A KNOWLEDGE-BASED PERFORMANCE MEASUREMENT SYSTEM FOR IMPROVING RESOURCE UTILIZATION

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Abstract: In current manufacturing industry, there are various challenges including short product life cycle, process automation and global competition. It is critical for the manufacturing companies to ensure effective utilization of production assets for overall business success. In order to focus scarce resources on areas that have the greatest impact on productivity, performance evaluation on the resource allocation is necessary to assist companies improving the resource utilization and accomplishing their objectives. In this paper, a knowledge-based performance measurement system (KPMS) is designed to evaluate the resource allocation decisions and provide recommendations to improve the performance and physical asset utilization. The framework of the proposed system, which is constructed by rule-based reasoning, case-based reasoning and a mathematical model, is introduced. By integrating the mathematical model with knowledge rules, performance indicators that are associated with the achievement of company objectives can be determined to quantify the performance of the resource allocation. Moreover, case-based reasoning technique is adopted to evaluate the performance and reuse the experience in past cases to provide recommendations for improvement.

1 INTRODUCTION

In recent years, manufacturing companies are confronted with challenges of shortening product life cycles, growing emphasis on process automation, global competition, and increasingly mobile work force. These challenges require robust methods for providing real-time monitoring and control, understanding asset utilization and capacity, and retaining valuable operation knowledge within company, in order to achieve reliable and economic performance (Wang et al, 2006). Moreover, it is necessary to ensure effective utilization of production assets for overall business success. The importance of asset management is growing.

To achieve the purpose of asset management, maintenance strategies have been widely adopted to reduce downtime and increase both quality and productivity. Many researchers have attempted to develop various preventive and predictive maintenance tools to assist companies monitoring the health degradation of machines and scheduling maintenance activities so as to avoid machine downtime. Although maintenance is significant in maintaining the physical assets in specified operating condition, it is still incapable to guarantee that companies can gain greatest utilization and effectiveness from their physical assets. To tackle this problem, it is necessary to measure the performance of resource utilization in order to reflect the productivity of the companies.

From the review of current studies, performance criteria were chosen to evaluate the performance pertaining to a specific goal of the company only. However, in the turbulent and competitive market, manufacturing companies often have to employ different strategies in order to react to changes responsively. This would affect the relative importance of manufacturing criteria for measurement. Therefore, performance measurement should be a dynamic process, in which the adoption of performance criteria and their relative importance are dependent of the strategies and objectives of the company.

In this paper, a knowledge-based performance measurement system (KPMS) is introduced. The purposes of the system are:

(i) Establish appropriate performance indicators in accordance with the company objectives.
(ii) Evaluate the performance of resource allocation

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and provide recommendations to improve physical asset utilization.
(iii) Retain the knowledge of resource allocation in the company to support continuous improvement.

To achieve the above purposes, the framework of the proposed KPMS consisting of seven main components, which are constructed by rule-based reasoning, case-based reasoning and a mathematical model, is developed. The remainder of the paper is organized as follows. Section 2 presents the reviews of related literature. The system architecture of the proposed system is explained in Section 3. In Section 4, the functions and benefits of the system are discussed. Finally, a conclusion is given in Section 5.

2 LITERATURE REVIEW

2.1 Background Study

In today's global and competitive manufacturing industry, companies often need to react quickly and cost-effectively to contingent changes such as demand fluctuations and changes in customer requirements. Their largest challenge is to increase operational effectiveness, profitability and customer satisfaction and reduce operating costs. As physical assets form the basic infrastructure of all businesses, it is essential to plan and monitor assets throughout their entire life cycle to ensure effective utilization of production assets.

Asset management is a strategic and integrated set of comprehensive processes, which include financial, management, engineering, operating and maintenance, to gain greatest lifetime effectiveness, utilization and return from physical assets (Mitchell and Carlson, 2001). Its overall goal is to optimize productivity in long term. Most researchers have emphasized the importance of maintenance in asset management. Preventive and predictive maintenance approaches have been adopted to avoid machine failure (Lee et al., 2006; Wang et al., 2006). Although maintenance is critical in failure prevention to assure the availability and reliability of machines, asset management should encompass a broader range of activities. Performance measurement is necessary to evaluate the asset utilization and improve the decision making quality of resource allocation.

2.2 Performance Measurement in Manufacturing

According to Ahmad and Dhafr (2002), a suitable measurement methodology enables companies to focus scarce resources on areas that have the greatest impact on productivity. Accordingly, additional production capacity can be achieved without investing new machinery. Performance measurement can quantify the efficiency and effectiveness of action that leads to performance. It is used to evaluate how well the activities within a process, or the outputs of a process, achieve specified goals (Chen, 2008). Key performance indicator (KPI) can be used to compare with internal or external target and identify any performance gaps.

