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Decision Making in Improvement of Process and Staff Utilization in Medical Devices Maintenance System Using Simulation

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Abstract

The medical service providers brought services to their customers continuously and rapidly with a minimum level of cost during the last a couple of decades almost all around the World. Furthermore, quality level of medical devices maintenance processes of a medical supplier is very important to guarantee customer safety and satisfaction. The number and qualification of staff working in a maintenance team and organizational structure of the service provider affect the cost of maintenance. Therefore, process and staff planning become important issues in the medical devices maintenance processes of medical sector.

The purpose of the current study is to investigate maintenance processes of medical devices in a hospital in Jordan by using simulation method. The system performance indicators which are the number of customers served, waiting times and resource utilization rates are the main interest to be forecasted by collecting data from a local maintenance unit of the hospital in Jordan. First, an initial simulation model is developed to analyze the current status of the maintenance process. The questions to be answered are the structure of the current breakdown occurrences, the resource utilization rates and the number of defects repaired in a time interval. The simulation results suggest that a new staff structure is necessary in maintenance teams to improve customer Safety and satisfaction.

Key words: medical devices maintenance system (MDMS); Medical Devices Maintenance Department (MDMD); Prince Hamza Hospital (PHH).

Introduction

The medical industry is becoming quite complex with a huge capital investment being incurred on process automation to enhance the reliability of system. Invariably, the proper maintenance of such systems and the frequency of maintenance are some of the issues that are gaining importance in industry.

The production suffers due to failure of any intermediate system even for small interval of time. The cause of failure may be due to poor design, system complexity, poor maintenance, lack of communication and coordination, defective planning, lack of expertise/experience and scarcity of inventories.

Thus, to run a process plant highly skilled/ experienced maintenance personnel are required. For efficient functioning, it is essential that various systems of the plant remain in upstate as far as possible. However, during operation they are liable to fail in a random fashion.

The failed subsystem can however be inducted back into service after repairs/replacements. The rate of failure of the subsystems in the particular system depends upon the operating conditions and repair policies used.

A simulation analysis of the system under given operative conditions is helpful in forecasting the equipment behavior which further helps in design to achieve minimum failure in the system i.e. to optimize the system working.

A hospital is an integrated complex system comprising of various system: logistics, health care delivery system and maintenance systems like Medical Devices Maintenance System (MDMS).

The effectiveness of MDMS is mainly influenced by the availability, reliability and maintainability of the plant. The present paper provides an Arena simulation model for MDMS in Prince Hamza Hospital (PHH) to analyze availability.

Simulation is one of the most widely used decision aid tools due to its power, flexibility, and robustness. Particularly the Discrete Event Simulation (DES) can model and analyze the behavior of many real life processes such as business processes and manufacturing processes.

Some of the salient features of the proposed model are as follows:

- ❖ The proposed model provides an integrated analysis framework for performance evaluation of

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contracted, lab and field medical devices maintenance process.

- The proposed model combines a strong mathematical foundation with an intuitive graphical representation.

Literature review

The simulation studies for the staff planning and measurement of service efficiency have presented in production systems, health service systems, shopping centers, education and finance facilities, traffic systems etc. in service systems .

Some research has been presented for staff planning with alternative structures of simulation models and performance measures [1]. In maintenance engineering, a simulation model has been developed by using Arena for MDMS to improve medical devices reliability and availability.

The historical roots of simulation for the practice of skills, problem solving, and judgment are evident. Medical simulation in primitive forms has also been practiced for centuries; Physical models of anatomy and disease were constructed long before the advent of modern plastic or computers.

Medical education evolved during the 1900s from a simple apprenticeship to incorporating the learning of scientific principles. The introduction of human patient simulation toward the end of the 20th century was a major step in the evolution of health sciences education.

If we consider a simulation model development as a project, and if we have a structured systematic tool to support the simulation project, we believe that these problems could be managed.

