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Managing maintenance resources for efficient asset utilization

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Abstract

Asset productivity is concerned with how an asset is efficiently and effectively deployed and utilized. It is related to maintenance resource management. The purpose of this paper is to discuss development of policies for managing integrated maintenance resources. These resources include human resource and supporting material required to perform maintenance activities for a complex maintenance system. Here, human resource management encompasses policy for recruitment, training, and outsourcing. Meanwhile, supporting material management includes policy for parts purchasing and inventory. Good asset productivity can be achieved by attaining a better performance of the asset using the same amount of maintenance resources or by reducing the amount of maintenance resources used for the same asset performance. A maintenance department may manage each kind of resources and have its own policy to achieve better asset productivity. In this way, an integrated policy with all related departments is required. In this research, a model to determine an integrated optimum policy with associated departments is developed. It consists of three sub models representing three different departments in an organisation including Maintenance, Human Resource, and Inventory and Purchasing department. Through the model, some combinations of the policies can be made and tested to find the best combined policy that, in turn, can help to generate better asset productivity.

Keywords

utilization, maintenance, resources, efficient, asset, managing

Disciplines

Engineering | Science and Technology Studies

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MANAGING MAINTENANCE RESOURCES FOR BETTER ASSET PRODUCTIVITY

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Summary

Asset productivity is concerned with how an asset is efficiently and effectively deployed and utilized. It is related to maintenance resource management. The purpose of this paper is to discuss development of policies for managing integrated maintenance resources. These resources include human resource and supporting material required to perform maintenance activities for a complex maintenance system. Here, human resource management encompasses policy for recruitment, training, and outsourcing. Meanwhile, supporting material management includes policy for parts purchasing and inventory. Good asset productivity can be achieved by attaining a better performance of the asset using the same amount of maintenance resources or by reducing the amount of maintenance resources used for the same asset performance. A maintenance department may manage each kind of resources and have its own policy to achieve better asset productivity. In this way, an integrated policy with all related departments is required. In this research, a model to determine an integrated optimum policy with associated departments is developed. It consists of three sub models representing three different departments in an organisation including Maintenance, Human Resource, and Inventory and Purchasing department. Through the model, some combinations of the policies can be made and tested to find the best combined policy that, in turn, can help to generate better asset productivity.

Keyword: Asset productivity, maintenance resource management, system dynamics simulation

1 INTRODUCTION

Maintenance resource management plays an important role in achieving better asset productivity and in supporting an asset performance in a firm. It comprises management of all resources required to perform all maintenance tasks, such as managing human resources (engineers, mechanics, or technicians), parts, tools and equipments, and other supporting and consumable materials. An incorrect decision leading to a shortage of required maintenance resource to support maintenance tasks may cause an ineffective result of maintenance process[1]. Similarly, the excessive amount of maintenance resources stored or provided by a company might lead to an inefficient use of the budget. Making policy or a decision in maintenance to attain the required asset performance is impacted by the number of available resources. Hence, from an integrated system perspective, it can be said that there are some causal impacts by maintenance policy and maintenance resource management on asset management effectiveness. This structure of causal impact in asset management constructs a complex environment for decision maker to make an appropriate decision in order to maintain or improve the assets' productivity. From a modelling perspective, the environment can impose complex factors if there are some non-linear behaviours in the decision making process. Component lifetime involving uncertain down time, for instance, can lead to non-linear requirement for maintenance resource.

This paper investigates the effects of certain decisions made on managing maintenance resources on the asset performance. In an extensive discussion, the maintenance resources optimisation with regarding to developing a maintenance resource policy to achieve the target level of asset performance is elaborated. For this purpose, a system dynamic model is developed and verified by a case study application. The model has the potential to serve as a tool for maintenance resource provision policies. A numerical example is incorporated into the model to demonstrate the analysis results.

2 RESEARCH BACKGROUND

The important role of maintenance in enterprises running complex assets has been elaborated, see for instance, Tam & Price [2] and El-Akruti & Dwight[3].As said by El-Akruti & Dwight[3], maintenance is one of asset life cycle activities collaborated with other supporting activities including human resource management and purchasing. Most studies in maintenance and optimisation (e.g. [4] and [5])seems to neglect any conditions in the practice in organisations such as the limited number of maintenance resources that, in fact, need to be considered[6].Most of the modelling approaches in this area are the analytical solutions that still have a limitation to model a complex system[7-8]. Thus, the limitation of modelling techniques can lead to the lack of good models to represent complex technical systems and its related environment. This shortage in modelling approaches, oppositely, provides an opportunity for us to explore the potential application of system dynamics modelling for fulfilling the requirement of integrating maintenance resource management into asset management system. It is argued that system dynamics modelling can overcome limitation caused by non-linear characteristics. In the modelling, the system characteristics can be described by system dynamics represented by feedback processes, non-linearity, time delays, and stock-flow representation (Pidd[9] and Sterman[10]). Additionally, it serves stock and flow structure in meeting easily the number of maintenance resource provided, the time delays, lead time in purchasing and recruitment process. This suggests that system dynamics modelling approach may be appropriate to modelling an integrated maintenance resource management for the targeted assets.

