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REPLACEMENT MODEL FOR ROBOTS IN AUTOMOTIVE ASSEMBLY PLANT

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ABSTRACT

The robots operated in automotive assembly plant are a large portion of investment which contributed to the automation level of the manufacturing assembly line. Significant impact on the profit and lost (P&L) of the company contributed from the operating efficiency of equipment including robots, in term of maintaining cost and replacement cost. Timely replacement could reduce the downtime which might result in significant saving on the company P&L. The objective of this research is to develop a replacement model for replacement of robots in automotive assembly line. The approaches used in this research are 1) gathering mean time between failures (MTBF) and mean time to repair (MTTR) data for availability assessment, 2) computational of the defender marginal cost (MC) and challenger equivalent uniform annual cost (EUAC) and 3) using spreadsheet computational model for sensitivity analysis. From the analysis the robot with lowest availability (99.41%) had the lowest MTBF of 5280 hours. The robot was taken as a candidate for replacement. Replacement study using MC and EUAC analysis was done for the robot and the potential candidate for replacement. Upon computing the defender MC and challenger EUAC cost analysis, the minimum EUAC of Malaysian Ringgit 68,619 and MC of Malaysian Ringgit 62,000, if it is kept in the services for only five (5) years. The MC of defender in year 5 is Malaysian Ringgit 71,000, hence it is due for replacement. Based on the sensitivity analysis, the initial capital investment is the most sensitive factor compared to other factor. The current robot can be maintained for one more year in service.

Keywords: replacement analysis, mean time between failures, mean time to repair, marginal cost, equivalent uniform annual cost.

INTRODUCTION

Automotive assembly line consists of several production shops; stamping, body, painting and assembly shop which are linked together to produce a car in a very efficient processes and in a timely manner. Automation is a major contributor for the production line speed which is associated with the production volume. Each shop contains several equipment, conveyors, manipulators, material handling equipment that are working simultaneously. The automated robotic system which acts as a material handler, manipulator, spot welder, paint sprayer is the most important elements in Assembly Line in order to achieve high volume demands of production.

In the automotive plant the robots are grouped in accordance to their functions for the production shops. Robots in stamping shop mostly act as material handlers, robots in body shop act as manipulators and spot welder welding guns, robots in painting shop act as paint sprayers and robots in assembly shop act as power assist or manipulators.

The objective of this study is to develop a replacement model for robots in order to avoid major downtime due to unplanned failure. The replacement model for robot in automotive assembly plant was developed based on availability factor of the robots and economic factor. The balancing of these two factors decided the decision making for replacement.

This is to be achieved by dividing the objective into three (3) sub-objectives.

i. Identified the candidate for replacement by developing availability model for robots.
ii. Determined when to replace by analyzing MC of current robot and EUAC cost for candidate robot replacement.
iii. Sensitivity analysis, in order to identify which parameter influenced the net present value (NPV) of challenger in term of capital expenditure (CAPEX), operational expenditure (OPEX) and salvage value.

The steady state availability is a proportional of total time that the robots are available to function. With the constant failure rate, λ and constant repair rate, μ the steady state availability is defined as the probability that an item will be available when required [1,4,5].

The robot replacement strategy is based on decision whether to replace or to use for one more year upon assessing the MC of defender and EUAC of challenger [2].

The main principle adopted for the proposed model is to keep and operate the existing robot as long as the MC of the defender is less than or equal to EUAC of the proposed new robot [2].

The study will consider the dynamic environment of the automotive industry taking in account the competitiveness of robot which offered competitive price for the new robot. In the case of replacement due to technological changes such as safety, health and environment requirement, it will not be covered in this study.

In the industry, replacing assets occurred frequently due to the ageing of equipment, safety, health and environment regulation changes, and technological changes. Many studies have been done and are applied to

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many industries and the main factors considered are the CAPEX of the defender and challenger.

Replacement study done by Nair was using the markov decision process framework [3] and further enhanced by Sloan which incorporation of economic factor and technological changes due to the environment factors [6]. Sloan studied how companies seek a way to balance between economic factor and the environment factor with respect to the replacement decision [6].