In measuring manufacturing performance, most manufacturers use criteria such as quality, productivity, speed, customer satisfaction, diversity of product line and flexibility. Ahmad and Dhafr (2002) assessed manufacturing performance in the areas of quality, delivery reliability, cost and delivery lead time as they are important aspects of manufacturing performance areas and easy to measure.

2.3 Research Issues

The strategy adopted by a manufacturing company can directly affect the relative importance of performance criteria. However, most researchers chose performance measures according to a particular objective such as profitability (Yurdakul, 2002), financial health (Wen et al., 2008) and plant utilization (Ahmad and Dhafr, 2002). It seems that these measures are not dynamic in nature and cannot adapt to the changing manufacturing environment. Since companies may revise their objectives over time, performance measurement should be a dynamic process that the performance criteria and their importance can be adjusted accordingly to reflect the changes in companies' objectives. Moreover, Chen (2008) stated that existing integrated performance measurement systems do not have an explicit feedback loop that supports improvement. It implies a need to include feedback mechanisms in performance measurement for companies to achieve continuous improvement.

To address these issues, this paper presents a knowledge-based performance measurement system which helps to establish appropriate performance indicators to deal with changes of company's objective in a dynamic environment. The proposed system is used to evaluate the performance of physical asset under different resource allocation decisions. Moreover, suggestions can be provided to improve the decision making quality of resource allocation, so that utilization of physical asset can be significantly improved.

3 THE ARCHITECTURE OF THE KNOWLEDGE-BASED PERFORMANCE MEASUREMENT SYSTEM

The proposed system is a knowledge-based system aiming at assisting manufacturing companies to evaluate the effectiveness of resource allocation in accordance with their company objectives. The proposed system not only assesses the effectiveness of the physical assets in performing the job orders and attaining the company objectives, but also provides recommendations to improve productivity performance. As illustrated in Figure 1, the framework of the KPMS is composed of seven main components: web-based platform, performance indicator selector, performance indicator analyzer, overall performance scoring model, performance evaluation, database and knowledge repository.

3.1 Web-Based Platform

The web-based platform is the user interface of the system that enables users to access its functions over the Internet with a standard web browser. It consists of web pages which are constructed by HyperText Makeup Language (HTML). Moreover, Active Server Page (ASP) and JavaScript are embedded to make the web pages dynamic and interactive and perform data validation and checking respectively. It also allows the staff to input their requests of performance measurement such as company objective criteria and resource allocation decision. Examples of the objective criteria for performance assessment include profitability, productivity, product quality and customer satisfaction. On the other hand, details of the resource allocation such as product type, machine category and manufacture process have to be entered for the proposed system to evaluate current performance.

The system displays the performance level of the assessed resource allocation decision and recommendations for improvement through the web-based platform. In addition, the rules stored in the knowledge repository for selecting appropriate performance indicators and assigning performance scores can be checked and updated through this platform in order to cope with a fast changing environment.

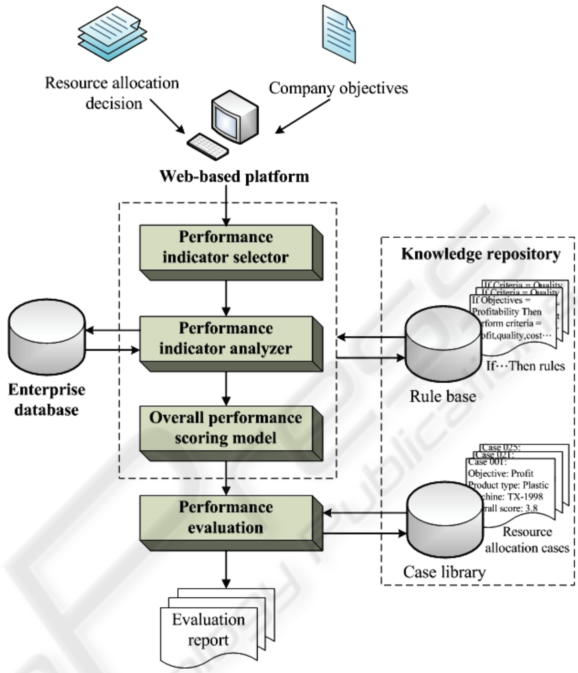

Figure 1: System architecture of KPMS.