The research articles on application of system dynamics simulation for maintenance and asset management is relatively limited comparing with the use of analytical solution or mathematical model. Some examples of system dynamics model development for investigating the dynamics behaviour of maintenance of an asset management system can be found in [4, 11-15]. In a literature review on system dynamics simulation for maintenance and assets management, most studies are focusing on one unit and do not consider the interrelation between maintenance resources of other units and other subsystems. The most relevant one to this research is an article given by Bivona & Montemaggiore[14] where a system dynamics model is used in management to find out the effect of a certain decision on the entire system. The model includes five major functions in the observed company: Production, Human Resources, Maintenance, Assets Management, and Finance. At an enterprise level, this model is considered sufficient to represent a general function, yet only one type of maintenance resource is included - Human Resource. So, in an environment where other resources (e.g. parts, tools, and equipment) have significant contributions to the total cost, a more complicated model should be considered in decision making. To comply with the requirement for a model that integrates maintenance resources policy in a complex system involving asset performance management, further investigation is required. A study was initially given by Cahyo et al. [15] where a preliminary model is developed as a basis of an integrated approach to analysing the interrelationships between assets performance in a multi-unit maintenance program and its related maintenance resource management (Human resource and Purchasing).

3 MAINTENANCE RESOURCE PROVISION FRAMEWORK

Figure 1 presents a framework for maintenance resources provision policy analysis in which the input and output of this maintenance resource policy are determined within a system. Here, the desired output is determined by an asset performance that can be maintained in accordance with a key performance indicator determined by the enterprise. The output provides feedback on the system’s input elements including, i.e., Machines, Human resources, parts, tool & equipment. The output is determined by the level of inputs provided by the enterprise through its maintenance resources provision policies. If productivity is chosen to be a measure of asset performance, it can be evaluated by the ratio of output to input. Since each type of maintenance resources is controlled by different department, different policy implementation control might occur simultaneously. As a result, a particular overall maintenance resource states can be constructed as policies in this situation. Further, the information about an overall resource states combined with desired performance of the asset is important in decision making in relation to a maintenance resource provision. To improve the performance, several sets of possible maintenance resource provision policies should be considered. Comparison bases in this case should be set to find the optimum policy implemented to improve the performance. In some occasions, the implementation policy requires a simultaneous action taken for input, process or the output of the system (i.e. integrated resource provision policy, maintenance process adjustment, and performance adjustment). This indicates then that the process of making a maintenance resource provision policy refers to an iterative process throughout the asset lifetime.

Integrated resource provision policy is an integrated action among relevant departments that provide the level of maintenance resource required for an effective maintenance process. This action on purpose is to achieve optimisation at the enterprise level and to eliminate sub-optimisation in each department. To improve asset performance, a number of interrelationship parameters between resources provision policy and the type of maintenance policies (e.g., fixed interval or periodic maintenance, breakdown maintenance, or condition based maintenance) are considered. At this point, the desired performance of the asset should be realistic - in other words, it is always better to adjust the output to be practically achievable.

The modelling approach used to represent this decision making process should be capable of covering the dynamics of each part of the system as necessary. In some particular systems, a decision maker also has to deal with an uncertain variable included in the system, especially for some uncontrolled variables such as part lifetime, lead time, and other external/environment influences.

