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A resources provision policy for multi-unit maintenance program

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Abstract

A System Dynamics model for resource provision policy in multi-unit maintenance program is developed. First, a scheme is developed to formulate and evaluate policies regarding the provision under uncertain condition or resource requirement in a period of planning to result in minimum maintenance cost. The model emphasizes on resourcing strategy involving human and procurement. It is composed of 3 sub-models presented in a causal loop modelling. The human resource sub-model focuses on policies related to provision and management. The procurement sub-model takes into account the procurement process and inventory system. Due to data availability, the verification has encloses only the relation between maintenance and human resources but further application on wide range of resources through case studies is intended. The advantage of this model is related to its wide outlook of interrelated variables of a complex multi-unit maintenance system. This model can show the impact of one decision in a certain maintenance resourcing system on the other maintenance resourcing system and will lead to an optimum policy for maintenance resource provision system.

Keywords

multi, policy, unit, program, provision, maintenance, resources

Disciplines

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A Resources Provision Policy for Multi-unit Maintenance Program

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Abstract A System Dynamics model for resource provision policy in multi-unit maintenance program is developed. First, a scheme is developed to formulate and evaluate policies regarding the provision under uncertain condition or resource requirement in a period of planning to result in minimum maintenance cost. The model emphasizes on resourcing strategy involving human and procurement. It is composed of 3 sub-models presented in a causal loop modelling. The human resource sub-model focuses on policies related to provision and management. The procurement sub-model takes into account the procurement process and inventory system. Due to data availability, the verification has encloses only the relation between maintenance and human resources but further application on wide range of resources through case studies is intended. The advantage of this model is related to its wide outlook of interrelated variables of a complex multi-unit maintenance system. This model can show the impact of one decision in a certain maintenance resourcing system on the other maintenance resourcing system and will lead to an optimum policy for maintenance resource provision system.

Keywords: Resource provision · Multi-unit maintenance system· System Dynamic Modelling

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1 Introduction

In engineering asset management, maintenance has become a mainstream of research focus. Most research is focusing on development of more effective, efficient and optimum maintenance systems that will contribute to better performance of assets. A broad range of models to enhance and achieve optimization in maintenance practice has been developed e.g. (Cui & Li, 2006; Ilyas Mohammed, Cassady, & Edward, 2006; Tsai, Wang, & Tsai, 2003; Wang, 2011). Maintenance resources play an essential role in such optimization. Optimization of maintenance practice becomes difficult for complex multi unit maintenance system. This complexity involves ensuring adequate maintenance resources and sufficient allocation of the maintenance resource to each unit to cover the requirement of maintenance process and guarantee that all units are able to achieve the desired reliability.

This research aims to model the process of managing maintenance resources in a multi-unit maintenance program for developing an effective maintenance resource policy. In multi-unit technical system, resource allocation is integrated into maintenance programs by synthesizing each unit along with the required resources from the maintenance program. In this manner, all required resources are accumulated into the total resources required for the whole technical system as a part of an integrated maintenance planning program. The required amount of resources as a result of maintenance resource planning has to be compared with the available maintenance resource. This process is similar to the aggregate planning process in manufacturing industry. It is a common situation that the number of maintenance resources becomes a limiting condition for a technical system to achieve a certain performance that must fulfil the business needs. In order to make a policy for such situation, an appropriate modelling approach is required.

In general, a large number of publications on maintenance method and resources exist but the nature of each industrial system requires a unique maintenance resource management system in terms of type, capacity and complexity (Ilyas Mohammed, et al., 2006). This argument leads to the need for undertaking research in developing a specific model for the compatibility of maintenance resource management with the particular nature of the industrial technical systems. In a multi unit technical system, each unit may require different maintenance policy that involves different amount of maintenance resources over time. The implementation of such maintenance policy in one unit will affect the availability of maintenance resources for the others. Unavailability of required maintenance resources may lead to ineffective maintenance programs and may cause unit failure (Wang, 2011).

