time of complaints and efficiency of electricians.

The modeling the various scenarios for both normal and peak period, it is seen that the utilization of electricians can be improved further without scarifying desired service level (T_q = 2 hours) customers. It is proposed that EMSF can provide the desired service to customers operating in three shifts by removing the general shift from current system. This improves the overall utilization to 35.98% from current average of 20.55%. The same shift pattern can be used during peak period to make system consistent throughout the year. The results show that the average waiting time exceed 2 hours due to large number of complaints during peak period. The model suggests to use of overtime in the first two shifts. This will make sure that that shift pattern remains same through the year. The walking time of electricians seems to be very significant. Therefore, it is suggested that bicycles can be used by the electricians for traveling to and from all the hostels. This will increase the physical efficiency while improving the service level of customers.

6. Conclusions

The research demonstrated the applicability of the simulation tool as an effective decision support tool in modeling, evaluating and selecting the alternative scenarios in order to improve the performance of electrical maintenance service system. It investigated the resource-planning problem in real-life electrical maintenance facility to meet the desired service level to customers. The study helped to make use of simulation to experiment various feasible options that were evaluated within a reasonable time without interfering the real system.

The analysis of the results indicated that EMSF system could meet two hours average waiting time (CI of 95%) for both normal and peak period by working in just three shifts. In order to meet the required service level in peak period, alternative scenario with one-hour overtime keeping same level of resources for the entire year was emerged as better option. Further, simulation model helped to find percentages of time spent on value added (i.e. fault repairing) and non-value added (i.e. walking) activities. It was found that percentage of time spent on value added activities was less than 50 percentages. This amount provides the top management, the significance and possible directions towards identifying appropriate actions to reduce amount of time on non-value added activities to make maintenance service very effective and efficient. The considerable percentage of time was spent in non-value added activity i.e. walking to various locations of complaints. The arrangement of bicycle or motorized vehicle could reduce walking time and improve resource availability and thus it could further reduce average waiting time of customers. The results supported the potential of implementing suggested changes for overall improvement of electrical maintenance service facility.

The limitation of the study is that the model does not consider the cost indicators of the system. The future studies can also consider the similar research approach in other services of estate department in the institute. The study can also be extended to analyze the tradeoff between resource utilization and service level. Finally, the proposed method of simulation contributes to literature, the effective and systematic way of modelling highly complex system like maintenance.

Acknowledgement

The authors are thankful to anonymous reviewer for their valuable comments, which improved the quality of the paper.

References

Aggarwal, S. C. (1982), “A focussed review of scheduling in services”, European Journal of Operational Research, Vol. 9 No. 2, pp. 114-121.

Alabdulkarim A. A., Ball, P. D. and Tiwari, A. (2014),"Influence of resources on maintenance operations with different asset monitoring levels", Business Process Management Journal, Vol. 20 No 2, pp. 195-212.

Alrabghi, A. and Tiwari, A. (2015),"State of the art in simulation-based optimization for maintenance systems ", Computer and Industrial Engineering, Vol. 82 No. 2, pp. 167-182.

Al-Zubaidi, H. and Christer, A. H. (1997), “Maintenance manpower modelling for a hospital building complex” European Journal of Operational Research, Vol. 99 No 3, pp. 603-618.

Banks, J., Carson J. S, Nelson, B. L. and Nicol, D. M. (2001), Discrete-event system simulation, 3rd ed., Pearson Education, Delhi.

Brignall, S. and Ballantine, J. (1996), “Performance measurement in service businesses revisited”, International Journal of Service Industry Management, Vol. 7 No. 1 pp. 6-31.

Chang, Q., Ni, J., Bandyopadhyay, P., Biller, S. and Xiao, G. (2007), “Maintenance staffing management”, Journal of Intelligent Manufacturing, Vol. 18 No 3, pp. 351-360.

Davis, M. M. and Heineke, J. (1998), “How disconfirmation, perception and actual waiting times impact customer satisfaction”, International Journal of Service Industry Management, Vol. 9 No. 1, pp. 64-73.

