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Development the conceptual design of Knowledge Based System for Integrated Maintenance Strategy and Operation

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Abstract. The importance of maintenance has escalated significantly by the increasing of automation in manufacturing process. This condition switches traditional maintenance perspective of inevitable cost into the business competitive driver. Consequently, maintenance strategy and operation decision needs to be synchronized to business and manufacturing concerns. This paper shows the development of conceptual design of Knowledge Based System for Integrated Maintenance Strategy and Operation (KBIMSO). The framework of KBIMSO is elaborated to show the process of how the KBIMSO works to reach the maintenance decision. By considering the multi-criteria of maintenance decision making, the KB system embedded with GAP and AHP to support integrated maintenance strategy and operation which is novel in this area. The KBIMSO is useful to review the existing maintenance system and give reasonable recommendation of maintenance decisions in respect to business and manufacturing perspective.

1. Introduction

For a long time manufacturing has been pointed as one of the drivers of business achievement [1], but not maintenance. It was caused by the way of maintenance being considered. It was not counted as a substantial function as long as the manufacturing works in the expected performance. Instead, when the manufacturing process deteriorated, the quality of product decreased, the production target was not achieved, and the corrective action ate up the production budget for repairing action, then maintenance was considered as the inevitable cost.

The rapid development of automation in manufacturing process leads the significant changes to maintenance perspective recently. The implementations of advanced technology and lean manufacturing philosophy have increased the complexity of maintenance [2]. By providing the logistic support for manufacturing, today's maintenance perspective is considered affecting manufacturing process more than ever before. The automation could reduce cost of manufacturing process but increase budget allocation for maintenance purpose instead. It has been proved by which the maintenance cost could reach up to 70 % of total production cost [3]. Furthermore, the activities of maintenance to keep manufacturing equipments working on the expected performance are considered as inseparable part of the overall business competitiveness [4]. Hence, every decision for maintenance strategy and operation should always integrate to business and manufacturing perspective. This paper aims to develop the conceptual design of Knowledge Based System for Integrated Maintenance Strategy and Operation (KBIMSO). It elaborates the indicators identified in KBIMSO framework and shows how those indicators are collaborated to obtain maintenance decisions.



2. Relationship of Maintenance with Manufacturing and Business Perspectives

The relationship between maintenance and manufacturing is firmly visible within the manufacturing plant as to keep manufacturing assets works on their expected performance. Maintenance is defined as the combination of technical, administrative and managerial actions during the life cycle of equipment to keep it in, or restore it to its designed function [5,6]. It clearly means that maintenance is working based on demand from manufacturing function by referring to organization goal, as depicted in Figure 1. Maintenance and manufacturing function as an individual system within the organization have their own elements which work collaboratively to gain the function's objective. As interrelated functions, the main role of maintenance is fulfilling demands of manufacturing to retain its production capacity by maintaining the manufacturing equipments to work on their expected function. The contribution of maintenance to manufacturing performance, such as product quality and quantity, lead time and safety makes maintenance is considered as one of competitive drivers which affect overall business competitiveness. Therefore, maintenance strategy and operation need to be referred to business strategy in order to achieve organization goal.

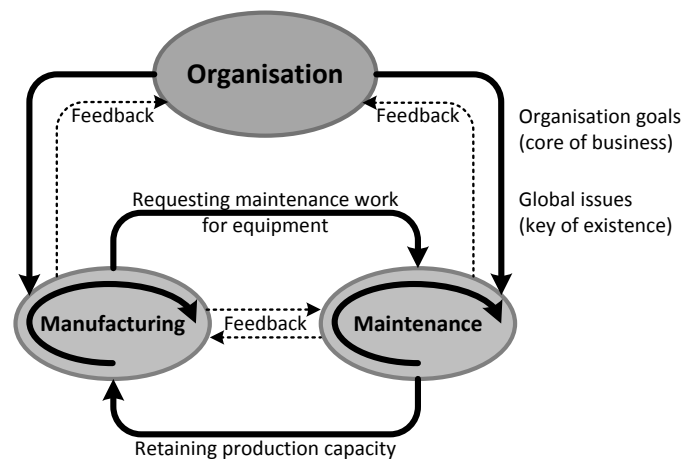


Figure 1. Relationship between organisation, manufacturing and maintenance [7]

The interaction of maintenance, manufacturing and business has been investigated on many studies. The survey conducted by Pinjala et al.[2] argue that a pro-active maintenance and better planning and control of manufacturing system are implemented by a quality business competitor. Meanwhile, Swanson [8] confirms the relationship between maintenance with manufacturing and business performance in term of product quality, equipment availability, and production cost. Gulati [9] emphasizes that implementation of best practice maintenance can improve performance, competitiveness and market share. Following these evidences, this paper is intended to configure the methodology required to take maintenance decision by referring to all contributed elements in maintenance itself, manufacturing, and business perspectives, which is called Knowledge Based System for Integrated Maintenance Strategy and Operation (KBIMSO).

