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Identifying the Optimal preventive maintenance interval for three of major medical equipment using discrete event simulation

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Abstract:

Designing a simulation model according to failure data to represent the maintenance policy is the aim of this study, then optimizing a model to maximize the utilization and reduce downtime for three major medical equipment.

Optimizing a model that determines the optimal preventive maintenance interval which gives the maximum value of utilization, by using the simulation model, to represent the current maintenance policy and conduct the current utilization of equipment.

This approach helps an organization to eliminate the corrective maintenance that will be minimal and increase the interval of preventive, which could reduce the downtime according to the requirements of spare parts availability.

This study shows that when applying the optimization model on three selected equipment: MRI, Mammogram, and Linear accelerator equipment the optimal preventive maintenance intervals was 209,373 and 467 working hours.

This research is highlighting the important aspects of simulation-based optimization of maintenance strategy within the medical field improvement, which is significantly different from the currently used, where it can be applied easily for any equipment without mathematical equations and long time-solving methods.

It was applied at one of the hospitals in Hashemite Kingdom of Jordan.

Keyword - Maintenance strategy, Simulation, Optimization, Preventive maintenance.

Introduction:

Maintenance is one of the most important issues to be considered in all fields, industrial, organizational, medical, and so on, this process involves functional checks, repairing or replacing of parts, equipment, machinery, building infrastructure, and supporting utilities, all these activities take place either before or after a failure.

There are three basic types of maintenance are Preventive maintenance PM which is extremely important as it could effectively avoid the occurrence of unexpected failures, and thereby save servicing costs [1].

Corrective maintenance is also called repair and defined as a repair activity to make the malfunctioned or broken equipment recover to the required technical state. It includes one or all of the following activities: malfunction location, malfunction isolation, decomposition, replace, re-install, adjustment, verification and fix the damaged parts [2].

And Predictive maintenance which it is includes condition monitoring and prognosis of future system maintenance to obtain decision making whether remaining useful life expects to be increased. Different scenarios assessment of models intends to compare results of maintenance indicators that enable to recognize troubles or any possible breakdown which prevent unannounced failure [3].

The most important issue and the challenge are how to select the proper type of maintenance or mix of these types to maximize the availability of the machine and minimize losses and source of wastes which include downtime, non-added value activity, additional cost, and resources. So selecting a successful maintenance strategy requires a good knowledge of equipment failure behavior and maintenance management practices. Once you know why equipment fails, how equipment fails and when equipment fails you can select the right mix of maintenance strategies to extend and maximize its service and performance.

Hospitals and medical services sector was selected in this study at which devices must be ready to be used anytime, according to receiving the patient 24hr a day, so the maintenance issues are very important to take into consideration especially the preventive and predictive types trying to avoid sudden breakdowns.

Simulation is one of the most useful tools to be used in selecting the suitable maintenance strategy by building a model that represents the current maintenance situation for the equipment considering preventive and corrective maintenance action then select the optimal period of time for preventive maintenance action to avoid corrective maintenance that leads to loss cost and time.

Methods:

Methodology and Case Study:

To achieve the required goal which is concentrated in increasing the utilization of medical equipment by identifying the optimal preventive maintenance action intervals and trying to avoid the corrective one, the following methodology was followed,as shown in figure 1.

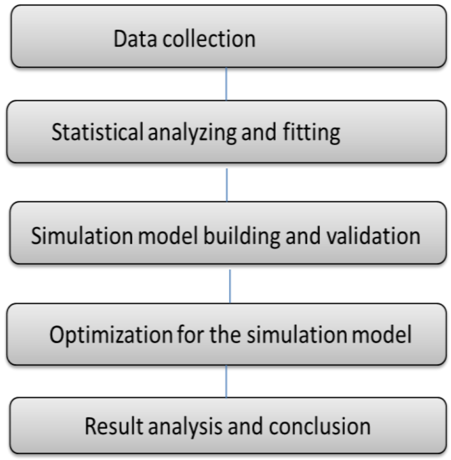


Figure 1: Research Methodology.

Before starting the research methodology, the proper equipment for this study must be selected carefully, three major and complex system equipment has been selected which were used frequently in the radiography department nine hours a day five days a week so the equipment must be ready to be used anytime. Sudden failure will make a problem and delay in the appointment schedule, the selected equipment were : the magnetic resonance imaging (MRI) , Senographe Essential (Mammogram) and the Linear accelerator.