Duffuaa, S. O., Ben-Daya, M., Al-Sultan, K. S. and Andijani, A. A. (2001),"A generic conceptual simulation model for maintenance systems", Journal of Quality in Maintenance Engineering, Vol. 7 No. 3, pp. 207-219.

Duffuaa, S. O. and Andijani, A. A. (1999), “An integrated simulation model for effective planning of maintenance operations for Saudi Arabian Airlines (SAUDIA)” Production Planning and Control, Vol. 10 No. 6, pp. 579-584.

Fitzsimmons, J.A. and Fitzsimmons, M.J. (2006), Service Management: Operations, Strategy and Information Technology, McGraw-Hill, New York, NY.

Greenwood, G. and Gupta, A. (2000), “Workforce constrained preventive maintenance scheduling using evolution strategies”, Decision Sciences, Vol. 31 No. 4, pp. 833-59.

Kleijnen, J. P. C. (1995), “Verification and validation of simulation models”, European Journal of Operational Research, Vol. 82 No. 1, pp. 145-162.

Luczak, H. and Mjema, E. (1999), “Quantitative analysis of the factors affecting personnel capacity requirement in maintenance department” International Journal of Production Research, Vol. 37 No 17, pp. 4021–4037.

Law, A. M. and Kelton, W. D. (2003), Simulation modeling and analysis, 3rd ed., Tata McGraw-Hill, New Delhi.

Mjema, E. (2002), “An analysis of personnel capacity requirement in the maintenance department by using a simulation method” Journal of Quality in Maintenance Engineering, Vol. 8 No 3, pp. 253–273.

Ntuen, C. A., and Park, E. H. (1999), “Simulation of crew size requirement in a maintained reliability system”, Computer and Industrial Engineering, Vol. 37 No. 1-2 pp 219-222.

Parida, A. and Kumar, U. (2006),"Maintenance performance measurement (MPM): issues and challenges", Journal of Quality in Maintenance Engineering, Vol. 12 No. 3, pp. 239-251.

Sheu, C., McHaney, R. and Babbar, S. (2003), “Service process design flexibility and customer waiting time”, International Journal of Operations and Production Management, Vol. 23 No. 8, pp. 901-917.

Sloan, T.W. and Shanthikumar, G. (2000), “Combined production and maintenance scheduling for a multiple product single machine production system”, Production and Operations Management, Vol. 6 No. 4, pp. 379-99.

Swanson, L. (2001), “Linking maintenance strategies to performance”, International. Journal of Production Economics, Vol. 70 No. 3, pp. 237-244.

Taylor, S. (1994), “Waiting for service: The relationship between delays and evaluations of service” Journal of Marketing, Vol. 58 No 2, pp. 56-69.

Yan, S., Yang, T. H., and Chen, H. H. (2004), “Airline short-term maintenance manpower supply planning”, Transportation Research Part A: Policy and Practice, Vol. 38 No. 9-10, pp. 615-642.

Zhao, X., Hou, J., and Gilbert, K. (2014), “Measuring the variance of customer waiting time in service operations”, Management Decision, Vol. 52 No. 2, pp. 296-312.

Biographies

Sanjay Choudhari is an Assistant Professor in Operations Management and Quantitative Techniques area at Indian Institute of Management Indore. His research areas include manufacturing strategy, application of optimization and simulation in operations and supply chain management. He has published his works and cases in International Journal of Production Research (IJPR), International Journal of Operations and Production Management (IJOPM), Asian Case Research Journal (ACRJ) and Asian Journal Management cases (AJMC). Previously, He was associated with National Institute of Construction Management and Research, Pune. He can be contacted at: sanjay.274@gmail.com

Hasmukh Gajjar is an Associate Professor in Operations Management and Quantitative Techniques area at Indian Institute of Management Indore India. His research interests include retail operations, modeling and optimization. He has published his research work in the leading journals like Annals of Operations Research, Asia-pacific Journal of Operational Research and International Journal of Retail & Distribution Management. He can be contacted at: hasmukh@iimidr.ac.in

