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Selecting A Sustainable Maintenance Schedule For Production Lines: A Case Study

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Abstract

Machine maintenance plays an important role in creating a sustainable production line. An effective machine maintenance schedule can reduce waste by reducing the machine failures and the time spent on failures. A proper maintenance schedule can also decrease the amount of wasted parts by decreasing the number of lost products, hence increasing productivity and sustainability. In this study, discrete event simulation software, Arena by Rockwell Automation, is used to model and simulate a fully automated production line. This study will review how to decide on a maintenance schedule technique by implementing a multi criteria decision-making (MCDM) process. The criteria that are considered for the MCDM process are Utilization, Total time Blocked (TTB), Total time Starved (TTS), Cost of Good Product (CGP) and Cost of Lost Product (CLP). For the MCDM process different weight assessment techniques are used to rank and assign weight values to the criteria.

The methodology examined in this study provides an overview of selecting a scheduling technique for production lines to improve sustainability and productivity of the lines. The used methodology can be applied to any production line.

Introduction

A circuit breaker assembly line with eight stations/machines is used as a model for this experiment. The purpose was to decide on a Preventive Maintenance (PM) schedule for a fully automated assembly line using discrete event simulation software, and implementing a multi criteria decision making process. Enforcing a proper maintenance schedule can also decrease the amount of wasted parts by decreasing the number of lost products, hence increasing productivity and sustainability. The preventative maintenance techniques tested are:

Global-based Maintenance (GBM): Requires halting production so all the machines can be maintained at the same time. There are two ways to apply this technique. The first is to stop the machines every 55 minutest for 10 minutes, given there are multiple maintenance personnel. The second is to stop the machines every 150 minutes for 100 minutes, given there is only one maintenance personnel.

Reliability-based Maintenance (RBM): Maintenance is performed on a machine once it reaches a specific reliability level. The four reliability levels tested are 70%, 80%, 90%, and 95%. We assign a mean time to fail for each machine. Machines 1,3,5 & 7 MTTF= 55 minutes, machines 2,6, & 8 MTTF= 60 minutes, and machine 4 MTTF= 50 minutes. We then use the equation $R(t)=e^{-\lambda t}$ to determine when to schedule the maintenance stops. λ= 1/MTTF. Maintenance stops are scheduled as following for 5 minutes:

MTTF	Reliability Levels			
	70%	80%	90%	95%
50 mins.	17 mins.	11 mins.	5 mins.	2.5 mins.
55 mins.	19 mins.	12 mins.	5.5 mins.	2.5 mins
60 mins.	21 mins.	13 mins.	6 mins.	3 mins.

Value-based Maintenance (VBM): favors the machines toward the end of the production line, so they undergo maintenance first.

Machine 8 is stopped every 55 minutes for 5 minutes.
Machine 7 is stopped every 60 minutes for 5 minutes,
machine 6 is stopped every 65 minutes for 5 minutes,
Machine 5 is stopped every 70 minutes for 5 minutes, etc.

Replications are set to 160 hours, to represent working 8 hrs./day, 5 day/week for 4 weeks. A total of 16 simulations were ran for each maintenance technique at each of the allowed reliability levels.

Methodology

Multi-criteria Decision Making

The Criterion evaluated in the simulations are: Utilization: the percentage of time the machine is actively working on a part, Total Time Blocked (TTB): the time machine had a line of parts waiting to be processed, Total Time Starved (TTS): the amount of time the machine spent not working, Cost of Good Product (CGP): the cost of producing a good product, and Cost of Loss Product (CLP): the cost producing a loss product.

The first step of implementing the MCDM method is to apply a weighted grade to each simulation result so they can be compared at the same scale. We decide if high or low values are preferred for each criteria. High values are preferred for Utilization and low values preferred for TTB, TTS, CGP, and CLP. We then compare the Preventative Maintenance technique at each reliability percentage to see which reliability percentage is best for each PM technique. If high values are preferred, we assign 1 to be the weighted grade to the highest number. We assign 0 to be the weighted grade of the lowest number and use the equation $\frac{x-l}{h-l}$ to determine the weighted value of the results in between. Similarly if low values are preferred, we assign 1 to be the weighted grade of the lowest number. We assign 0 to be the weighted grade of the highest number, and use the equation $\frac{h-x}{h-l}$ to determine the weighted value of the results in between. (*h*- highest number, *l*- lowest number, *x*- values between the highest and lowest). This process is repeated for each criteria.

GBM -100				
	70%	80%	90%	95%
Arc Chute Sub Assembly	0	0.096	0.37	1
Barrier Units Arrival	0	0.1	0.38	1
Base Assembly	0	0.105	0.4	1
Bi-Metals Arrival	0	0.108	0.41	1
Calibration Station	0	0.105	0.4	1
Chute Arrival	0	0.103	0.39	1
Circuit Breaker Leaves	0	0.105	0.4	1
Cross Bars Arrival	0	0.1	0.39	1
Final Inspection Station	0	0.105	0.4	1
Handle Arms Arrival	0	0.108	0.41	1
Mechanical Sub Assembly	0	0.097	0.37	1
Molded Casting Arrival	0	0.103	0.392	1
Packaging Station	0	0.105	0.4	1
Stationary Sub Assembly	0	0.102	0.39	1
Trip Units Arrival	0	0.103	0.93	1