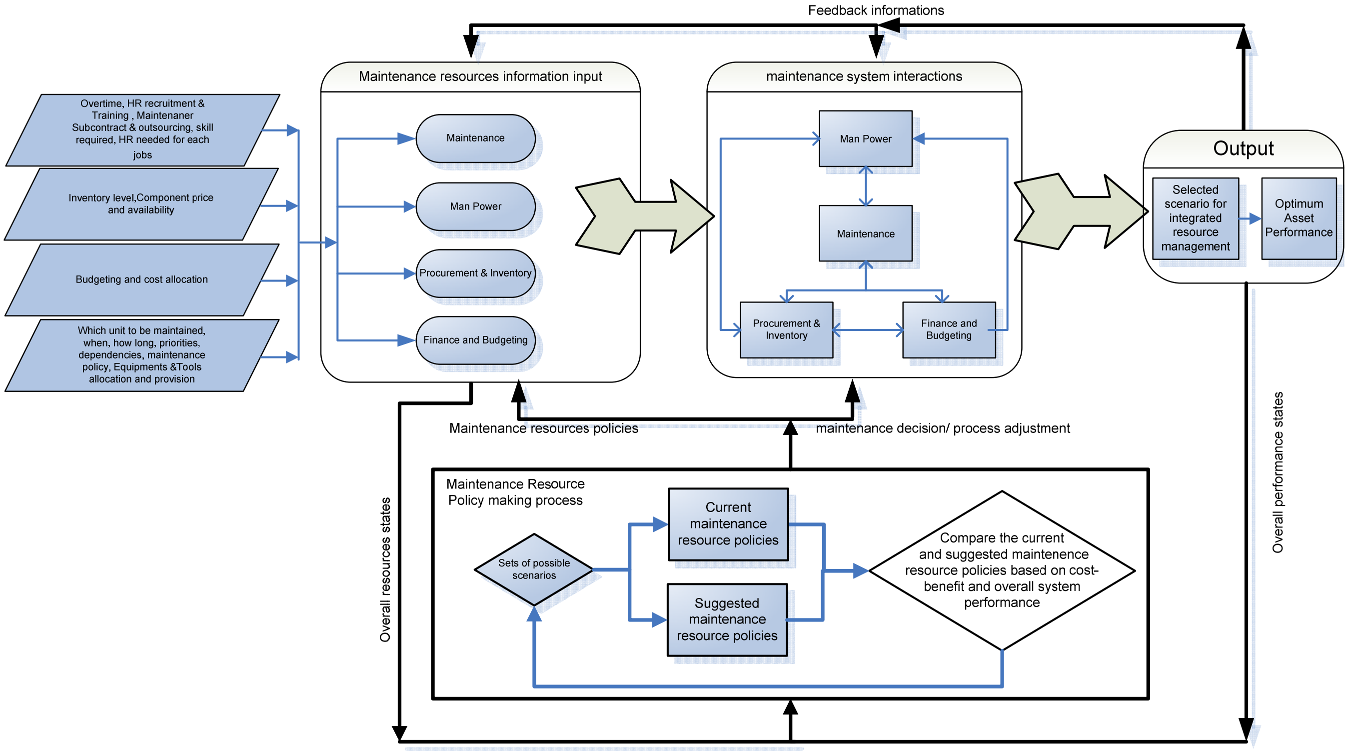


Figure 1 : of integrated maintenance resource analysis (adopted from [15])

4 CASE APPLICATION: NUMERICAL VERIFICATION

As a continuation of the study presented in [15]this case application involves the verification of the model while including human resource, procurement & inventory in the decision making process. The selected case is a wind farm as shown in Figure 2. In this case study, resources provision policy development is focused highly on the maintenance process of converter modules in each wind turbine. One wind farm consists of a number of wind turbines usually located in a remote area. It requires a good plan and preparation in term of maintenance resources brought to the location. In other words, the quantity and quality of maintenance resources need to be reliable to support the maintenance tasks considering that the cost to visit the wind farm is relatively not lower. In this case, the model consists of only 10 representative wind turbines.

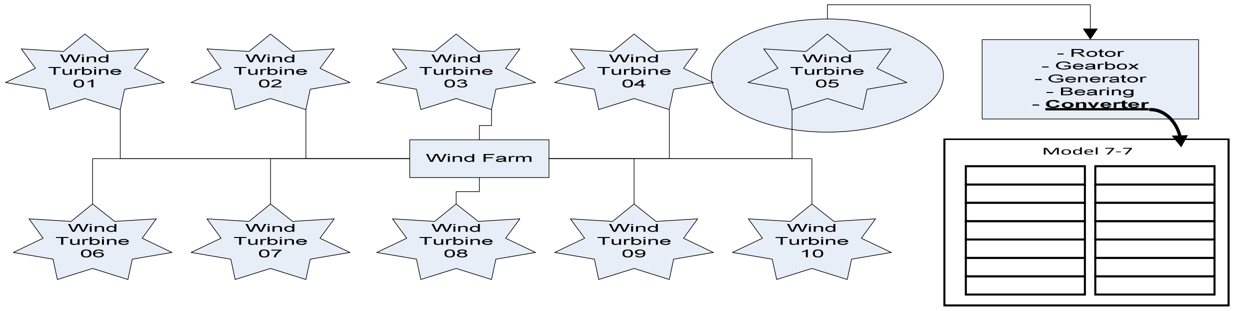


Figure 2 : Schematic presentation of the wind farm case study

In general, blades, gearbox, generator and converter are main components in a wind turbine in terms of maintenance. The function in detail of each major component can be seen in [16]. Briefly, converter is used to convert one electricity form to another, such as from AC to DC or vice versa, and from one voltage or frequency to another [16]. Each wind turbine has one converter subsystem that consists of 14 basic converter modules and is able to tolerate 2 failed modules in this case study. The failure of three converter modules causes failure of converter that makes the wind turbine stop operation . In this occasion, an unscheduled maintenance (UM) will be required in general. Scheduled maintenance (SM) is to be performed every 6 months (180 days) to replace failed converter modules found in each converter. All maintenance is performed as required as long as some maintenance resources are available. Each component has a different lifetime (hours) that follows an exponential distribution with $\lambda = 10^{-5}$in this case study. In this case, two maintenance resources, human resources measured in man-hours (MH), and spare parts measured in pieces (pcs), are involved in modelling. In human resource part of the model, 8 persons are assumed available with 8working hours per day. Thus, there are 64 man-hours available each day. One maintenance task (SM or UM) requires 2 persons for 2 hours for one converter in each wind turbine. To ensure the availability of maintenance resource, part purchasing is regularly done based on its safety stock level. When the stock level is less than 15 units, a purchase order will be sent to supplier and the new parts will be received within 30 days after order.

Figure 3, presents a flowchart of the logic of the system dynamics model developed. In the beginning of simulation, initial system state is determined by generating the value of some variables: initial lifetime of each converter module in all converters, initial inventory level, initial man hours provided and the interval of scheduled maintenance. Once the initial state of the system is determined, the next step is to execute the simulation. During the simulation, the logic is used to check the number of components failed in each converter system. In the simulation, SM order will be generated based in SM interval. Generated SM order will be followed by determining the number of maintenance resources required for SM (i.e. number of parts to replace failed components, and man-hours required). If required resources are available, SM can be performed. If not, maintenance resource provision must then be carried on to fulfil the requirement. The procedure to fulfil the maintenance resource requirement for UM is similar to SM.