Wang also studied the replacement analysis due to technological changes but the approach adopted the operational research perspective [7]. While Richardson [8] incorporated the traditional method of replacement analysis by using NPV and life cycle cost with long and uncertain lead time of replacement timing. Henning O. [9] applied economic, analytical and strategic justification methods for replacement analysis. MC analysis was used by James S. *et al*. [10] for robot optimal replacement strategy. The proposed strategy is to keep and operate the robot as long as the MC of operating robot is less than or equal to expected average total cost of a new robot over its lifetime.

There is no published study integrating MTBF analysis, MC and EUAC analysis in replacement model. Hence, the focus of this study is to develop model which incorporate MTBF, MC and EUAC criteria for the replacement model.

In the engineering economic analysis on the present worth (PW), the technique most frequently adopted for sensitivity analysis is by plotting a sensitivity graph or spider plot. This technique demonstrated the impact of uncertainty of estimated factors of concern such initial capital investment, annual saving, market value and minimum attractive rate of return (MARR) [2].

In line with the needs of the industry particularly in automotive industry to have an analytical model for replacement analysis for decision making, this model focused on robot in Malaysia automotive assembly plant.

The study covers 10 years life cycle of the robots. The failures based on robots used for saloon assembly model range from 1000cc to 2000cc and the assembly plant capacity of the production of approximately180k units per year.

METHODOLOGY

The methods to achieve the objective involved 10 (ten) steps as shown in Figure-1.

- Identification of Automotive Assembly Plant Robots. Literature reviews on robots in automotive assembly plant. Quantity of the robots and their functions for each shop were identified.

- Technical specification, Economic Parameters. Identify and group the category of robots in assembly line. Capital expenditures and operational expenditures were identified.
- Categorization Critical Robot Criteria. Categorized and grouped the critical failures.

- MTBF / MTTR Data Acquisition. The field data Measurement Method was used to measure the actual field failures. This method produced more accurate measure of robot failures rate than simulation.

- Evaluation of Availability. The evaluation was based on the data from MTTR and MTBF.

- Economic Data Acquisition. For more accurate assessment actual data of the CAPEX and OPEX, were acquired from operating plant.

- Develop Replacement Model. The basis of the model is using MC for the defender and EUAC for challenger as per Figure 2: Model Development.

- Validation Using Case Study. Derived from sixteen (16) selected robots to validate the model.

- Sensitivity Analysis. Determined the impact on the challenger relative to changes in the capital investment, annual saving, market value, study period and MARR.

- Final Report. Presented the research findings.

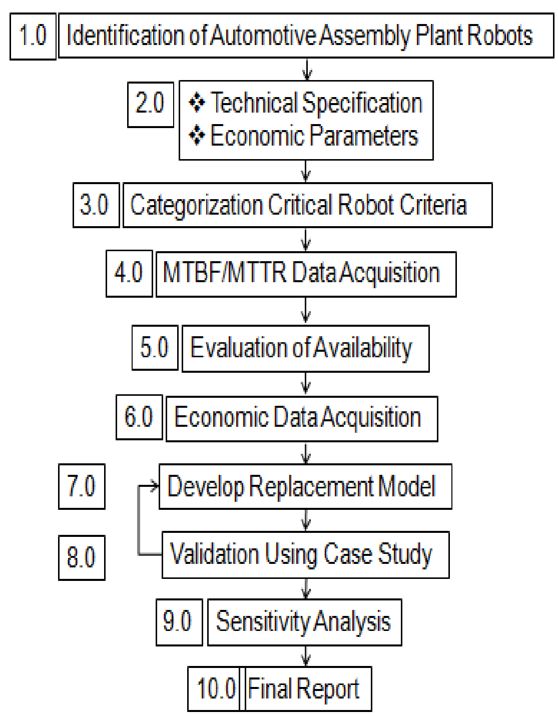

Figure-1. Research methodology.

MODEL DEVELOPMENT

The steps in model development are as in Figure-2.