Table 1: Shift schedule

Shift type	Shift timing	Assignment
General Shift	10 am to 06 pm	Pair of electrician and helper in each shift
1st Shift	08 am to 04 pm	
2nd Shift	04 pm to 12 am	
3rd Shift	12 am to 08 am	
Total employees: 1 supervisor 1, 5 electricians and 5 helpers Source of data: EMSF staff		

Table 2: Arrival data of complaints

Arrival distribution		
Period	No of complaints in 15 days period	Type of arrival distribution (min)
Peak period	555	-0.001 + 119 * BETA (1.37, 4.52)
Normal period	173	-0.001 + WEIB (69.7, 0.721)

Proportion of complaints from respective hostels													
H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14
10%	8%	9%	5%	5%	10%	5%	5%	10%	4%	10%	6%	6%	5%

Data source: main complaint book
Data of each complaint: complaint serial number, date of arrival, time of arrival, hostel number, location of compliant i.e. room no, nature of complaint

Table 3: Service data

Complaint types	Service time distribution (min)	Proportions
Hostel Major	TRIA(15, 40, 70)	7%
Hostel Minor	4.5 + 46 * BETA(0.915, 1.6)	42%
Room Major	TRIA(14.5, 32, 45.5)	8%
Room Minor	4.5 + 36 * BETA(1.03, 1.52)	43%
Data source: hostel service book Data of each complaint: complaint serial number, date of fault repair, time of fault repair, location of compliant i.e. room no, time spent on complaint, nature of complaint		

Table 4: Average waiting time and resource utilization

Average waiting time for complaint (in minutes)					
Period	Scenario	Improvement	Average waiting time (Ta) minutes	95% CI (minutes)	
Normal	N0	-	20.22	23.94	16.5
	N1	Without General shift	31.86	36.06	27.66
Peak	P0	-	45.06	48.96	41.10
	P1	Without General shift	118.20	126.60	109.80
	P2	Without General shift + Over Time	88.80	93.60	84.00

Table 5: Average resource utilization in hours (hrs) and percentage (%)

Scenario	Scenario N0: Current performance , normal period						Scenario P0: Current performance , peak period					
	Fault rectification time		Walking time		Total time spent in shift towards compliant		Fault rectification time		Walking time		Total time spent in shift towards compliant	
	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%
General	1.07	13.18	0.75	9.18	8.13	22.36	3.29	40.40	2.33	28.54	8.15	68.94
Shift 1	1.04	12.90	0.83	10.22	8.112	23.12	3.93	47.95	2.43	29.72	8.19	77.67
Shift 2	1.48	18.42	0.99	12.25	8.05	30.67	4.22	50.23	2.66	31.60	8.41	81.83
Shift 3	0.31	3.87	0.17	2.15	8.04	6.02	1.65	20.61	0.91	11.39	8.01	32.01
Average	**0.9775**	**12.10**	**0.6831**	**8.46**	**8.0777**	**20.55**	**3.27**	**39.98**	**2.08**	**25.430**	**8.19**	**65.41**
Scenario	Scenario N1: Performance without general shift, normal period						Scenario P1: Performance without general shift, peak period					
	Fault rectification time		Walking time		Total time spent in shift towards compliant		Fault rectification time		Walking time		Total time spent in shift towards compliant	
	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%
General	-	-	-	-	-	-						
Shift 1	2.58	31.60	1.64	20.01	8.17	51.61	4.82	57.12	3.03	35.85	8.45	92.97
Shift 2	2.47	30.49	1.54	18.98	8.11	49.47	5.91	68.68	2.64	30.70	8.59	99.39
Shift 3	0.32	3.95	0.19	2.43	8.01	6.38	2.95	36.49	1.66	20.53	8.08	57.02
Average	**1.79**	**22.11**	**1.12**	**13.87**	**8.09**	**35.98**	4.56	54.44	2.44	29.16	8.37	83.60