3.2 Performance Indicator Selector

The performance indicator selector adopts rule based reasoning method to select the appropriate performance indicators for measurement. The knowledge of selecting suitable performance indicators is presented in the form of "*if* <antecedent clauses> *then* <consequent clauses>" statements. If the antecedent clauses are true, then the consequent clauses are true. Based on the knowledge rules, the selector chooses the relevant performance criteria and their involved key performance indicators according to the company objectives. Many companies tend to pursue certain objectives such as profitability, market share, customer focus, product quality and productivity. As shown in Figure 2, they are related to different performance criteria including cost, quality, customer satisfaction and efficiency, which consist of different key performance indicators. Examples of rules involved in the performance indicator selector are presented below:

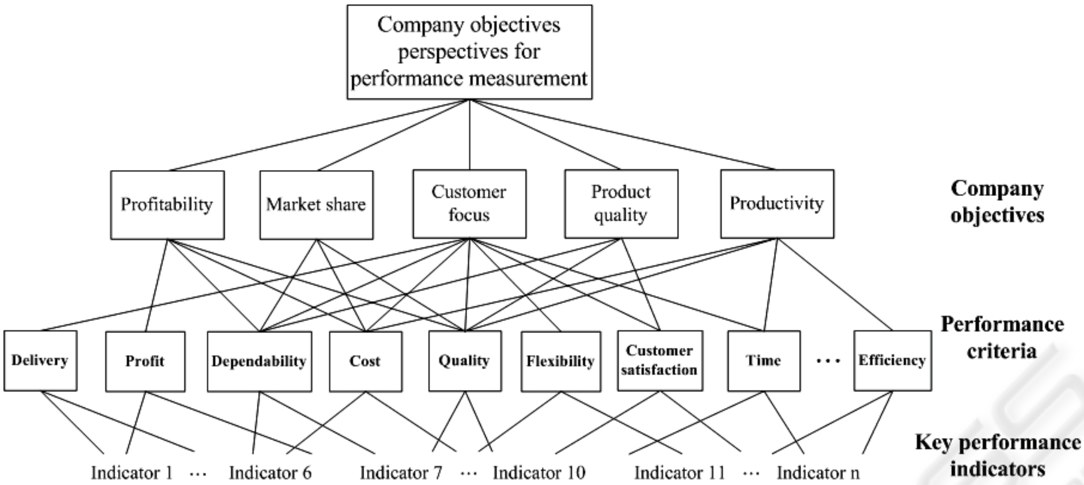

Figure 2: Hierarchical structure of performance indicator selection.

Rule 1:
If Company_Objective = Profitability then Performance_Criteria = "Profit, Cost, Dependability, Quality"
Rule 2:
If Company_Objective = Productivity then Performance_Criteria = "Cost, Quality, Time, Efficiency"
Rule 3:
If Performance_Criteria = Cost then Key_Performance_Indicator = "Unit_Cost, Inventory_Cost, Running_Cost"
Rule 4:
If Performance_Criteria = Quality then Key_Performance_Indicator = "First_Pass_Yield, Defect_Ratio, Scrap_rate"

After knowledge reasoning in the rules, performance indicators that are associated with defined company objectives are selected and passed to performance indicator analyzer for analysis.

3.3 Performance Indicator Analyzer

The performance indicator analyzer is responsible for analyzing operational data retrieved from the enterprise database and assigning score to the key performance indicators determined by the performance indicator selector. The values of the performance indicators can be retrieved from the database directly or determined by equations. For instance, the key performance indicator of defect ratio can be found in Equation (1).

$$Defect\ \ ratio = \frac{Defects}{Total\ \ production} \tag{1}$$

The number of defect units and total production units are retrieved from the database and calculated to get the defect ratio. After that, the value of the performance indicator is analyzed together with decision rules retrieved from the rule base so as to assign a performance score to each indicator. An example of knowledge rules to assign a score to the performance indicator of defect ratio is given below:

Rule 1:
If Defect_Ratio < 5% then Performance = "Very satisfied" and Defect_Ratio_KPI = 4
Rule 2:
If Defect_Ratio > 5% and Defect_Ratio < 10% then Performance = "Satisfied" and Defect_Ratio_KPI = 3
Rule 3:
If Defect_Ratio > 10% and Defect_Ratio < 20% then Performance = "Normal" and Defect_Ratio_KPI = 2
Rule 4:
If Defect_Ratio > 20% and Defect_Ratio < 40% then Performance = "Unsatisfied" and Defect_Ratio_KPI = 1
Rule 5:
If Defect_Ratio > 40% then Performance = "Very unsatisfied" and Defect_Ratio_KPI = 0

3.4 Overall Performance Scoring Model

The overall performance scoring model is used to integrate all key performance indicators into an overall performance score according to appropriate weighting. The parameters used in the model are shown below.

Parameters

S	Overall performance score of a resource allocation decision,
f_i	Performance score obtained related to the perspective of objective i ,
x_i	Weighting of the objective i to evaluate the overall performance,
n	Number of objectives to be considered in performance measurement,
KPI_j	Score of key performance indicator j ,
w_j	Weighting of key performance indicator j to determine the performance score related to a particular objective,
a	Number of key performance indicators that are required to determine the performance score related to a particular objective.