Data Collection; The required data: mean time between failures (MTBF), mean time to repair (MTTR) and maintenance time for preventive action. All data was collected from archive files at maintenance department in the hospital

Table 1: MTBF and MTTR for MRI .

MTBF(Days)	MTBF (hr)	MTTR (hr)
-	-	1
36	324	3
39	351	5
7	63	6
34	306	5
47	423	4
18	162	5
25	225	2
9	81	3
11	99	5

1. 16	144	3
2. 19	171	4
3. 21	189	3

4.

Table 2: PM intervals and maintenance time for MRI .

5. 6. 7. 8. PM intervals (Days)	PM intervals (hr)	Maintenance time(hr)
-	-	9
83	1992	5
89	2136	3
105	2520	5

Statistical Analyzing and Fitting : The collected data was statically analyzed by using Minitabsoftware to select the best fit distribution using individual distribution identification feature , after that the data can be used as inputsfor the simulation model,a probability plots for main distributions and gave the parameters for each one, then the proper distribution can be selected according to the p-value which should be greater than .05 ,in addition to that the data must be approximately follow a straight line as much as possible ,for example the probability plot for MTBF's data for MRI equipment shown in figure 2 :

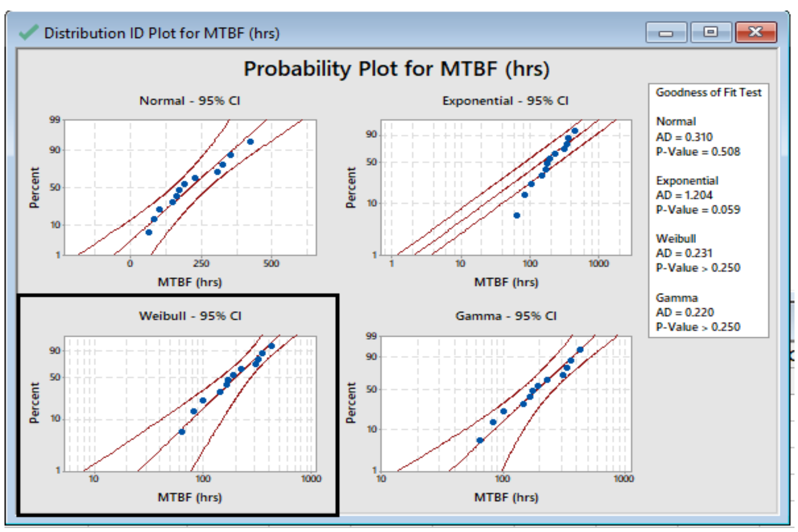


Figure 2: Probability plot for MTBF for MRI .

According to figure 2 the best fit distribution for the data was the Weibull where the p-value was greater than 0.05 and the data are approximately follow a straight line, the same manner was followed for the whole data and for all equipment, table 3 below summarized the best fit distribution for MRI equipment's.

Table 3: Best fit distribution for MRI equipment's data .

Data	Best fit distribution
MTBF	Weibull(239.74,2.04)
MTTR	Normal(3.77,1.42)
PM maintenance time	Normal(5.5,2.52)

Simulation Model Building and Validation:A simulation model was designed to predict when the failure may occur according to the collected data,then the optimal preventive maintenance interval can be easily determined, the model was shown in the figure:

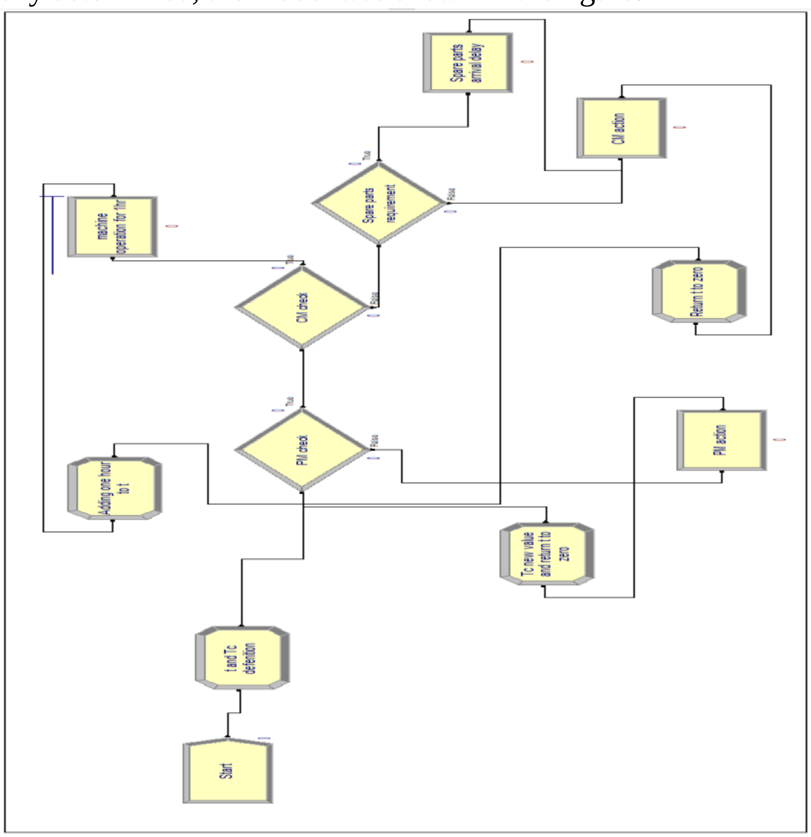
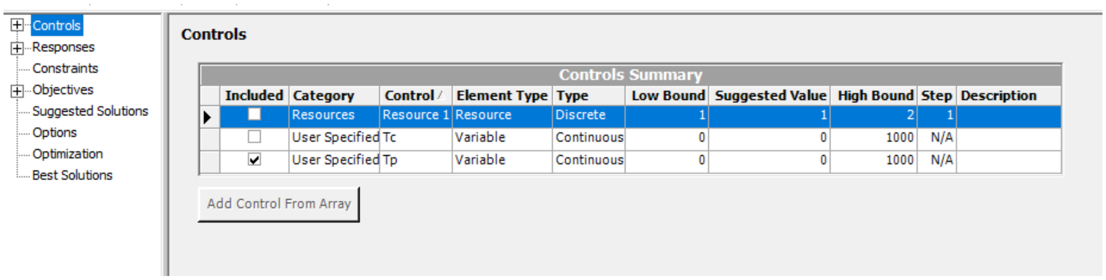


Figure 3 : Simulation model for determine the optimal preventive maintenance interval

Then the model was validated by entering the current interval for preventive maintenance actions and extracting the results about the utilization of the equipment and then comparing it with the real utilization value that calculated manually to make sure that the model gave correct and accurate results , for example MRI equipment have current utilization value of 90% and the simulation result (when entered the PM interval in real case (3 months)) was near 91% , and that acceptable because of that the two values was closed to each other's.

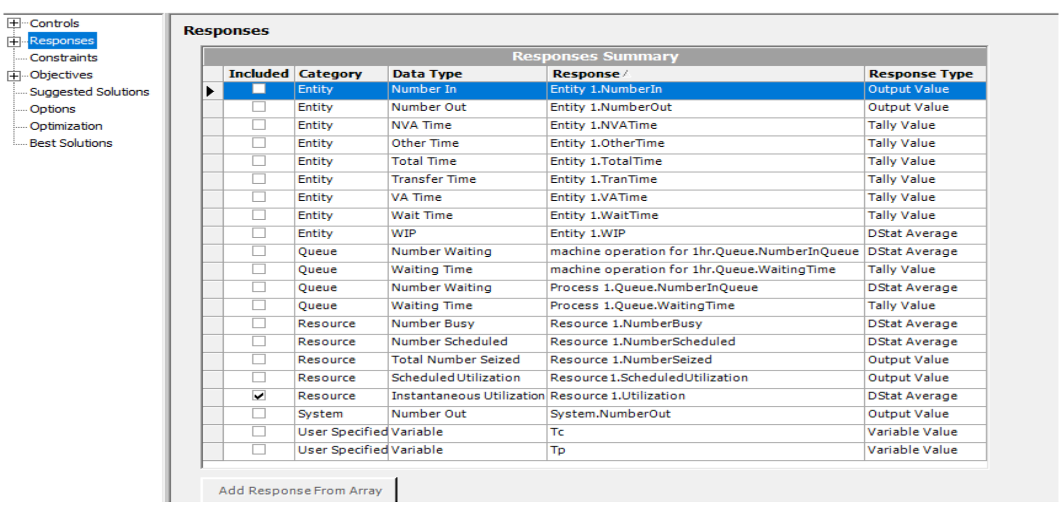
Optimization for The Simulation Model: The final step was the optimization process to select the optimal alue for preventive maintenance interval so the maximum utilization value for the equipment was achieved, and for that Arena OptQuest feature was used,and for that many issues must be determined, first the control variable must be selected and in this case the Tp (PM interval) will be that value as shown in figure 4 :