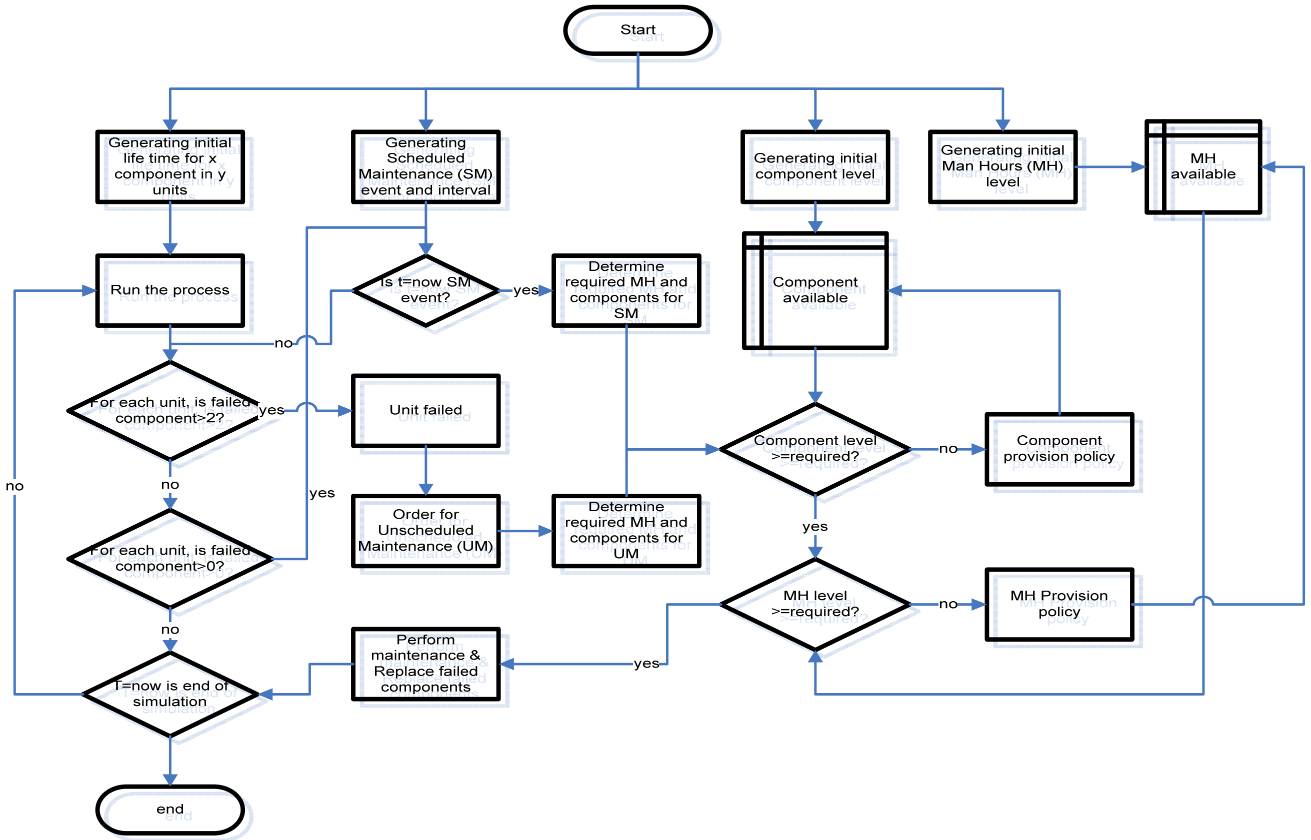


Figure 3 : Modelling Flowchart

In general, a model should be established based on a valid modelling methodology. To surely achieve this, this research follows the methodology established by Maani & Cavana[17]. In brief, the methodology consists of five phases: (1) Problem structuring, (2) Causal loop modelling, (3) Dynamic modelling, (4) Scenario planning and modelling, and (5) Implementation and organizational learning. In the second phase, a causal loop modelling must be developed. For this, the logic of the flowchart is converted into a conceptual model of system dynamics, usually in the form of causal loop diagram (CLD). As presented in Figure3, a CLD for converter system dynamics simulation is developed.

The CLD consists of 3 major sections: human resource, maintenance, purchasing and logistic. Analysing the CLD starts from the number of components failed in the maintenance section. The increasing number of failed components finally leads to asset failure and required UM, respectively. In contrast, the completion of UM reduces the number of components in failure. This loop (# of components failed➔Asset failure➔required UM➔completed UM➔#of components failure) forms a loop that, in this case, is called loop B1, representing unscheduled maintenance process. The process in loop B1 is affected by loop B5 that represents component procurement (# of component failed➔Asset failure➔required UM➔UM required part➔Expected demand➔order quantity➔available part➔replaced components➔completed UM➔# of component failed) and loop B3 that represents the required man-hours. According to this relationship, UM is unable to be completed without available components and man-hours. A similar process is also applicable in the loop R2 and B4 (SM process), R5 (component procurement for

SM), and R3 (man-hours required for SM). The next process of system dynamics modelling is to converting the CLD into the system dynamics simulation program. At this preliminary stage, not all components or variables in the CLD will be considered in the model.

The CLD in Figure 4 only represents a relationship between maintenance process and human resource and procurement &inventory for one converter module. Generally, the CLDs are similar one to each other. For integrated units that require maintenance resources from the same source, the total requirement from all units is the accumulation from the units covered by suggested maintenance process. In practice, each department in an enterprise may have its own strategy that, in this case, is considered as the most efficient strategy to save cost (Figure 5). If each of “the most efficient strategies” is implemented independently without considering other department, however, this may not lead to the most efficient strategy at the enterprise level. For instance, an inventory department as well as purchasing & logistic one tend to keep the inventory level to minimum level to save cost, but maintenance department may argue to keep the level as high as possible. Hence, it is deemed important to decide the optimum level of maintenance resources in general to achieve optimisation at enterprise level by considering all related internal and external situations and by accommodating the interest of each department. This conflict presumably can be reduced by seeing the whole system using the system dynamic model. If the model is verified by all related departments and validated. Some scenarios can be tested to find the possible best solution in the enterprise level (Phase 4 of [17]).