The overall performance scoring model:

$$S = \sum_{i=1}^{n} f_i x_i \tag{2}$$

where

$$f_i = \sum_{j=1}^{a} KPI_j w_j \text{ , } i = 1,2,\cdots n \tag{3}$$

$$0 \le x_i \le 1 \text{, } i = 1,2,\cdots n \tag{4}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{5}$$

$$0 \le w_j \le 1 \text{, } j = 1,2,\cdots a \tag{6}$$

$$\sum_{j=1}^{a} w_j = 1 \tag{7}$$

The goal of Equation (2) is to determine the overall performance score of a resource allocation decision, S , which is calculated by multiplying the score obtained in each objective perspective, f_i , with the weighting of that objective on overall performance, x_i . x_i represents the relative importance of the objective i in evaluating the overall performance and it is determined by the managers when they input the requests of performance measurement. As shown in Equation (3), f_i is found by multiplying the score of key performance indicator, KPI_j, which is determined by the performance indicator analyzer, with its weighting to determine the performance score related to an objective, w_j , which is retrieved from the knowledge base. Moreover, constraints are included in the model. Constraints (4) and (6) specify that the weighting of objective and the weighting of key performance indicator should be a numeric value between 0 and 1 respectively. Constraints (5) and (7) require that the summation of all weighting of objectives and weighting of key performance indicators should be equal to 1 respectively.

3.5 Performance Evaluation

The performance evaluation module is used to evaluate the overall performance score of the resource allocation decision and present the results of the performance along with suggestions for improvements. It adopts case based reasoning method to retrieve past cases for performance evaluation. The objectives for performance measurement and the specifications of resource allocation are case attributes that are used to browse and retrieve relevant cases from the case library. After generating a list of cases based on the degree of similarity, their overall performance scores can be compared with the new case to assess whether current resource allocation decision is correct and identify any new approach to improve the performance level. If the performance of the current case is poorer than that of past cases, the resource allocation decisions in those past cases can serve as useful suggestions for the staff to reallocate the resource effectively. Subsequently, a performance evaluation report can be generated to show the results and recommendations of the performance while the new case is retained in the case library.

3.6 Database

The database is built to manage and store different enterprise information, such as production requirements, resource conditions, customer order specification and asset information. Operational data required in calculating the KPIs is included in the database and stored in relational table format. In the proposed KPMS, Microsoft Access is adopted to create the database and an ODBC driver is used to access the data stored in the database.

3.7 Knowledge Repository

The knowledge repository contains a rule base and a case library for storing knowledge of performance indicator analysis and resource allocation respectively. The rule base is used for storing the knowledge of selecting, weighting and analyzing the key performance indicators. It is presented in “If-

Then" rule structure to reason and analyze the key performance indicators. The case library is used to record all past cases of resource allocation decisions. In those cases, the basic job requirements, resource adoption, performance scores and their objectives for assessment are organized and saved. They can be retrieved in the performance evaluation module for assessing the performance.

4 DISCUSSION

The proposed KPMS enhances the performance of manufacturing companies by facilitating them to acquire the greatest utilization and effectiveness from their production assets, which is the ultimate purpose of asset management. Performance measurement enables managers to understand the effect of their resource allocation decisions through an overall performance score. As it is a dynamic system that can select appropriate performance indicators according to the company objectives, it is suitable for current competitive environment in which companies occasionally need to revise their strategies and objectives for enhancing the competitiveness. The importance of performance criteria would be adjusted by the system to react to the changes in company objectives.

Moreover, the system encourages companies to achieve continuous improvement on their resource utilization. After determining the overall performance score, the assessed resource allocation decision, as a new case, is evaluated against some past similar cases of resource allocation retrieved from the case library in order to realize current performance and identify any area for improvement. Consequently, it can suggest ways for improving the performance by reusing the experience gained in past cases while the new case of resource allocation can be retained in the knowledge repository.

This paper mainly provides a framework of the proposed KPMS. Implementation of the system is being conducted in a local polyfoam manufacturer. Once results are obtained, they will be presented in further publication.

5 CONCLUSIONS

A good resource allocation planning is important for manufacturing companies to utilize their physical assets effectively. Performance measurement on the resource allocation is necessary to assist companies improving the resource utilization and accomplishing their objectives. However, selection of suitable performance indicators in accordance with company objectives is a complex task especially in a dynamic manufacturing environment. The staff usually judge the resource allocation decisions by their own knowledge and experience. However, it cannot guarantee that the physical assets are utilized in the most effective way. In this paper, the knowledge-based performance measurement system establishes an approach for evaluating the performance of resource allocation decisions. It helps manufacturing companies to improve their operations in order to gain maximum utilization and effectiveness from the physical assets.

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