3. Conceptual Model of Knowledge Based System for Integrated Maintenance Strategy and Operation (KBIMSO)

The KBIMSO conceptual model is generated from the KBIMSO framework [7] which is rearranged and emphasized to present the structure of KBIMSO model, as presented in Figure 2. Every single element on business perspective, manufacturing perspective and maintenance perspective is treated as a module and explored in detail into sub-modules to present the key factors contributed into KBIMSO. The business and manufacturing perspectives in KBIMSO framework are pointed as the strategic level in KBIMSO structure, while the maintenance perspective is presented through the operational level.

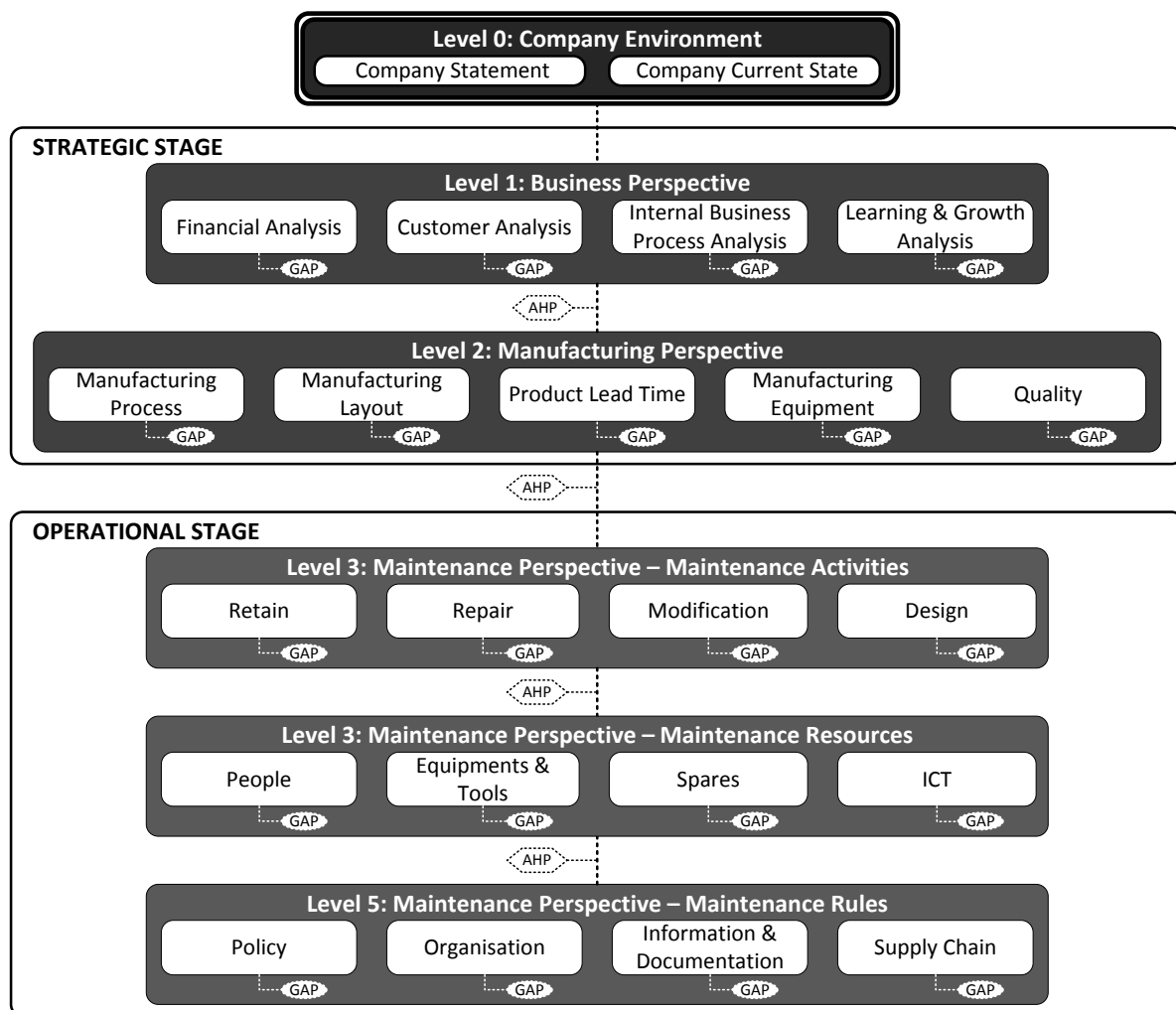


Figure 2. Structure of KBIMSO model

3.1. Level 0 – Company Environment

Level 0 is a top level of KBIMSO model which is intended to describe the company environment through identifying company statement and company current state. Company statement includes vision, mission and objective of company to compete in business. The company statement is required to generate the suitable strategy and operation for the lower level of function. To accommodate the uniqueness of the company, it is important to consider the current state in which the company is running. The point of this identification process is to consider each company as a customized system and to classify any particular company into different characteristic which enable to arrange the suitable requirement on the development of KBIMSO model.

3.2. Level 1 – Business Perspective

The first level in strategic stage is *Business Perspective*. This perspective adopts Balanced Scorecard (BSC) approach to provide the overall business performance measurement through four perspectives; financial, customer, internal business process, and learning and growth. These four perspectives are noted to be able to effectively represent existing business performance and help to identify the prospective achievement in the future [10]. The ability of BSC to translate company statements into functional strategies points it as the main techniques to identify the business requirement towards manufacturing and maintenance in the business perspective of KBIMSO.

3.3. Level 2 – Manufacturing Perspective

Another factor examined in the strategic stage is *Manufacturing Perspective*. Maintenance as the manufacturing's logistic function treats manufacturing to take part to influence the maintenance decision making [11]. This level is corresponded to some factors of manufacturing which have high interaction with maintenance. Its modules consist of the manufacturing equipment, manufacturing process, manufacturing layout, product lead time, and quality. The chosen specifications of those aspects then will be sent to maintenance function to assist describing the expected maintenance performance required to support manufacturing function.

3.4. Level 3, 4 and 5 – Maintenance Perspective