Sheppard proposed a widely cited "40-40-20" simulation model development time rule which states that analyst's time should be distributed as follows for a successful simulation project: (1) 40% to requirement collection phase such as problem formulation, project planning, conceptual model development, and data collection; (2) 20% to model translation phase; (3) 40% to experimentation phase such as model verification, validation, implementation, and interpretation [2].

About preventive maintenance, a study at a distribution warehouse has been presented for a conveyor system. The integrating predictive maintenance strategies with production planning strategies have been used to reduce of downtime for the management of equipment breakdown and failure conditions by simulation with Arena. For instance, the downtime was reduced more than 50 % and work in process inventory was reduced more than 65 % [3].

An optimized maintenance design has been implemented to analyze the capability of an auto part manufacturing production system by using simulation. The maintenance scheduling procedures and their effects have been presented for the overall system performance. The results have been validated through real-life applications and this study has been demonstrated to help for manufacturing performance improvement [4].

Hence, for successful implementation of any simulation project, it is particularly important to have a right approach to the requirement collection and the experimentation phases. This paper intends to provide an integrated framework for those two phases in a simulation project.

3. The Case Study: Analysis of MDMS in PHH by Simulation

The purpose of this study is to investigate maintenance process of medical devices by using the Arena simulation software that is based on mechanisms of event-oriented simulation. The feature of event-oriented simulation is that each planned event has a time of occurrence and its occurrence causes a certain transition of status.

3.1 The Workflow of Maintenance Process in MDMS

A MDMS is analyzed systematically, two scenarios for working sequences are simulated and the mean process time per order and the mean quantity per order are compared. Consequently, the different allocation of resources and the best distribution of staff have been found for the individual scenarios.

A maintenance process workflow for a MDMS is presented. The customer requests and/or complaints are summarized in Figure 1 which represents the sources of problems which are failed medical devices from the lab or the field of PHH.

In this point, some medical devices are maintained by the local agent because of being under the warrantee; remaining devices are transferred to maintenance teams.

Three different categories of maintained devices are placed in the system as follows:

- Scrapped medical devices, in which case they can't be repaired and they are to the scrape section in the main store.
- The medical devices that don't need spare parts to be repaired, in which case we start the maintenance process immediately and repair the device.
- The medical devices that need spare parts to be repaired, in which case we get the required spare part either from main store or from the local agent, and we then start the maintenance process and repair the device.