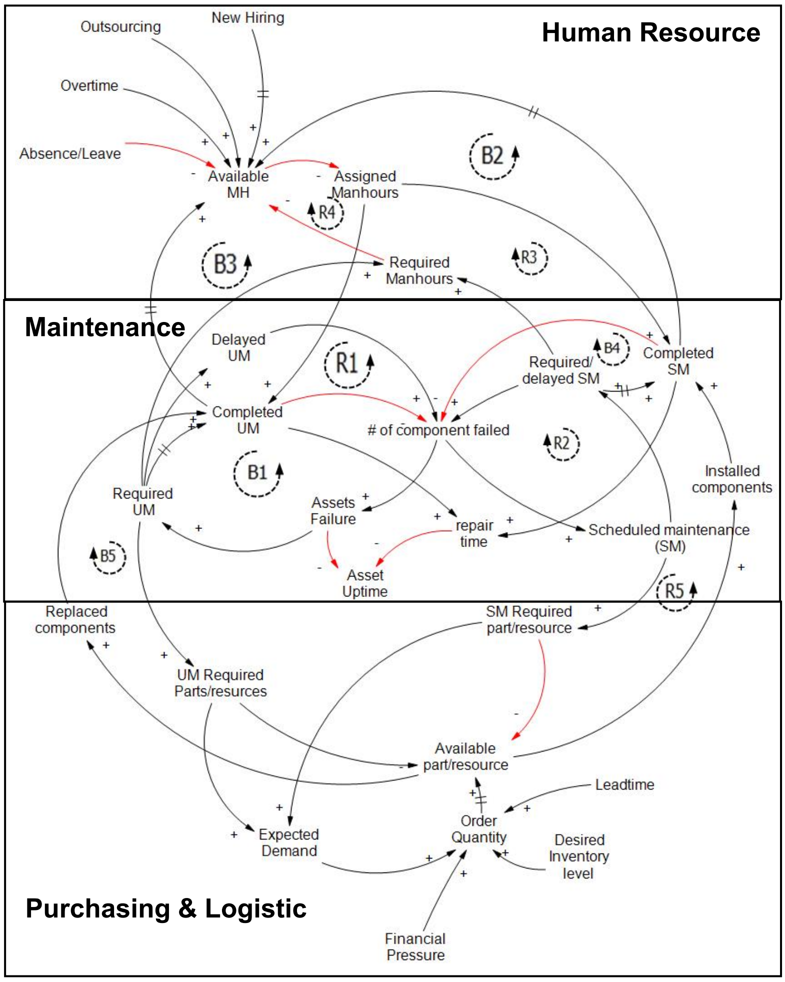


Figure 4 : CLD of converter maintenance process

5 SYSTEM DYNAMICS MODEL

In the proposed methodology after developing causal loop model, the next step is to convert the CLD into system dynamics model based on modelling flowchart. The model consists of four sub-models: sub-model for converter, sub-model for maintenance, sub-model for procurement & inventory, and sub-model for human resources. The sub-model of converter contains the system dynamics model of 10 modules. It represents the model for generating random initial lifetimes based on the selected distribution of each component. This involves procedures of how the lifetime is decreased over time and increased by new replacements, logic to generate component or modules of working or failure status.