GBM -100				
	70%	80%	90%	95%
Arc Chute Sub Assembly	1	0.9	0.6	0
Barrier Units Arrival	1	0.9	0.6	0
Base Assembly	1	0.9	0.6	0
Bi-Metals Arrival	1	0.9	0.6	0
Calibration Station	1	0.9	0.6	0
Chute Arrival	1	0.9	0.6	0
Circuit Breaker Leaves	1	0.9	0.6	0
Cross Bars Arrival	1	0.9	0.6	0
Final Inspection Station	1	0.9	0.6	0
Handle Arms Arrival	1	0.9	0.6	0
Mechanical Sub Assembly	1	0.9	0.6	0
Molded Casting Arrival	1	0.9	0.6	0
Packaging Station	1	0.9	0.6	0
Stationary Sub Assembly	1	0.9	0.6	0
Trip Units Arrival	1	0.9	0.6	0

Above are the results for Utilization and Cost of good product of each machine on the assembly line. If a Global-based maintenance with one maintenance person is applied, the machines would be more proactive at 95% reliability, but would create more profitable product at 70% reliability. The goal is to decide on a maintenance schedule that would benefit both criteria at the same reliability level.

Utilization 70%				
	GBM-10	GBM-100	RBM	VBM
Arc Chute Sub Assembly	0.55	0	1	0
Barrier Units Arrival	0.55	0	1	0
Base Assembly	0.54	0	1	0
Bi-Metals Arrival	0.55	0	1	0
Calibration Station	0.54	0	1	0
Chute Arrival	0.55	0	1	0
Circuit Breaker Leaves	0.52	0	1	0
Cross Bars Arrival	0.55	0	1	0
Final Inspection Station	0.54	0	1	0
Handle Arms Arrival	0.55	0	1	0
Mechanical Sub Assembly	0.55	0	1	0
Molded Casting Arrival	0.55	0	1	0
Packaging Station	0.53	0	1	0
Stationary Sub Assembly	0.55	0	1	0
Trip Units Arrival	0.55	0	1	0
Average	**0.54467**	**0**	**1**	**0**
Sum	**8.17**	**0**	**15**	**0**

Utilization 95%				
	GBM-10	GBM-100	RBM	VBM
Arc Chute Sub Assembly	0.75	1	0	1
Barrier Units Arrival	0.75	1	0	1
Base Assembly	0.74	1	0.0087	1
Bi-Metals Arrival	0.75	1	0	1
Calibration Station	0.74	1	0.018	1
Chute Arrival	0.75	1	0	1
Circuit Breaker Leaves	0.78	1	0.0032	1
Cross Bars Arrival	0.75	1	0	1
Final Inspection Station	0.76	1	0.0032	1
Handle Arms Arrival	0.75	1	0	1
Mechanical Sub Assembly	0.75	1	0	1
Molded Casting Arrival	0.75	1	0	1
Packaging Station	0.77	1	0.018	1
Stationary Sub Assembly	0.75	1	0	1
Trip Units Arrival	0.75	1	0	1
Average	**0.75267**	**1**	**0.00341**	**1**
Sum	**11.29**	**15**	**0.0511**	**15**

Methodology cont.

Von Neumann & Morgenstern's Utility Theory

The next step to applying the MCDM method is applying Von Neumann & Morgenstern's Utility Theory because as seen previously deciding on a maintenance schedule based on a weighed grade is not conclusive. The utility theory uses the equation $U_i = \Sigma(w_i * u_i)$, where U_i is the utility, w_i is weight value assigned to each criteria, u_i average value. The maintenance schedule with the highest utility is favored.

We first assign a weight value to each criteria. There are 5 methods of assigning weight, but the sum of the weights must be one. The first method is called the equal weights method. We have 5 criterion, so each criteria is .2. The remaining 4 methods require ranking the criteria in order of most important to least. Ranking order can vary due to professionals opinion, so 2 rank orders we created. Rank A: Utilization> TTB> CGP> CLP> TTS, and Rank B: CGP> Utilization> TTB> TTS> CLP. The second method is called Rank Order Sum Method. It uses the equation $w_i = \frac{n-r+1}{\Sigma_{r=1}^{n}(n-r+1)}$, where *n* = total number of criteria (n=5), *r* = ranking of each criteria under consideration. The order of the weight values will be .33, .27, .2, .13, .07. The third method is Rank Order Reciprocal uses the equation $w_i = \frac{(\frac{1}{r})}{\Sigma_{r=1}^{n}(\frac{1}{r})}$, and the corresponding weight values will be .44, .22, .15, .11, .09. The fourth method is Rank Order Centroid Method uses the equation $w_i = \left(\frac{1}{\text{n}}\right)\sum_{r=1}^{n}\left(\frac{1}{r}\right)$, and the corresponding weight values are .46, .26, .16, .09, .04. The fifth method allows the experimenter to decide how to distribute the weight values to each criteria. The corresponding weight values are .41, .25, .17, .11, .06.

We then compare each criteria at the same reliability level for each PM technique. We take the average grade of each PM technique and apply it to Von Neumann and Morgenstern's Utility theory (u_i), as shown to the left.

Results and Conclusion

Once the Utility theory is applied there are 36 results to compare. For instance at 70% reliability Global maintenance order with one maintenance person was favored 6 out of 9 times. At 80% reliability, rank order A favored Global based maintenance with multiple maintenance personnel, and rank B favored Global based maintenance with one maintenance person. At 90% reliability, Reliability-based maintenance was favored 6 out of 9 times. The difference was Rank A favored Value-based maintenance the remaining 3 times. At 95% reliability, Value-based maintenance was favored 6 out of 9 times, with Rank B favoring Reliability-based maintenance. We can conclude that at the higher reliability levels, Value-based and Reliability-based maintenance are favored, and at lower reliability level Global-based maintenance is preferred for the circuit breaker assembly line. The order of how the criterion are ranked could affect the utility outcomes. The method used above could be applied to any production line.

References:
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