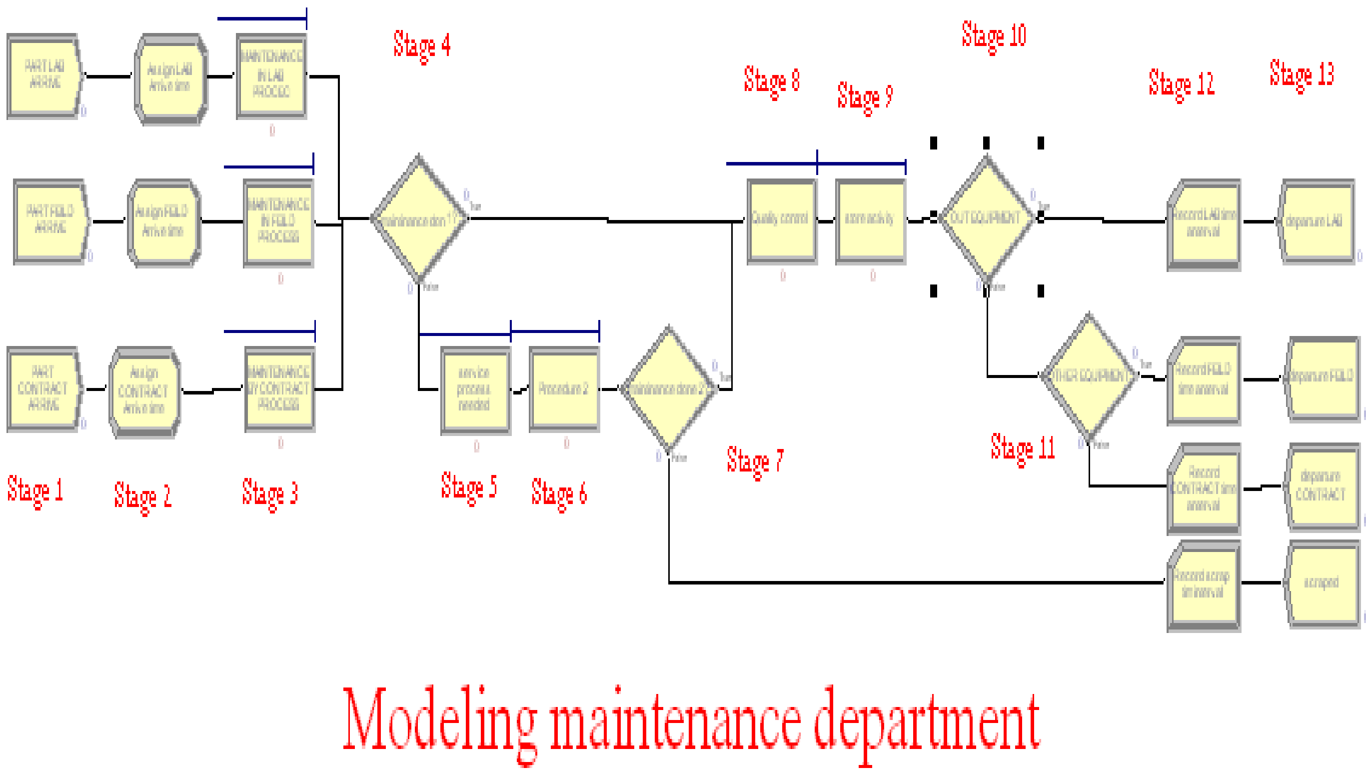

Figure 1: The Workflow Diagram for MDMS

3.2 Inceptive and Alternative Staff Structures in MDMS

In this section, three different scenarios other than the current situation are developed and evaluated for customer requirements. The entities are classified in two classes which are field and lab failed medical devices.

The percentages of arrivals to the system have an exponential distribution with parameters of 12 and 1 days for filed and lab failed medical devices respectively. 18 % of arrivals are classified as field devices, 84 % of arrivals are classified as lab devices.

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The service time distribution parameters are given in Table 2 with details.

Service activity	Distribution Type (Hour)
New work order	Exponential, EXPO(.3)
Equipment under maintenance contract	40%
Call the local agent	Triangle; TRIA (.1,1,2)
local agent maintains the device	Triangle; TRIA (3,8,16)
Setting the device as scrape	Triangle; TRIA (2,8,12)
Initial Check	Triangle; TRIA (1,2,3)
Repairing of no need for spare part device	Triangle; TRIA (3,8,16)
Final check	Triangle; TRIA (1,4,8)
Device is ok	80%
The device needs spare parts	Triangle; TRIA (8,56,147)
Get the spare parts from the local agent	Triangle; TRIA (8,32,56)
Deliver the repaired device	Triangle; TRIA (1,8,16)
Determining the type of non contracted device	25%
Needs spare part	75%
Repair equipment after getting spare part	Triangle; TRIA (1,3,8)
Get the spare part for non critical device	Triangle; TRIA (8,56,200)
Repair non critical equipment after getting spare part	Triangle; TRIA 8,64,128)

Table 2: Service Times Distributions

Process times are determined in two different ways. The arrival time of work orders from the field and lab are determined from a historical data of Medical Devices Maintenance Department (MDMD) in PHH. The other process times are determined from brainstorming and interviewing the expertise of MDMD in PHH.

The initial and alternative models are simulated for a year by collecting the data of the study in Arena 10.

4 Experimental Results

In the beginning, the initial model is simulated and then the alternative scenarios are developed to find the better performance levels of staff allocations and qualifications. The results are evaluated to reduce waiting times in queues, and to increase the number of replies as outputs and better utilization rates in all alternative scenarios.