The operational stage totally reflects the elements of maintenance system, which are *Maintenance Activities*, *Maintenance Resources*, and *Maintenance Rules*. It is started from identifying the required maintenance activities to keep manufacturing equipment's reliability in acceptable business recommendation. To execute maintenance activities, the maintenance resources are obviously required. Hayes et al. [12] emphasize trade-offs as an option to deal with resources limitation and resources allocation in respect to business strategy. Furthermore, the discussion about how those maintenance resources are collaborated and managed in a particular manner to gain the optimal result should also be taken into account. Thus, after the hardware of resources to execute the maintenance actions, maintenance rules are required as the software to manage and control it. These infrastructure elements cannot be separated from the structural and physical elements to gain successfulness of maintenance strategy and operation [2]. It examines the required rules and control facilities to manage maintenance activities and maintenance resources.

Maintenance perspectives on the operational level are not only describing the current performance of maintenance, but intended to specify the best combination of maintenance activities, resources and rules to fulfil the demand of manufacturing function and to achieve the aim of maintenance as a driver of business competitiveness.

4. Methodology of Knowledge Based System for Integrated Maintenance Strategy and Operation (KBIMSO)

Regarding the contributed elements in maintenance strategy and operation, the challenge to take maintenance decision can be figured out based on three points. First, determine the targets and prerequisite conditions to be reached, and then identify the gaps between the current condition and the prerequisite condition. Second, decide priority of contributed elements to achieve the optimal result as there are many elements which should be considered at the same time. Third, enable the computer programme to support the complicated calculation and decision making process through Knowledge Based (KB) system.

4.1. Gauging Absences of Prerequisites (GAP)

GAP is a benchmarking technique used to identify and assess the gap between a prerequisite state and an existing state in a particular system [13]. It analyses the responses of users toward some questions provided regarding the existing condition of organization. The responses are divided into two categories. The availability of prerequisite condition is identified as Good Point (GP). Instead, the absence of any prerequisite condition is described hierarchically from the most important one, so called Problem Category (PC-1) to the less important of that does not have any effect at all to the system sustainability, so called PC-5 [14].

4.2. Analytic Hierarchy Process (AHP)

AHP is performed by breaking down the problem, focussing on the goal, identifying the contributed criteria and structuring them into a hierarchy [15]. The process is continued by comparing criteria with pair-wise comparison manner. The weight of each criterion represents the level of importance of

them in respect to the aim of decision making. In KBIMSO, level of importance of criteria is referred to GAP analysis as the preliminary step.