Scenario	Scenario P2: Performance without general shift + 1 hours overtime, peak period					
	Fault rectification time		Walking time		Total time spent in shift towards compliant	
	Time (hrs)	%	Time (hrs)	%	Time (hrs)	%
General	-	-	-	-	-	-
Shift 1	5.01	53.99	3.07	33.02	9.29	87.01
Shift 2	5.90	63.00	3.17	33.85	9.37	96.85
Shift 3	2.23	24.04	1.41	15.22	9.29	39.26
Average	**4.38**	**47.05**	**2.55**	**27.38**	**9.32**	**74.43**

Fault rectification time: This is time required by pair of electrician helper to repair electrical problem after attending complaint

Walking time: Time required to walk to various hostels from EMSF by pair of electrician helper

Total time spent in shift towards compliant: Fault rectification time + walking time but excludes idle time spent in EMSF when no complaints are pending

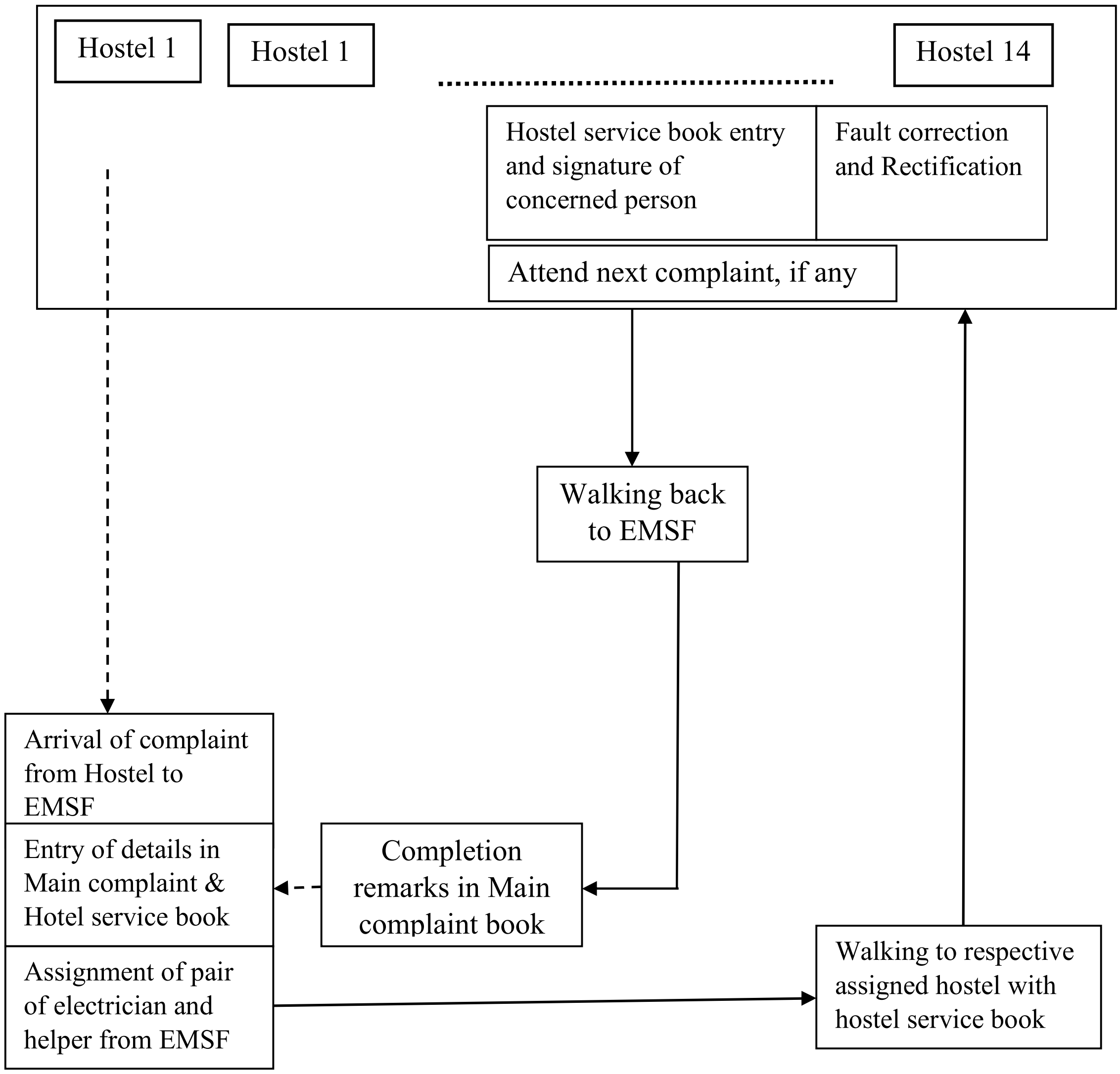

Figure 1: Process flow diagram for Electrical Maintenance Service Facility (EMSF)