A range of research models have been developed for multi unit maintenance system, either utilizing analytical solution or simulation. Models used for multi unit maintenance system that utilize analytical solution are usually referred to as mathematical models (Cui & Li, 2006; Okogbaa, Otieno, Peng, & Jain, 2008; Tsai, et al., 2003). In a certain complexity of a technical system, a mathematical model can be adequate to model the system, however; when the system is getting more complex, the use of simulation is a preferable option (Altiok & Melamed, 2007). Altiok and Melamed (2007) argued that it is difficult to find a proper model to represent the system being observed, and developing such model can be expensive. Endrenyi (2001) stated that the mathematical modelling involves a large number of input information that sometimes is not easily obtained. For those reasons, the decision makers will be likely to avoid complex mathematics and modelling techniques that time-based data (Tam, Chan, & Price, 2006) and consider simulation as an alternative for modelling.

Beside the system complexity of resource allocation in a multi unit maintenance system, the time horizon of the policy must be considered in the modelling process because it is a dynamic system where the maintenance resources' states always change over time (Dwight, Gordon, & Scarf, 2012; Xiaohu, Xisen, Yanling, & Yongmin, 2007). This situation requires a detailed analysis of requirement, provision, and allocation of maintenance resources and therefore a systematic and dynamic maintenance resources policy model is required. The modelling technique must be able to capture the dynamics of the system to describe the effect and feedback of the maintenance policy of each unit to the overall technical system control (Xiaohu, et al., 2007). Based on this analysis, system dynamics methodology tends to be an appropriate method to deal with the development of a model for the maintenance resource policy making purpose.

2 Research outlook

The implementation of any maintenance resource policy for a unit in a system will influence the other units directly or indirectly. According to Yang, et al. (2009), for making a good decision regarding to this maintenance decision making, it is important to have a good structure of the complex technical system to allow for analysing the important relationship among elements in the system and sub-system. The system structure must also allow for explaining the feed-back or consequences of a certain implemented decision to the whole system performance.

It is proposed that system dynamics can be useful for enhancing the maintenance infrastructure to improve maintenance performance. Kothari (2004) and Xiaohu, et al. (2007) developed system dynamics models for maintenance system analysis. Kothari (2004) developed a system dynamics model in order to analyse the dynamics behaviour of maintenance policy's components in the area of system's economic and technical performance. He defined the dynamics of behaviour and then formulated and tested alternative policies to improve system performance. Similarly, Xiaohu, et al. (2007) also developed a system dynamics model to analyse maintenance system's basic elements and structure for multi components technical system. Both Xiaohu, et al. (2007) and Kothari (2004) in their model have apparently assumed the number of maintenance resources is unlimited. More advance, Bivona and Montemaggiore (2010) developed a model that connected maintenance system with human resource, finance, service provision and assets management systems. The purpose of the modelling is to observe short and long term implication of such maintenance policies in a city bus company. The model included human resources management system to cover maintenance process however did not include other maintenance resources which made it impractical for industrial multi unit maintenance system. Considering the importance for managers to understand the dynamics behaviour of maintenance system (Kothari, 2004) and see its practical implications (Bivona & Montemaggiore, 2010), this paper focus on developing a system dynamic model to support managers deal with the resource provision policy making for a multi unit maintenance system.

3 Development of the model

From system modelling perspective, the model of maintenance system policy making purpose consists of input, process and output. The input of maintenance system can be in the form of maintenance system information of all its resources such as human resource, spare part, equipments, and machine information. The maintenance process involves interactions between the elements: machines/units, human resources, parts, and tools & equipments. The output is related to the purpose of the policy analysis.

In this research, the main purpose is how to achieve the desired system performance measured by maintenance system reliability while minimizing the cost of maintenance through an appropriate resources provision policy. Representation of the analysis for the resources provision policy in maintenance system is presented in Figure 1. As seen in Figure 1, to make a policy for maintenance resource provision, information about the state of overall maintenance resources and the desired overall performance is required.