Although AHP plays a satisfying method to tackle multi criteria problems, it is considered that the calculation of KBIMSO might be tedious in practices. For this reason, the collaboration of GAP and AHP in KB system surely will provide the valid and consistent recommendation within a shorter time.

4.3. Knowledge Based (KB) System

Decision making is usually taken by some experts within the organisation who acquire knowledge on that particular area. Unfortunately, such knowledge might be disappeared when they leave the organization [16]. Therefore, the computerized system of KB system is intended to imitate the thinking process of expert to generate the reasonable conclusion. KB system consists of facts and rules. Expressing facts in rules could be done on a simple way called production rules by using IF, AND, THEN, and OR statements.

To provide the illustration of KB rules in KBIMSO, the example of KB rules for sub-module *Repair* in module *Maintenance Activities* is presented as the following: (only some rules are presented)

- IF** the equipment is repaired after its expected life time (Yes: GP; No: PC-1)
- AND** the equipment is repaired before the functional failure (Yes: GP; No: PC-1)
- AND** the deterioration of equipment has been detected (Yes: GP; No: PC-1)
- AND** the equipment is repaired due to run-to-failure approach (Yes: GP; No: PC-1)
- AND** the corrective action is done on the planned maintenance schedule (Yes: GP; No: PC-1)
- AND** the corrective action is done by the planned maintenance resources (Yes: GP; No: PC-1)
- AND** the corrective action is preferable than replacement (Yes: GP; No: PC-1)
- THEN** the maintenance activity of repair is applied effectively
- OR** the maintenance activity of repair is not applied effectively

The KB rules above indicate the prerequisite condition of effective maintenance activity of repair. The fulfilment of such statements mean the corrective action is natural, under schedule and can be managed appropriately. Therefore, any positive response is considered as Good Point (GP). Instead, the negative response is classified as Problem Category (PC)-1 based on GAP description, which imply a very serious problem to overall system performance. The rest of KBIMSO modules and sub-modules will have the same pattern as KB rules above.

4.4. Typical Output of KBIMSO

The KB rules are presented to the users to get the responses of the most representative current state. The results obtained are then tabulated, as shown in Table 1, to find out the aspects that have been implemented on its good practice already and the aspects that have not reached its prerequisite condition, namely Problem Category (PC).

Table 1 Typical output of KBIMSO for *Maintenance Activities* module

Sub-Module	Dimension	Number of Questions	Good Point	Problem Category (PC)				
				PC-1	PC-2	PC-3	PC-4	PC-5
Retain	Work Planning	38	21	17	0	0	0	0
	Work Scheduling	21	13	8	0	0	0	0
	Resources Availability	25	16	5	4	0	0	0
Repair	Corrective Procedures	24	15	9	0	0	0	0
	Economic Analysis	26	19	5	2	0	0	0
	Risk and Safety Analysis	12	9	3	0	0	0	0
Total		146	93	47	6	0	0	0

As illustrated in Table 1, there are only two sub-modules presented in *Maintenance Perspective* module out of four sub-modules, for sake of brevity. The total number of rules contained in both sub-modules is 146, with 93 rules shows good practices (Good Point) and 53 rules identify problems.

From those problem, there are 47 problems are categorised as PC-1 and 6 problems are categorised as PC-2 based on GAP description. Later on, all identified problems will be weighted within AHP technique to get prioritisation for improvement of maintenance strategy and operation.

5. Conclusion

KBIMSO is developed to synchronize maintenance decision with business and manufacturing concern. KBIMSO conceptual design elaborates KBIMSO framework onto two main stages, strategic and operational. Strategic stage discusses the contributed elements of business and manufacturing perspectives toward maintenance, while operational stage focuses on maintenance elements to execute maintenance strategy and operation. As the methodology, KBIMSO employs GAP and AHP into the KB system. GAP works by identifying the gap between the existing and expected condition within maintenance environment. Then AHP works by structuring and weighting the contributed elements in order to provide recommendation for maintenance decision.

The verification and validation of this KBIMSO conceptual design will be done in the automotive industries due to its high automation equipments, advanced technology implementation, and flexibility. Nevertheless, with its generic design, KBIMSO can be applied on most manufacturing industries to review current maintenance practice as well as to give recommendation for optimal maintenance strategy and operation.

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