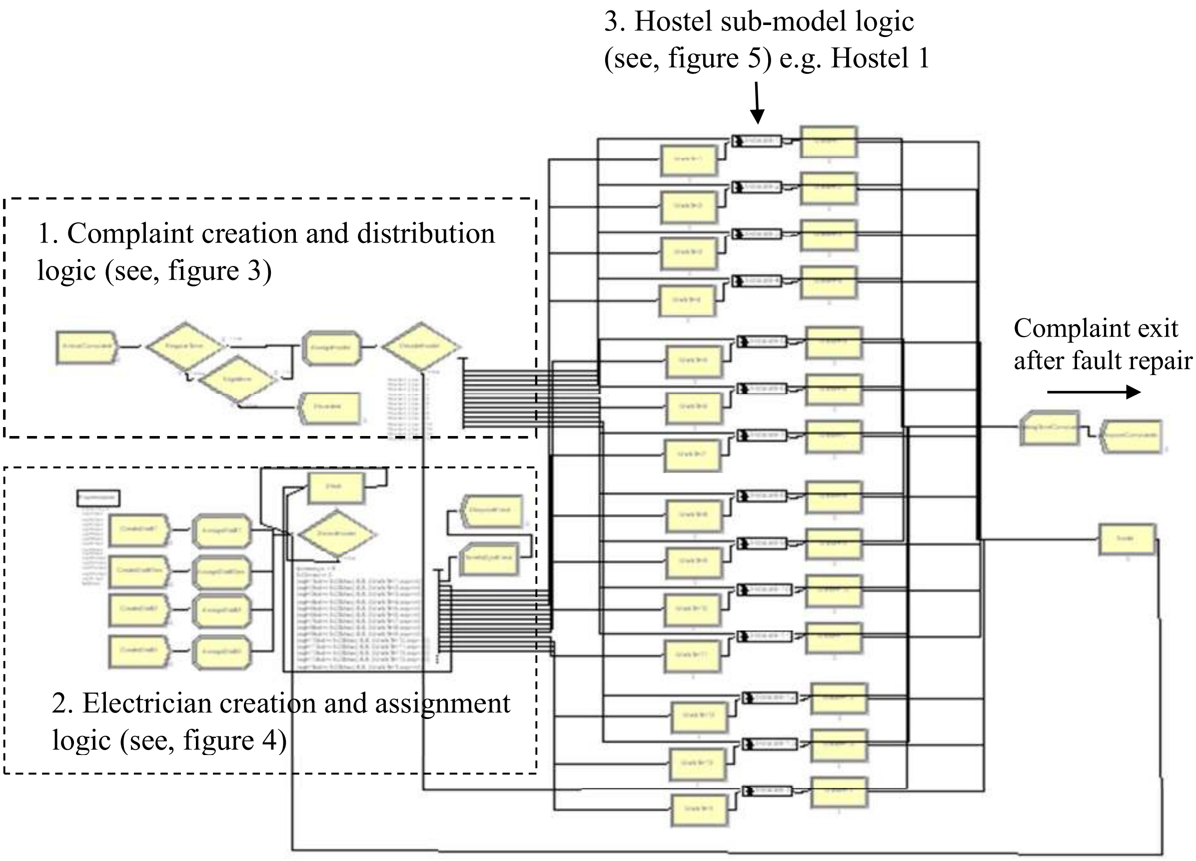

Figure 2: ARENA simulation model interface

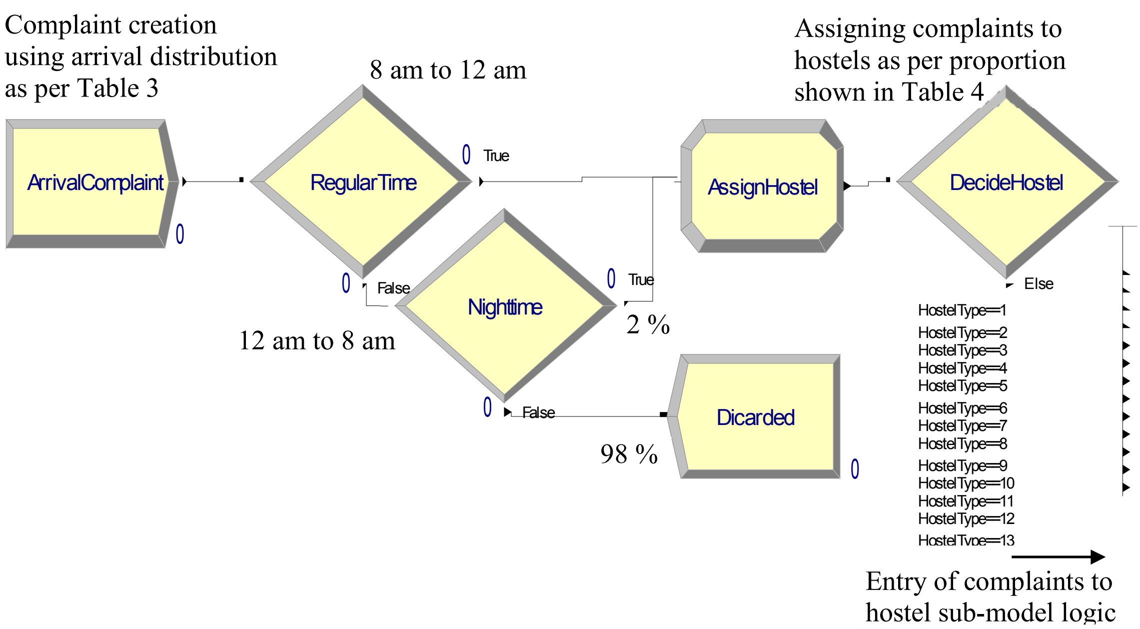