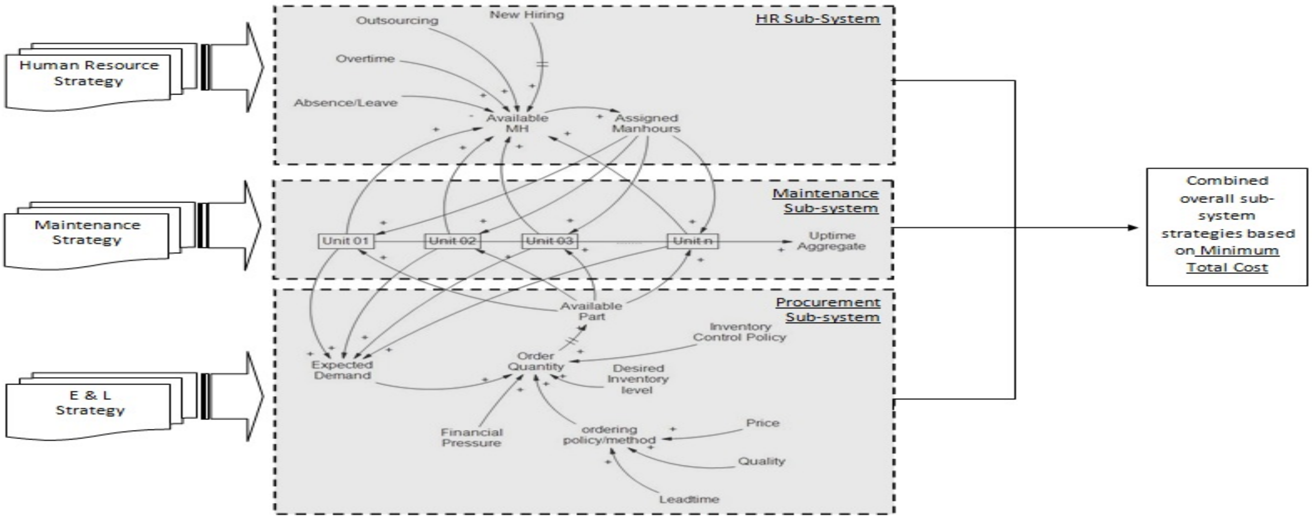
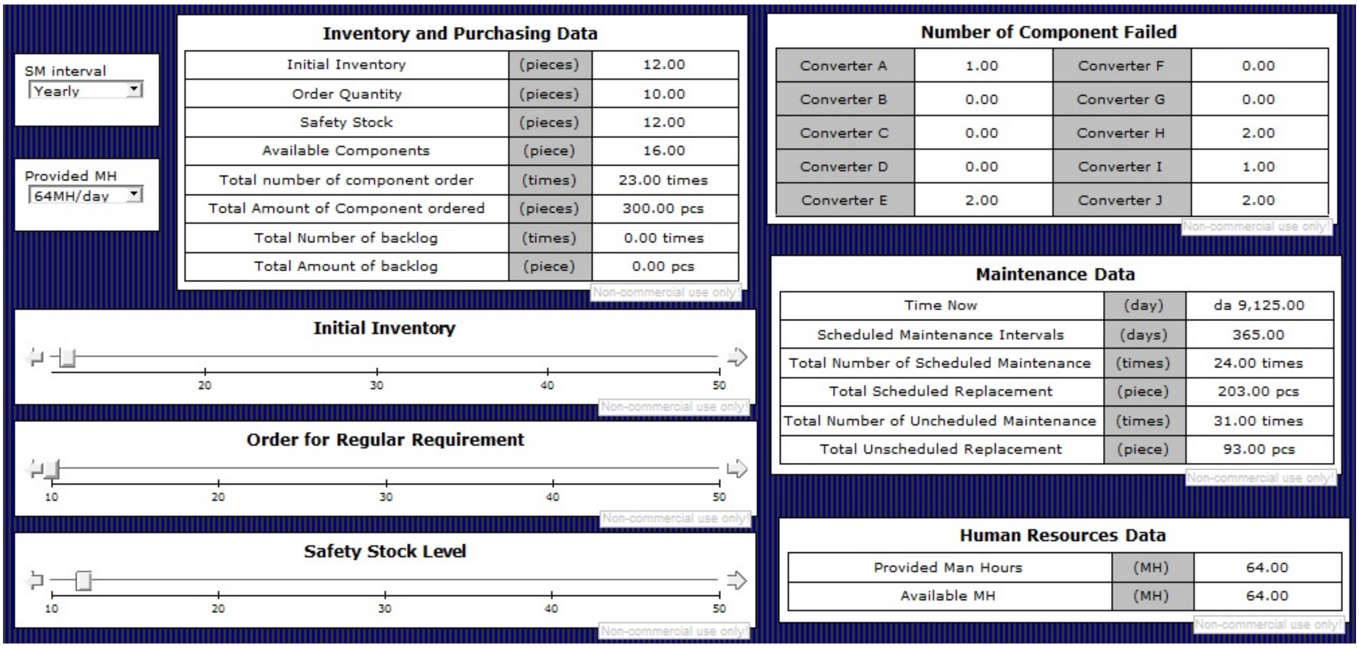


Figure 5 : Scheme for finding possible best scenario

In the maintenance sub-model, a condition to generate SM and UM orders is presented. SM orders are generated periodically based on SM policy and UM order is generated when a converter failure takes place. When SM order is generated, the model collects data about how many components are failed to determine the number of required parts for SM of other converter systems. After the required part is identified, this amount is compared with available parts in the purchasing & logistic sub-system. If available parts are sufficient, the requested amount will be prepared and delivered to maintenance sub-system for replacement processes. A similar process is also implemented in human resource sub-model. After this procedure is done on the whole model, a model dashboard is created to ease the model observation and selected input adjustment, see Figure 6.


SM interval: Yearly

Provided MH: 64MH/day

Inventory and Purchasing Data

Initial Inventory	(pieces)	12.00
Order Quantity	(pieces)	10.00
Safety Stock	(pieces)	12.00
Available Components	(piece)	16.00
Total number of component order	(times)	23.00 times
Total Amount of Component ordered	(pieces)	300.00 pcs
Total Number of backlog	(times)	0.00 times
Total Amount of backlog	(piece)	0.00 pcs

Number of Component Failed

Converter A	1.00	Converter F	0.00
Converter B	0.00	Converter G	0.00
Converter C	0.00	Converter H	2.00
Converter D	0.00	Converter I	1.00
Converter E	2.00	Converter J	2.00

Maintenance Data

Time Now	(day)	da 9,125.00
Scheduled Maintenance Intervals	(days)	365.00
Total Number of Scheduled Maintenance	(times)	24.00 times
Total Scheduled Replacement	(piece)	203.00 pcs
Total Number of Uncheduled Maintenance	(times)	31.00 times
Total Unscheduled Replacement	(piece)	93.00 pcs

Human Resources Data

Provided Man Hours	(MH)	64.00
Available MH	(MH)	64.00

Figure 6 : Dashboard of the simulation model

Figure 6 shows a brief view of parameters used in simulation tabulated as information about procurement and inventory data, components failed in converters, maintenance, and human resources. On the other part of the dashboard there are some facilities used to change the simulation input of certain variable in order to generate a different scenario implemented in the model. These are the combo box menu for SM interval and provided MH, sliders menu for Initial inventory, order for regular requirement, and safety stock. To investigate to what extent the better productivity can be achieved; four different scenarios are then given. In this case, the scenarios are differentiated based on the combination of different SM internal and order quantity. Scenarios 1 and 2 have the same SM interval but different order quantity in each purchasing order. Similarly, Scenario 3 and 4 have the same SM period but different order quantity. Table 1 below presents the details about the initial data of each scenario.