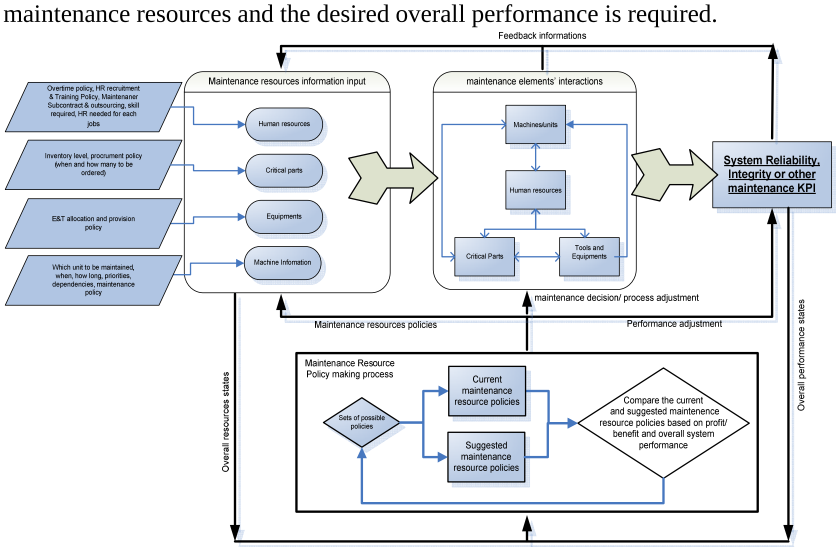

Figure 1: Representation of analysis for maintenance resources Provision policy.

Based on this information, a set of alternative policies can be made and compared. Generally, the selected policy can be implemented either in terms of recruitment or procurement policies, or in terms of process adjustment policies that impact the maintenance system output or the desired maintenance system performance.

The main objective of this research is developing a system dynamic model that can be used to analyse the maintenance system in order to make a suitable maintenance resource provision policy. The model should examine the current approach of maintenance resources provision and develop scenario for better resource provision policies for comparison. The performance of the current resource provision policy is compared with the suggested scenario developed by the system dynamic model to find the best for implementation.

As discussed, system dynamics methodology is used to model the resources provision policy for the maintenance system. The system dynamics methodology consist of five phases as presented by Maani & Cavana (2007).

In the early modelling process in Maani & Cavana (2007) causal loop modelling or causal loop diagram (CLD) is presented as a conceptual model. In this paper, the CLD is developed based on the same concept associated with maintenance system modelling. The focus of this paper is related to human resource management system and procurement system. The human resource management system caters for a policy on human resource provision which manage man hours based on availability and assignment. The procurement system deals with purchasing of spare parts, consumable materials, tools, and equipments or contracting with service providers. A simple dynamic model of human resource management system, maintenance and procurement system is as shown in Figure 2.

The model is built based on the observation of unit failure rate in relation to the causal process of preventive and corrective maintenance and the maintenance resource requirement of each maintenance process in each unit. Failure rate increases overtime and can be reduced by preventive and corrective maintenance (loop B1 and B4). Preventive maintenance is performed based on the schedule (PM schedule) with the required man hours while man hours for corrective maintenance are allocated as required. Man hour required to perform maintenance task over time are compared with the available man hours. The result of the comparison is a number of man hours to be assigned to each maintenance job (Loop R3 and R4).

In human resource management system, available man hours are reduced by absence or leave but available man hours can be increased by overtime, outsourcing and new hiring.

In procurement system, availability of resources is influenced by the requirement of those resources for maintenance purposes and the quantity and number of resources' orders launched to suppliers. The number of order quantity is considered based on qualitative parameter (e.g. expected demand, desired inventory level, Inventory policy control) and qualitative parameter (e.g. financial pressure, ordering policy/method). Expected demand is compiled from projection of maintenance activities in the future based on historical data owned by management.