Figure 3: Complaint creation and distribution logic

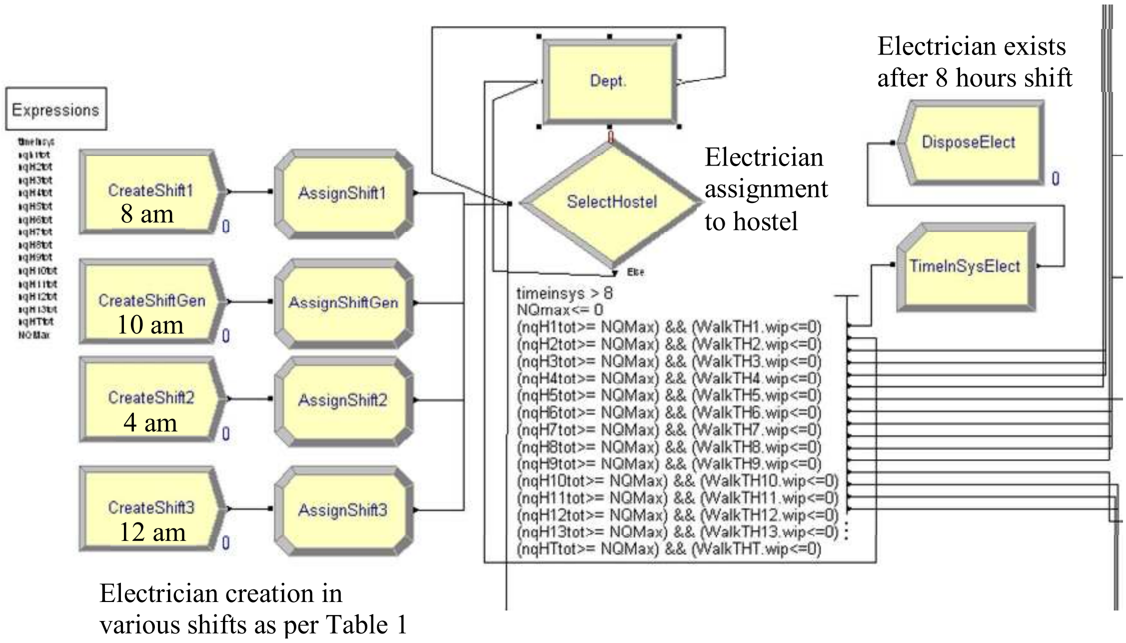