Table 1: Initial input data for each scenario

input	unit of measure	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SM interval	**days**	**180**	**180**	**365**	**365**
initial inventory	pcs	10	10	10	10
Safety stock level	pcs	15	15	15	15
Order quantity	**pcs/order**	**50**	**30**	**50**	**30**
MH	MH/day	64	64	64	64

To use facility to change simulation input in the model dashboard, each scenario is implemented in the model. For simulation output data collection, all scenarios are run for 100 replications. Table 2 presents the summary of the simulation output data for each scenario.

6 OUTPUT ANALYSIS AND DISCUSSION

In this study, two SM intervals of 180 days and 365 days are used is to investigate the impact of longer SM interval on other variables. It can be observed that during simulation the same SM internal (in scenarios1 &2, and scenarios 3 & 4) has resulted in the similar number of performed UM. In contrast, longer SM interval causes the number of UM performed to significantly increase from around 10 times in scenarios1 and 2 to around 29 times in scenarios 3 and 4.The data of total UMs in each replication at different scenario is shown in Figure 7. The longer SM interval also affects the number of backlog order. In Scenario 1 and 2, there are no parts ordered caused by insufficient number of available parts in storage - except only in Scenario 1 replication 23. However, in Scenario 3 and 4 the significant number of backlog order appears (Figure 8). Related to information about average number of total parts ordered from 100 replications in Table 2, the numbers of statistical calculations have been performed using the hypothesis test to compare data in scenario 1 and 3, and scenario 2 and 4.

These two comparisons are to investigate the difference of total number of parts ordered under the same order quantity but different SM interval situation. The result of the statistical calculation shows that there is no difference on the average value of total number of parts ordered in Scenario 1 in comparison to Scenario 3 and in the comparison of Scenario 2 and 4.

Table 2: Summary of simulation output for 100 replications

variables	unit of measure	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		average	stdev	average	stdev	average	stdev	average	stdev
Number of SM performed	times	50.00	0.00	50.00	0.00	24.00	0.00	24.00	0.00
Number of UM performed	times	10.65	3.27	10.64	3.37	29.01	5.85	29.83	5.54
Total part required for SM	pcs	269.49	17.28	269.94	15.57	207.09	12.33	206.18	11.79
Total part required for UM	pcs	31.64	9.85	31.83	10.10	86.93	17.63	89.18	16.60
Total number of order performed	times	5.87	0.42	8.92	0.73	5.81	0.54	8.78	0.66
Total number of part ordered	pcs	332.83	22.57	323.84	21.94	328.68	27.82	316.49	21.71
Total backlog occurred	times	0.03	0.17	0.00	0.00	0.70	0.48	0.65	0.52
Total number of part ordered in Backlog	pcs	1.82	11.41	0.00	0.00	74.92	75.39	63.16	66.39
average daily available component	pcs	41.55	1.38	31.19	0.90	40.26	1.38	30.24	0.92

At this stage of research and simulation modelling, human resource for SM and UM has not been considered in the scenario development since the determination of the number of optimum MH provided is found relatively simple. The maximum MH requirement of all 10 converters for maintenance purposes (SM and UM) is 40 MH/day - equal to 5 persons/day. However, for safety purposes, all maintenance processes need to be done by 2 persons in one wind turbine. One additional person is adequate to cover one converter SM process in one day. At this stage, the lack of data and information about human resource for wind turbine maintenance also becomes the reason for not putting MH in the scenario development.

6.1 Discussion

For the situation where UM has to be reduced or avoided, a decision maker is recommended to chose Scenario 1 or 2, which have the shorter interval of SM. Based on simulation output, the backlog order may be associated with the longer interval of SM in Scenario 3 and 4. The longer SM interval requires more spare parts to accomplish the maintenance task. With the same number of order quantity in each order, the chance of having backlog order with longer SM interval is higher. Furthermore, to avoid backlog order, it is recommended to increase the number of order quantity but it consequently can cause the higher number of daily inventory of spare parts. In the event that backlog appears in Scenario 1, it is indicated that the backlog order is caused by the extreme condition of simultaneous components failures.