The simulation models answered the questions that arisen in the beginning of the study. The all results of the simulation are illustrated in the following Figures (2-6) for Entity I (lab devices) and Entity 2 (field devices).

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	1824.68	78.024	1818.54	1830.82	473.35	3526
Entity 2	1777.93	993.911	1699.70	1856.15	560.97	2940

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.000	0.00	0.00	0.00	0
Entity 2	0.00	0.000	0.00	0.00	0.00	0

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	360.15	354.427	332.26	388.05	0.00	1618
Entity 2	368.13	1,056.003	285.02	451.24	0.00	1580

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.000	0.00	0.00	0.00	0
Entity 2	0.00	0.000	0.00	0.00	0.00	0

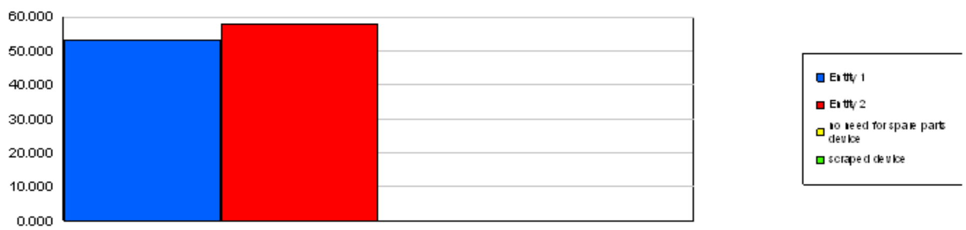
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.000	0.00	0.00	0.00	0
Entity 2	0.00	0.000	0.00	0.00	0.00	0

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	2184.84	276.404	2163.08	2206.59	473.35	3661
Entity 2	2146.06	2,049.914	1984.72	2307.39	560.97	3774

Other

Figure 2 :(VA, NVA, Wait and Transfer times) of Entity 1 and Entity 2

Number In	Average	Half Width	Minimum Average	Maximum Average
Entity 1	53.0000	0.000	53.0000	53.0000
Entity 2	58.0000	25.412	56.0000	60.0000
no need for spare parts device	0.00	0.000	0.00	0.00
scraped device	0.00	0.000	0.00	0.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
Entity 1	47.0000	50.824	43.0000	51.0000
Entity 2	48.5000	57.177	44.0000	53.0000
no need for spare parts device	0.00	0.000	0.00	0.00
scraped device	0.00	0.000	0.00	0.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	6.4902	0.432	6.4562	6.5241	0.00	15.0
Entity 2	6.8518	3.694	6.5611	7.1425	0.00	15.0
no need for spare parts device	0.00	0.000	0.00	0.00	0.00	0
scraped device	0.00	0.000	0.00	0.00	0.00	0

Figure 3 :(Number in, number out, WIP) of Entity I and Entity 2

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Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
initial field devices diagnostice procedure.Queue	1.2143	3.142	0.9671	1.4616	0.00	27.44
initial HQ devices diagnostice procedure.Queue	1.2753	2.257	1.0977	1.4529	0.00	19.07
the device is not within contract category.Queue	494.84	1,958.012	340.74	648.94	0.00	2059

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
initial field devices diagnostice procedure.Queue	0.00410456	0.012	0.00313406	0.00507505	0.00	1.00
initial HQ devices diagnostice procedure.Queue	0.00391145	0.007	0.00336668	0.00445621	0.00	1.00
the device is not within contract category.Queue	2.8239	11.279	1.9362	3.7116	0.00	13.00

Figure 4: Waiting times and number waiting of Entity I and Entity 2

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
maintenace staff field	0.07894156	0.044	0.07550184	0.08238129	0.00	1.00
maintenace staff HQ	0.07355559	0.015	0.07240698	0.07470420	0.00	1.00
non contracted devices maintenance staff	0.8377	0.361	0.8092	0.8661	0.00	1.00