Figure 4: Electrician creation and assignment logic

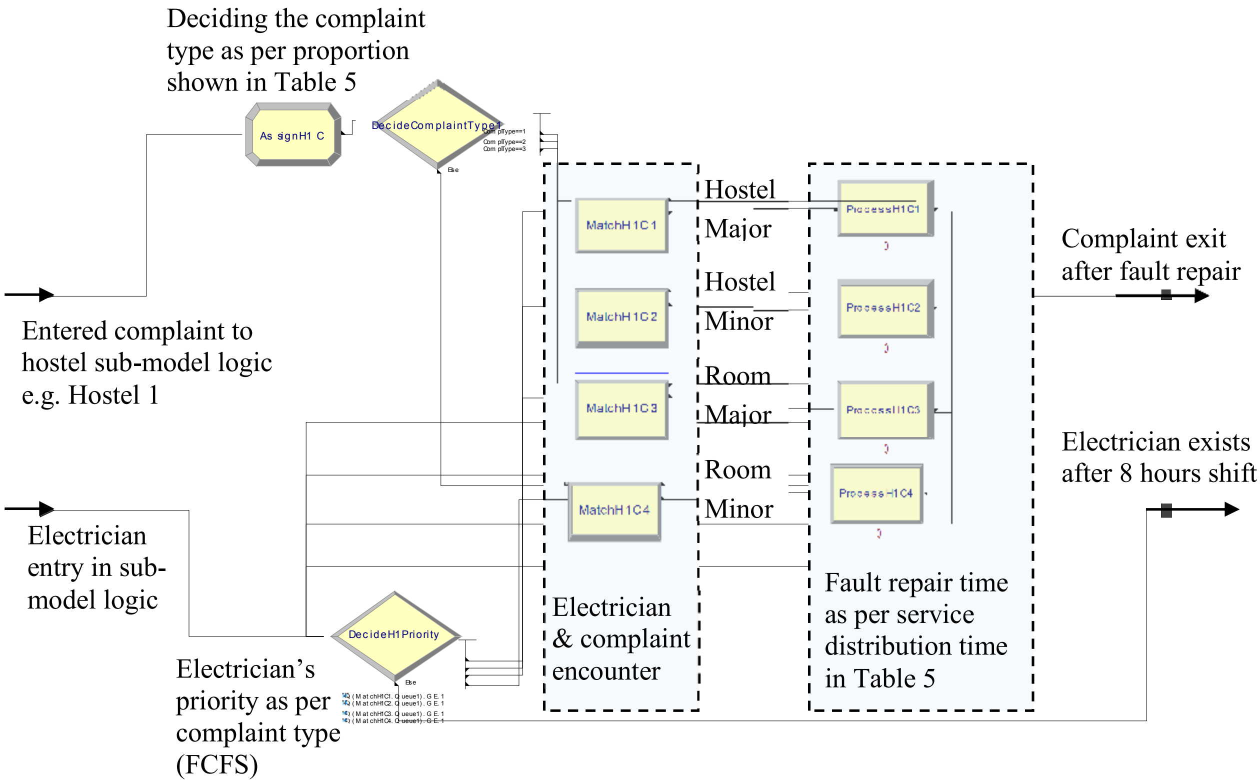

Figure 5: Hostel sub-model logic