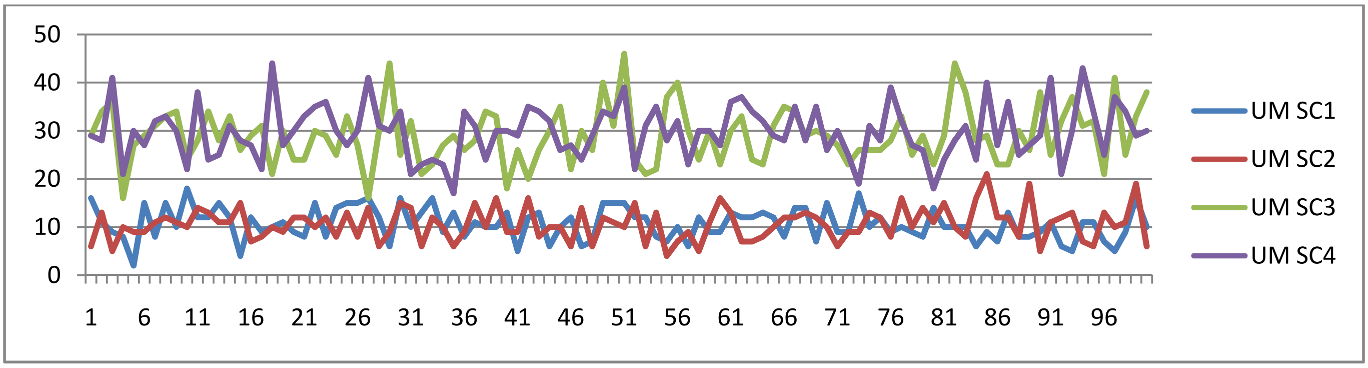


Figure 7 : Chart of Total UM in each replication

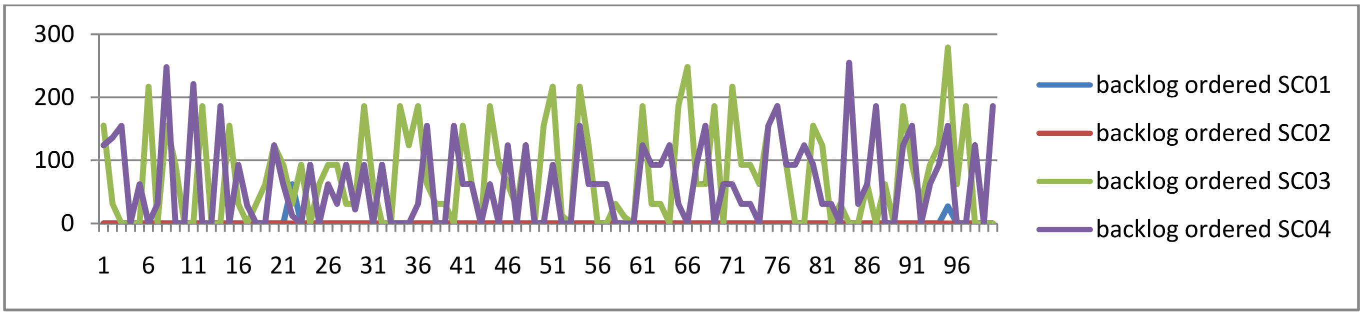


Figure 8 : Chart of total parts ordered in backlog order in each replication

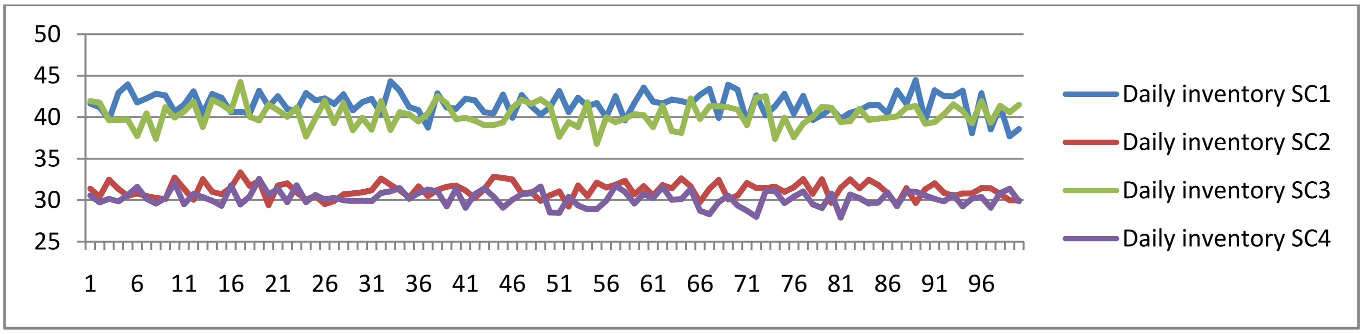


Figure 9 : Chart of average daily inventory in each replication

On the out variable of average daily available component, some similar results are shown by scenarios with the same number of quantity order. Here, Scenario1 is similar to 3 and Scenario 2 is similar to 4. Hence, it is argued that the higher the quantity order is, the higher the daily inventory will be. An interesting result is shown on the relation of SM interval and daily inventory. The longer interval of SM may not affect daily inventory. It can be seen on Scenario 1 and Scenario 3 that have a different SM interval but similar daily average. This same occurrence also happens in Scenario 2 and 4. The other interesting point is found in the relation of SM interval and total number of parts ordered. The result of statistical calculation shows that SM interval has no significant effect on the total number of components ordered. This claim is based on the result showing a difference on the average value of total order quantity between Scenario 1 and 3 and between Scenario 2 and 4.

7 CONCLUSION

A system dynamics model for maintenance resources provision optimisation has been developed. For verification, it has been applied to a wind farm converter system maintenance analysis. Overall, by considering that the wind turbines need to supply power continuously, Scenario 1or 2 is a good option. Both scenarios produce a similar output, except on the number of orders placed and number of average daily available inventory parts. In the situation where inventory cost is not an issue and order cost is expensive, Scenario 1 is the best option in view of the capability of higher inventory in providing more support for maintenance activity. In another situation where inventory cost needs to be considered and the order cost can be ignored, Scenario 2 is a good option.

Through the simulation presented in this paper, the causal effects of a certain decision on the system performance are identified. The future steps of the research should include the investigation of an overall human resources involved in wind farm maintenance and associated costs in all activities. By considering the associated costs into the simulation model, the simulation results can be used by a decision maker such as a wind farm manager to make a decision in selecting the best scenario in product lifecycle maintenance.

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