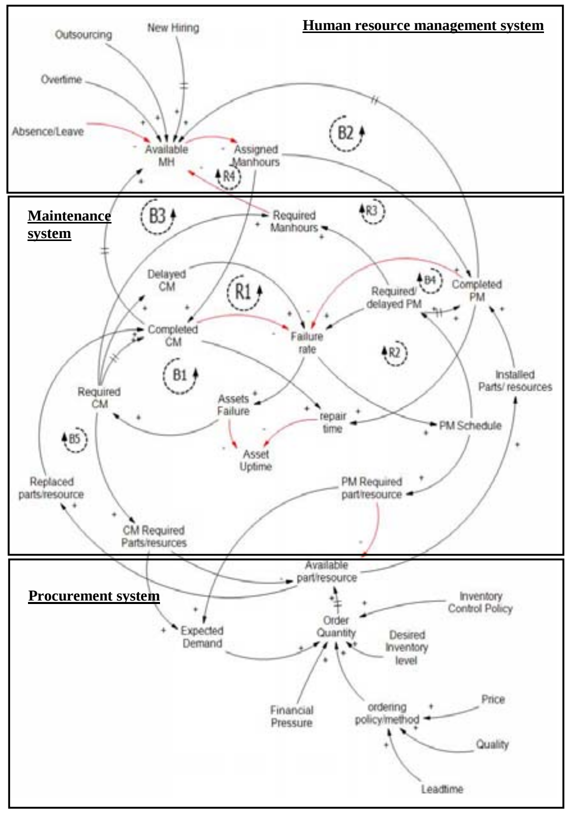

Figure 2: CLD for maintenance and related system

For illustration, the modelling technique is mapped for one unit technical system as shown Figure 2. The general model for multi unit maintenance system is presented in Figure 3 where each system has its strategy to achieve the desired system objective. The strategies are implemented in each system ensure that optimal conditions are achieved. In a system approach, the system is not considered as the sum of elements but the optimum integration of each element to attain the system objective effectively and efficiently. In this perspective and as reflected in Figure 3, the best system performance may not be the accumulation of each best strategy in each system but the best combined strategy. To determined the best combined strategy for overall systems, each strategy in each system must be simulated in the model to know which combination has the best outcome related to the objective of the policy making process.

The idea presented in Figure 3 is very complex. The complexity is reflected on the complexity of the model, however; the model can be simplified by disintegrating it into small models. The smaller models are analysed and validated and then integrated into the overall model analysis for the overall optimum performance. This principle is known as “Keep It Simple” (KIS). Building on this principle, in this paper a system dynamic model involving human resource management for a multi unit maintenance system is discussed. Figure 3 shows, the CLD of maintenance system and partially the CLD of human resource management system.

It is argued that system dynamics modelling approach provides simplification to the complexity associated with developing a resources provision policy for multi unit maintenance system. The system dynamics model for multi unit maintenance system has been developed based on the CLD shown in Figure 2 and 3 and then transformed into a system dynamics model as presented in Figure 4. This model is reviewed and then verified using data from a selected case study.

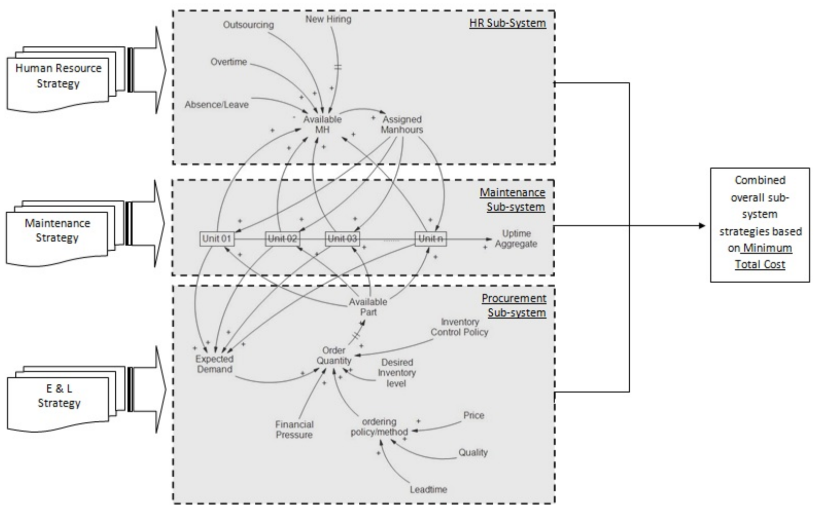

Figure 3: Relation of multi unit maintenance system with other systems

4 Case Study

Case studies are suitable methods that can be used to verify the developed model for the maintenance resource policy. Afefy (2010) in his paper discussed the methodology, application of Reliability-Centered Maintenance (RCM) in a case study. The result of the case study shows that the implementation of RCM can reduce labour cost significantly. This paper adopts the same case study data to verify the implementation of the system dynamics model.

In this case study, there is a process-steam plant that consists of 5 different units of assets which are: fire-tube boiler, steam distribution, dryer, feed-water pump and process heater. These assets are respectively considered in this paper as unit 1, unit2, unit 3, unit 4, and unit 5. The system dynamics model has been developed based on CLD presented in Figure 2 but integrated all the 5 units of the case study. The complete system dynamics model used for this case study is presented in Figure 4. Based on the case study, each unit has different down time and failure rate. Three different types of preventive maintenance system are implemented in each unit: weekly, monthly and six monthly. Each type of preventive maintenance requires different number of workers and duration which make up the man hours for the preventive maintenance activities.