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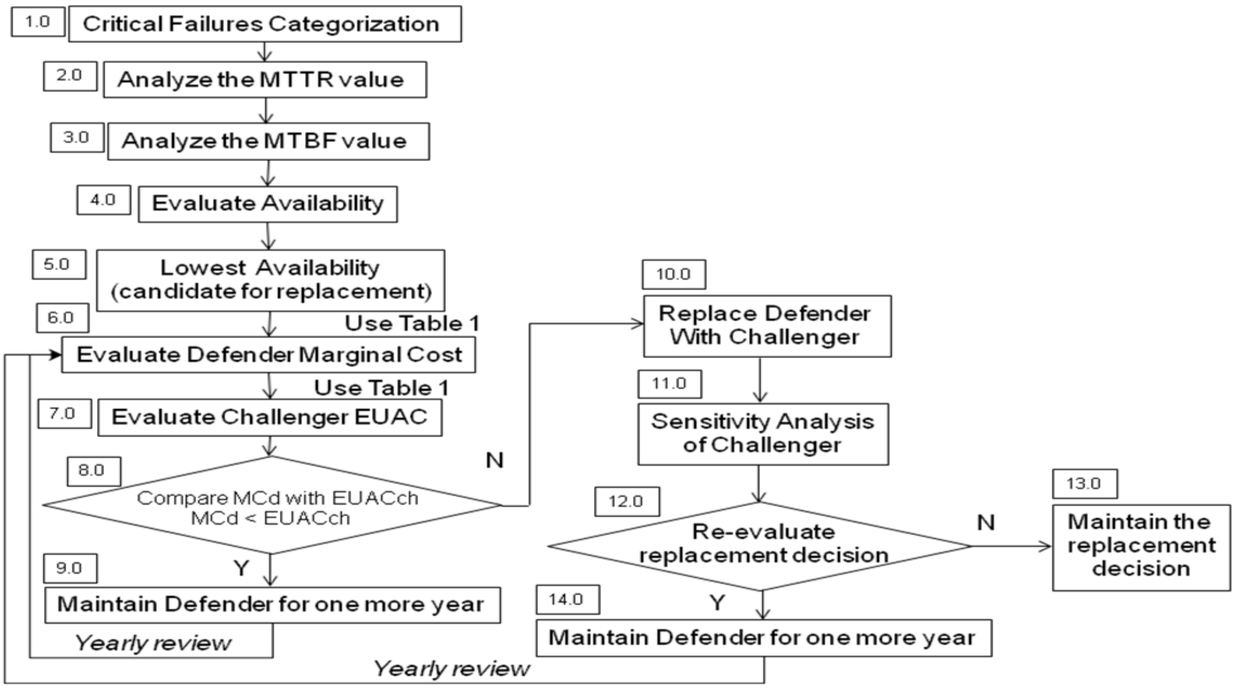

Figure-2. Replacement model for robot in automotive assembly plant.

- Critical Failures Categorization, Categorize all the failures occurred in the assembly line's robots.

- Analyze the Mean Time to Repair(MTTR) *value,* Analysis the MTBF value based on equation (1)

$$MTTR = \frac{\text{Production downtime (min)}}{\text{Number of repairs}} \quad (1)$$

- Analyze the Mean Time between Failures *(MTBF) value,* Analysis the MTBF value based on equation (2).

$$MTBF = \frac{\text{Time (Annual)}}{\text{Number of emergency work orders}} \quad (2)$$

- Evaluate Availability, The evaluation was based on equation (3)

$$Availability = \frac{MTBF}{MTBF + MTTR} \cdot 100\% \quad (3)$$

- Lowest Availability, Availability should be less than specified standard in the industry. As for replacement candidates, the lowest availability value selected.

- Evaluate defender marginal cost, Use Table-1, to evaluate defender marginal cost.