Controls Summary									
Included	Category	Control	Element Type	Type	Low Bound	Suggested Value	High Bound	Step	Description
☐	Resources	Resource 1	Resource	Discrete	1	1	2	1	
☐	User Specified	Tc	Variable	Continuous	0	0	1000	N/A	
☑	User Specified	Tp	Variable	Continuous	0	0	1000	N/A	

Figure 4: Control variable for MRI model optimization.

Then the response variable must be determined which was the utilization of the equipment as shown in figure 5:



Responses Summary				
Included	Category	Data Type	Response	Response Type
☐	Entity	Number In	Entity 1.NumberIn	Output Value
☐	Entity	Number Out	Entity 1.NumberOut	Output Value
☐	Entity	NVA Time	Entity 1.NVATime	Tally Value
☐	Entity	Other Time	Entity 1.OtherTime	Tally Value
☐	Entity	Total Time	Entity 1.TotalTime	Tally Value
☐	Entity	Transfer Time	Entity 1.TranTime	Tally Value
☐	Entity	VA Time	Entity 1.VATime	Tally Value
☐	Entity	Wait Time	Entity 1.WaitTime	Tally Value
☐	Entity	WIP	Entity 1.WIP	DStat Average
☐	Queue	Number Waiting	machine operation for 1hr.Queue.NumberInQueue	DStat Average
☐	Queue	Waiting Time	machine operation for 1hr.Queue.WaitingTime	Tally Value
☐	Queue	Number Waiting	Process 1.Queue.NumberInQueue	DStat Average
☐	Queue	Waiting Time	Process 1.Queue.WaitingTime	Tally Value
☐	Resource	Number Busy	Resource 1.NumberBusy	DStat Average
☐	Resource	Number Scheduled	Resource 1.NumberScheduled	DStat Average
☐	Resource	Total Number Seized	Resource 1.NumberSeized	Output Value
☐	Resource	Scheduled Utilization	Resource 1.ScheduledUtilization	Output Value
☑	Resource	Instantaneous Utilization	Resource 1.Utilization	DStat Average
☐	System	Number Out	System.NumberOut	Output Value
☐	User Specified	Variable	Tc	Variable Value
☐	User Specified	Variable	Tp	Variable Value

Figure 5: Response variable for MRI model optimization.

Then the objective function must be determined and that was 'to maximize the utilization of the equipment' as shown in figure 6.below:

Figure 6: Objective function for MRI model optimization .

Then the optimization model was run to extract the results, the running model shown in figure 7 and the results shown in figure 8below:

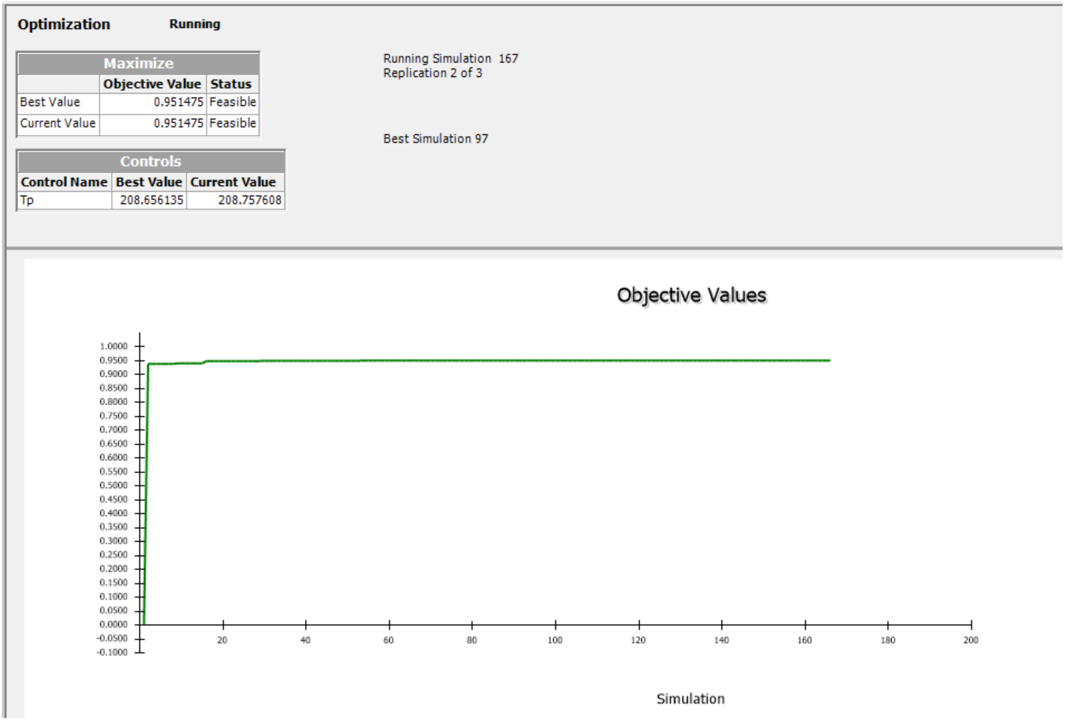


Figure 7: Running of optimization model for MRI.

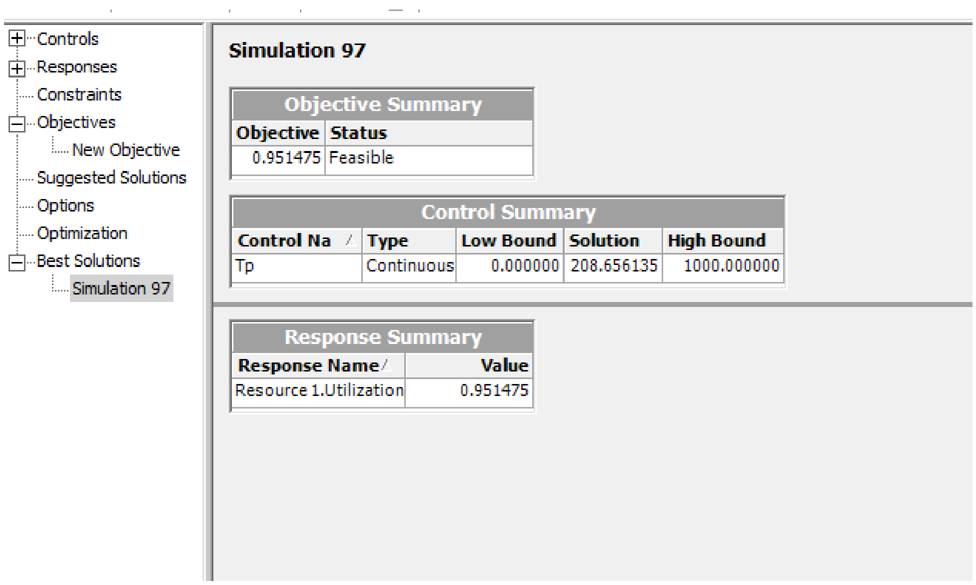


Figure 8: The result for MRI optimization model.

According to OptQuest results the maximum value for MRI equipment utilization was 95% that achieved when made a PM action each 209 working hours, the same procedure was applied for remaining equipment, table 4 below summarized the optimal values for PM intervals.

Table 4 : optimization result for PM interval .

Equipment	PM interval (working hrs)	Utilization
MRI	209	95%
Mammogram	373	96.4%
Linear accelerator	467	97.5%

Conclusion and recommendations:

The model was applied to maximize the availability of three selected equipment in medical field (MRI , Mammogram and Linear accelerator equipment). For MRI the current PM interval (540 working hours) gives a utilization value of 91% and after applying the concept of this research the optimal utilization value was 95% with PM interval of 209 working hours that cause 4% improvement percentage , for Mammogram the current PM interval (1080 working hours) gives a utilization value of 93% and after applying the concept of this research the optimal utilization value was 96.4% with PM interval of 373 working hours with 3.4% improvement percentage and finally for Linear accelerator the current PM interval (1080 working hours) gives a utilization value of 94% and after applying the concept of this research the optimal utilization value was 97.5% with PM interval of 467 working hours that gives 3.5% improvement percentage . This research added value in highlighting the important aspects of simulation based on optimizing a maintenance strategy within the medical field improvement, which is significantly different from the currently used , where it can be applied easily for any equipment without mathematical equations and longtime solving methods.

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