One advantage of using a system dynamic simulation model is its ability to capture uncertain event from the real system. To capture the uncertain events, the input of simulation must be in a stochastic variable that can be represented in a certain distribution function. In the original case study, the number of required man hour is presented in a fixed number that is not convenient to capture the uncertainty. If the distribution is unknown, the best way is to assume it as a uniform distribution. So, for simulation purpose, required man hour is converted into uniform distribution. The result of the conversion is provided in Table 1 along with the corrective maintenance at the time of undertaking it.

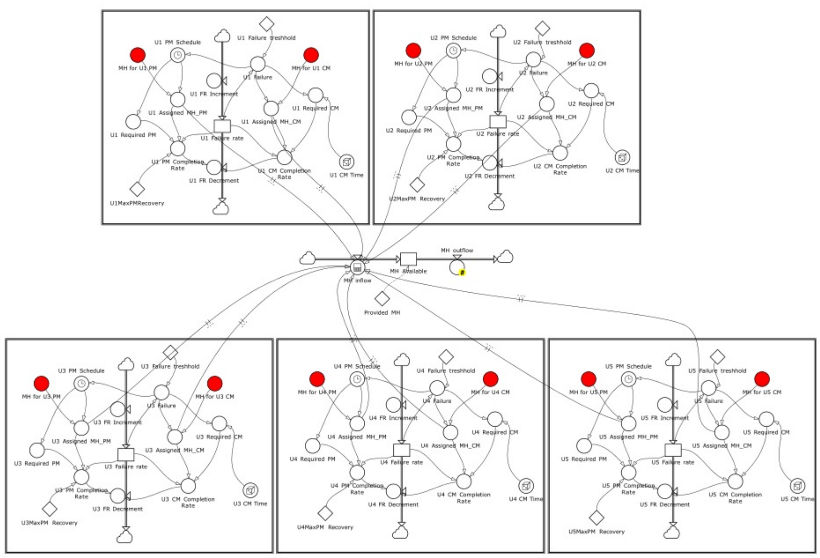

Figure 4: System dynamics model for multi unit maintenance system

In this case study, the total labour per day is 27 man day and it is assumed that a person work for 7 hour per day. Therefore the total man hour available each day is 189 man hours per day. Another assumption used in this model is all people have the same ability as a maintainer.

Simulation is conducted in two different scenarios. First scenario is the current condition where there are 189 man hours provided. The second scenario is based on reducing the number of man hours relative to the result of the first scenario. The failure rate of each unit associated with these two different scenarios is compared.

Table 1: Man hours required for each maintenance activity

	Required MH for Preventive Maintenance			Corrective maintenance
	weekly	monthly	Six monthly	
Unit 1				Uniform (29,31)
Unit 2				Uniform (29,31)
Unit 3	Uniform (5,7)	Uniform (8,12)	Uniform (80,88)	Uniform (9,11)
Unit 4				Uniform (12,21)
Unit 5				Uniform (9,11)

The simulation is performed for 365 workdays to understand the behaviour of the multi unit maintenance system in the whole year. The result of the first scenario is shown in Figure 5 and Figure 6. Table 2 shows the comparison between daily required man hours and available man hours. Table 3 shows the daily failure rate of each unit.

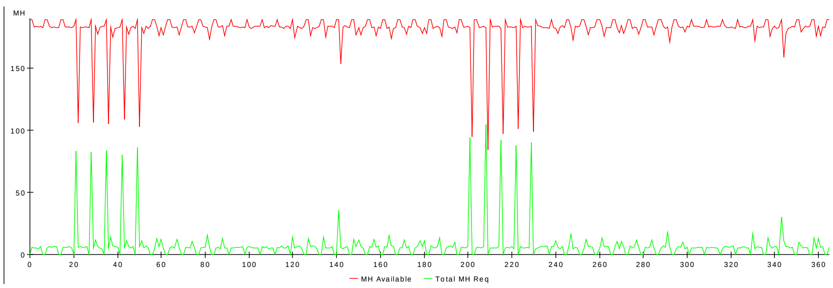

Figure 5: Daily required and available man hours (scenario 1)

Figure 5 shows that in average, there are significant numbers of man hour that are available. It designates that there is excess in the number of labour provided for the maintenance system. The simulation result also shows that the maximum required number of man hours in the whole simulation process happens in day 215 as much as 91.99 man hours. In Figure 6, most of the daily failure rate is under 30% but unit-1's failure rate is considerably different. Unit 1 (fire-tube boiler) experienced failure twice in the simulation time horizon. According to this result, the second scenario is developed with reducing man hours to 91 man hours and run the simulation for 365 days. The result is presented in Figure 7 and Figure 8.