- Evaluate Challenger Equivalent Uniform Annual *Cost,* Use Table-2.

$${}^{n}\mathrm{EUAC}_k = \left[\sum_{j=1}^{k} \mathrm{TC}_j(P/F, 10\%, j)\right](A/P, 10\%, k). \quad (4)$$

- Compare Marginal Cost with EUAC, if marginal cost of defender less than minimum equivalent uniform annual cost, maintain the defender for one more year. (MCd < min EUACch). Otherwise, replace defender with challenger.

- Maintain Defender for one more year, continue evaluation for next year and it is yearly review activity.

- Replace defender with challenger, installation of challenger in the production line.

- Sensitivity Analysis of challenger, Do the sensitivity analysis technique or spider plot graph on the potential impact of several factors such as initial capital investment, annual saving, market value, study period and MARR.

- Re-evaluate the replacement decision, Each factor was considered based on impact to PW values. It was varied over a range of ±50% from the most likely estimate. The management to judge on the impact to company economic factor, if it is no impact, maintain the replacement decision. If yes, big impact to company economic situation, maintain defender for one more year.

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- Maintain the replacement decision. To propose maintain the replacement option.
- Maintain defender for one more year. Continue review on yearly basis for the defender.

The spreadsheets modelling using excel Microsoft software was adopted for the sensitivity analysis [2].

RESULTS AND DISCUSSION

Upon completing the MTTR, MTBF and availability analysis using the equation (1), (2) and (3), the third robot in the subsystem of robotic system in production line was found to have the lowest MTBF and availability. The MTBF and availability are 5280 hours and 99.41% respectively.

These findings could assist the maintenance manager to evaluate in terms of tightening up the maintenance schedule or carry out the replacement of the robot. In this study the next level of analysis is the replacement analysis by evaluating the defender MC and the challenger EUAC.

The computational of defender MC and challenger EUAC are tabulated in Table-1 and Table-2 respectively. The equations used for defender and challenger MC computation are incorporated in both tables. Equation (4) was used to calculate the EUAC of challenger. Table-3 and Table-4 summarized the results of challenger MC and EUAC, and results of defender MC respectively.

Table-1. Marginal cost for defender.

a) Marginal cost for defender

(1) End of Year k	(2) MV, End of Year k	(3) Loss in Market Value (MV) during Year k	(4) Cost of Capital = 10% of Beginning of Year MV	"(5) Annual Expenses (E_k)	(6) [=(3) + (4) + (5)] Marginal Cost for Year (TC_k)
0	100,000	-	-	-	-
1	90,000	10,000	10000	35,000	55,000
2	80,000	10,000	9000	40,000	59,000
3	70,000	10,000	8000	45,000	63,000
4	60,000	10,000	7000	50,000	67,000
5	50,000	10,000	6000	55,000	71,000

Table-2. Marginal cost and EUAC for challenger.

b) Marginal cost and EUAC for challenger

(1) End of Year k	(2) MV, End of Year k	(3) Loss in Market Value (MV) during Year k	(4) Cost of Capital = 10% of Beginning of Year MV	"(5) Annual Expenses (E_k)	(6) [=(3) + (4) + (5)] Marginal Cost for Year (TC_k)	(7) EUAC through Year k
0	250,000	-	-	-	-	-
1	210,000	40,000	25000	10,000	75,000	75001
2	175,000	35,000	21000	15,000	71,000	73095
3	145,000	30,000	17500	20,000	67,500	71401
4	120,000	25,000	14500	25,000	64,500	69922
5	100,000	20,000	12000	30,000	62,000	68619

Table-3. MC and EUAC analysis for challenger.

Year	1	2	3	4	5
MC	75,000	71,000	67,500	64,500	62,000
EUAC	75,000	73,094	71,400	69,922	***68,619***
					Min EUAC

The MC of challenger at year 5 is Malaysia Ringgit 62,000, is lowest. Similarly the EUAC in year 5 is Malaysia Ringgit 68,619 is lowest. Hence, the current robot is fit to be in service for one more year.

Table-3. MC analysis for defender.