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
maintenace staff field	0.07894156	0.044	0.07550184	0.08238129	0.00	1.00
maintenace staff HQ	0.07355559	0.015	0.07240698	0.07470420	0.00	1.00
non contracted devices maintenance staff	0.8377	0.361	0.8092	0.8661	0.00	1.00

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
maintenace staff field	1.0000	0.000	1.0000	1.0000	1.0000	1.00
maintenace staff HQ	1.0000	0.000	1.0000	1.0000	1.0000	1.00
non contracted devices maintenance staff	1.0000	0.000	1.0000	1.0000	1.0000	1.00

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Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
maintenace staff field	58.0000	25.412	56.0000	60.0000
maintenace staff HQ	53.0000	0.000	53.0000	53.0000
non contracted devices maintenance staff	94.5000	44.471	91.0000	98.0000

Figure 5: Resources usage of Entity I and Entity 2

User Specified

Tally

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
record contracted devices	99.39	67.967	94.0445	104.74	59.4092	128
the amount of local agent spare parts bills	640.14	1,990.795	483.46	796.82	124.56	2174
the amount of mainstore spare parts bills	779.04	1,945.796	625.90	932.18	112.16	2331
the amount of this type of devices in this category	693.31	1,943.742	540.33	846.29	61.5177	2305

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
the amount of checked up the device	95.5000	108.001	87.0000	104.00
the amount of deliverd devices in this category	95.5000	108.001	87.0000	104.00
the amount of local agent spare parts orders	66.0000	0.000	66.0000	66.0000
the amount of mainstore spare parts delivered	25.0000	63.530	20.0000	30.0000
the amount of mainstore spare parts orders	25.0000	63.530	20.0000	30.0000
the amount of maintained devices in this category	95.5000	108.001	87.0000	104.00
the amount of ocal agent spare parts delivered	64.0000	0.000	64.0000	64.0000

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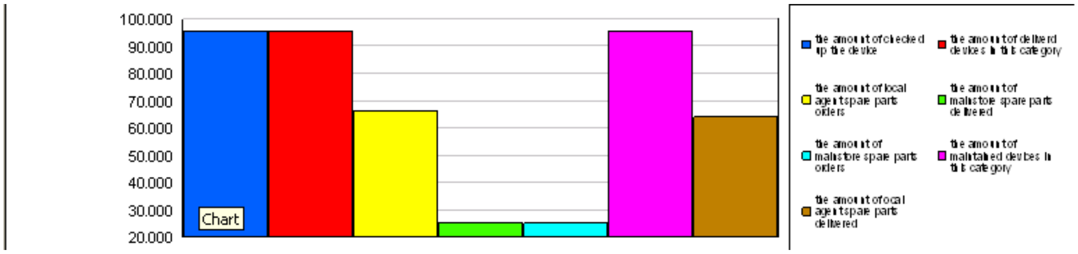

Figure 6: Tally and counter statistics of Entity I and Entity 2

These results can be summarized as follows:

- **The number of Outputs:** The number of outputs of Entity two 48.5 was better than of Entity one 47 Therefore, more problems are solved for Entity two.
- **Queue waiting times:** Queue waiting times for field devices was 1.2143 which was better then lab 1.2753.
- **Resource utilization rates:** The average utilization rates of maintenance staff field was .0789 and for maintenance staff lab was .0735.

The simulation results showed that some improvements are necessary to have better efficiency of the actual maintenance system for waiting times, utilization rates, and qualification of the staff for processes of the MDMS.

5 Summary and Conclusion

The simulation models provide some opportunities to analyze the current situation of systems for improving system parameters with the performance measures. Some scenarios are analyzed before purchases of expensive equipments. Therefore, the better organizational structures are designed for the systems with many organizational goals as higher level of customer satisfaction.

A maintenance unit of PHH in Jordan is investigated with initial model and alternative models for evaluating queue waiting times and outputs of the performance measures first time in this study.

The results are discussed with the management of PHH. This study has noticed them to start works on a new organizational development process. The further research can be assessment of working hours and cost analysis of staff with simulation method.

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