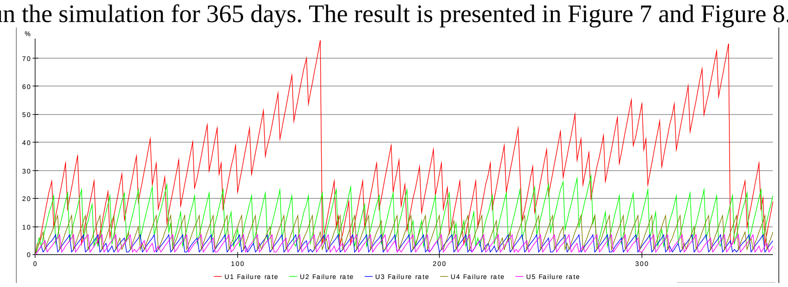

Figure 6: Daily failure rate for all unit (scenario 1)

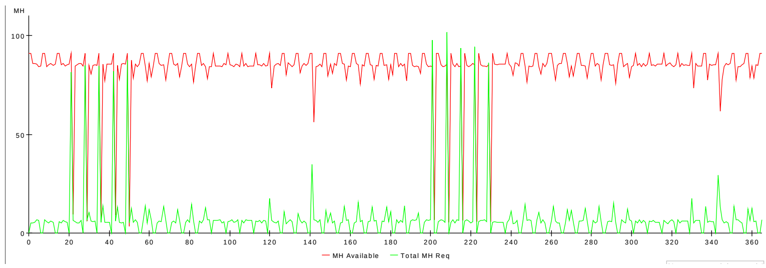

Figure 7: Daily required and available man hours (scenario 2)

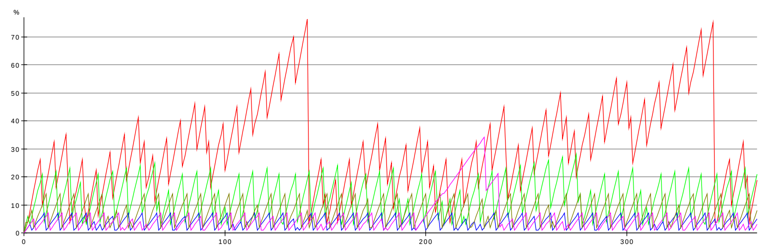

Figure 8: Daily failure rate for all unit (scenario 2)

5 Discussion

Figure 7 and 8 show the result of the second scenario of the simulation model. It can be seen in Figure 7 that although after 200 days the required man hour is more than the available man hour but overall the performance of the multi unit technical system is similar based on the daily failure rate. The significant difference can be found in unit 5 where the failure rate rises significantly after 200 days. This happens because at that period, the available man hour is insufficient to do preventive maintenance for all units. However, the man hour inadequacy to cover the preventive maintenance is only temporary and then the required preventive maintenance of unit 5 can be covered by available man hours in the next day. In this situation the shortage in man hours was resolved by delaying allocation of man hour for one day without causing failure or breakdown. So overall, considering the number failure and allocation of man hours led to proper management of the whole maintenance system.

6 Conclusion

Maintenance resources provision has a major role in asset management. More efficient maintenance resource provision process can lead to a better overall asset management performance. In this case, system dynamics model can be used to optimize the overall performance of multi unit maintenance system by determining the appropriate number of available resources to cover maintenance activities. Based on a case study data, a policy of maintenance resource provision is developed based on analysing and comparing the output of current and suggested system dynamics model.

For the purpose of this paper, the system dynamics model in this case study has only dealt with human resource management system for multi unit maintenance system, however; the mode can be implemented in include a wide range of resources. This paper is one step in a research that aims at developing a more complex model that involves procurement of resources as well human resources management. This may require improvement of the model in terms of better man hours scheduling to smooth the requirement of daily man hours. Some adjustment might also be added to the model to accommodate outsourcing.

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