Year	1	2	3	4	5
MC	55,000	59,000	63,000	67,000	***71,000***

By analyzing the MC for defender, the MC is Malaysian Ringgit 71,000 at year 5. Hence, replacement should be made by end of year 5. Further analysis is to explore the impact on the present worth of challenger relative to change in the capital investment, annual savings, market value, study period and MARR using spreadsheet formulas.

The excel spreadsheet modeling application to answer "what if" questions was adopted [2]. The robot present worth can be determined using a spreadsheet for sensitivity analysis. Figure-3 shows the sensitivity analysis graph for initial capital investment, annual saving, market value and MARR. Capital investment is the most sensitive to present worth (PW).

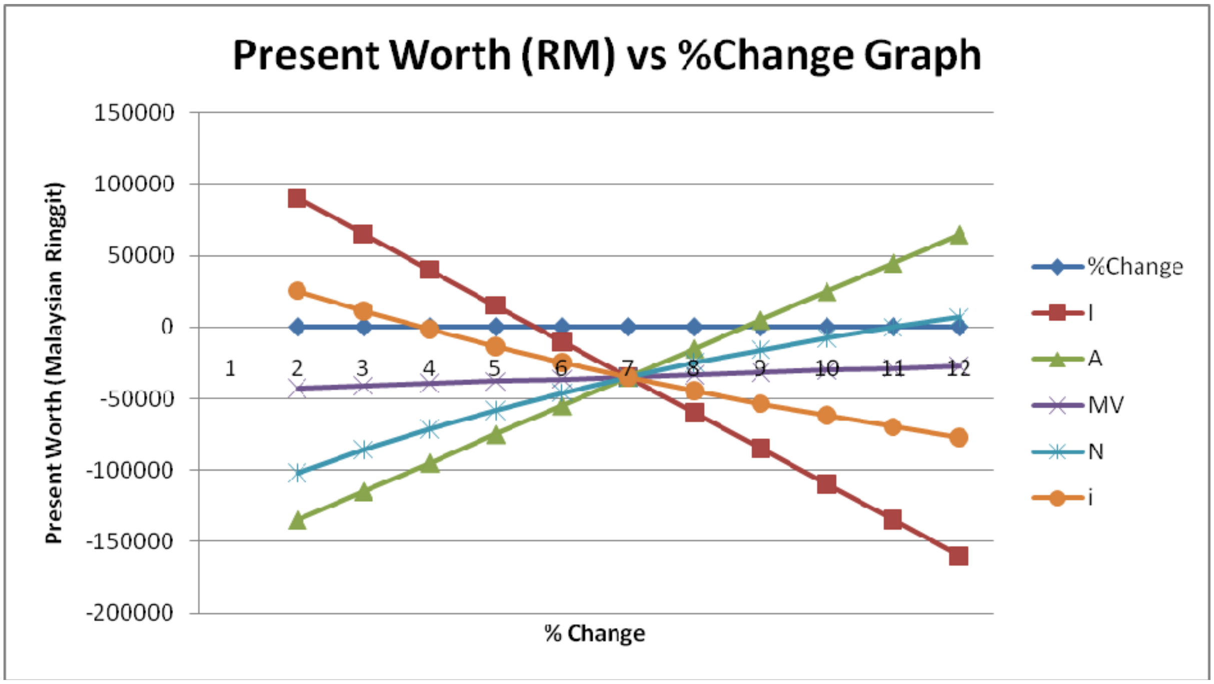

Figure-3. Present worth (RM) vs % change graph.

CONCLUSIONS

The proposed model on replacement incorporated both the technical and economical criteria. The incorporation of these critical failures covers the commercial requirement of the industry. Hence, the model could be useful for the industry to make a decision on the robot replacement. The third robot which was having the lowest MTBF value 5280 hours and availability value 99.41% is candidate for replacement. At the year 5, MC of defender is Malaysian Ringgit 71,000 and challenger EUAC is Malaysian Ringgit 68,619. Hence the defender should be considered for replacement. Replacement of robot with challenger could be done at the end of year 5. Sensitivity analysis of the challenger with respect to initial capital investment, annual saving, market value and MARR found out that the initial capital investment is the most sensitive factor to PW compared to the other factors.

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