A Framework for Integrating Overall Equipment Effectiveness with Analytic Network Process Method

Ratapol Wudhikarn, *Member, IACSIT*

***Abstract*—When managing with equipment, an organizationrequires to apply an appropriate decision method in order to unleash hidden losses and identify existing performance also. One of crucial and widespread applied tools of performance measurement in manufacturing industry is Overall Equipment Effectiveness (OEE). However, OEE is still not suitably comparable method, because the weighting of each element in OEE is still equivalent, whereas, their losses are totally different and also interrelate to each other, hence these unconformities possibly mislead a judgment of decision maker. Therefore, this research has an objective to propose a new quantification frameworkby applying Analytic Network Process (ANP) with OEE for improving the weaknesses of original the OEE and other adapted measurement.**

***Index Terms*—Performance measurement, overall equipment effectiveness, total preventive maintenance, multi criteria decision making, analytic network process.**

I. Introduction

In the present, firms have faced an extremely changing and competitive environment, so organization improvement and innovation is critical importance. Moreover, in dynamic competitive business, a firm cannot ignore the need to make improvements and changes in organization if it hopes to be a business leader. This competitiveness pushes manufacturers to improve their quality, cost, delivery time and so on in order to take advantage over competitors. For this present situation, high competiveness and demand stimulate manufacturers to increase production capacity by replacing human labor with automatic machine. As machines are higher reliability, capacity and also lower error and operating costs than human. However the advantages arise only when machines are able to perform with high effectiveness and efficiency. Hence to attain the success, management system is really required. Several management systems have been proposed in many studies such as Total Quality Management (TQM), ISO9000, Six sigma, etc. Anyhow, one of management systems broadly used is Total Preventive Maintenance (TPM). TPM is a method for managing shop floor machine as well as overall organization.TPM brings several advantages to firm such as enhancing product quality, reducing manufacturing costs and wastes, and especially preventing machine breakdown.

Originally, the TPM methodology concentrates on manufacturing equipment, because it highly influences on product quality, production effectiveness and efficiency, manufacturing costs, inventory capability, safety, health and morality. However, TPM or whichever managerial concepts still totally requires an appropriate assessment method to evaluate performance. Performance measurement is a crucial driver concerning to several decisions in company. A poor decision could result in loss of money, resources, and time. Hence, it is important that the decision makers make logical and well-reasoned decisions. Moreover, TPM activities can be achieved in long-term effectiveness from accurate equipment performance information [1]. One of important and widely used metrics in TPM activities is Overall Equipment Effectiveness (OEE). OEE is a comprehensive top-down-oriented capability measurement system [2]. It is also a managerial tool for unleashing hidden capacity, for reducing production lost times as well as for extending a major capital investment [3]. Furthermore, Dal [4] identified that OEE is not just only an operational measurement tool, but it is also a key performance indicator for detecting process improvement activities in shop-floor operation as well as manufacturing environment. Even though OEE is generally recognized as a simple indicator, it is able to measure performance in several comprehensive dimensions. It is potential measurement tool for assessing the effectiveness of a single machine and also a continuous equipment system [5]. Several studies [6]-[9] implemented OEE and resulted in major improvement can be found. However, the OEE has some weaknesses; especially, the weight of each element is equivalent, whilst, their losses are totally different. For example, availability rate associates with the time losses whereas a quality rate is composed of qualitative losses. Therefore, several studies, including this study, have proposed the adapted measurement for improving its weaknesses.

This paper has an objective to improve weaknesses of OEE by integrating Analytic Network Process concurrently with OEE approach. This study is organized as follows. To illustrate the usefulness of this proposed model, Section II considers the theoretical concept and also discusses herewith the regarding literatures. Section III deals with the construction and calculation of improved model. Finally, a short conclusion is presented in Section IV.

II. Methodology

A. Overall Equipment Effectiveness

Nakajima [10] firstly proposed OEE in the late of 1980s. OEE is a comprehensive tool for measuring performance of machine. Nakajima introduced this tool for assessing the success of TPM philosophy. According to Nakajima, OEE is applied to measure machine performance in term of availability, efficiency, and quality issue. These three elements concern with different losses presented in Table I.

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R. Wudhikarn is with College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand (e-mail: ratapol.w@ cmu.ac.th).

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TABLE I: PERFORMANCE ASPECTS OF OEE AND RELATING LOSSES [10]

Performance aspects	Relating losses
1. Availability Rate	- Equipment failure/breakdown losses
	- Set-up and adjustment losses
2. Performance Efficiency	- Idling and minor stoppage losses
	- Reduced speed losses
3. Quality Rate	- Defect and rework losses
	- Start-up losses

From Table I, the relating losses are normally specified as the "six big losses" and their descriptions can be defined as follows:

1) *Equipment failure/breakdown losses*: These losses relate with time losses leading to decrease of productivity, and also product amount losses resulting from machine failure or breakdown.
2) *Set-up and adjustment losses*: These losses represent to loss of time occurring when machine is setup to converge with the requirement of another consecutive product.

These two failures are classified as time losses, which are applied for computing the availability rate.

1) *Idling and minor stoppage losses*: The losses occur when manufacturing process is temporarily interrupted by a minor malfunction or when a machine is idling.
2) *Reduced speed losses*: These losses occur when the machine speed is slower than design speed or present technological standards or the desirable condition.

These two losses are defined as speed losses measured for calculating performance efficiency.

1) *Defect and rework losses*: Volume and time losses due to defect and rework, financial losses due to product downgrading, and time losses required to repair defective products to turn them into finished products.
2) *Start-up losses*: Start-up losses are defined as time and volume losses. For example, start-up after periodic repair, start-up after breaks, and so on.

These last two losses are concluded as quality losses. These losses directly relate to the quality rate of equipment.

Generally, the outcome of OEE is computed by using the six big losses. These losses are accounted with Availability Rate (A), Performance Efficiency (P) and Quality Rate (Q).These three major elements can be determined follows:

The availability rate is represented to the summation of stoppage time which results from downtime, set-up and adjustment as well as other unexpected stoppages. The calculation of availability can be computed as (1)

$$A = \frac{Operating\ time}{Loading\ time} \tag{1}$$

where, loading time is the planned time available per time period for production operations, and operating time is calculated from loading time minus the time of equipment failures, set-up and adjustment requirements, exchange of dies and other fixtures, etc.

The performance efficiency can be expressed as the ratio of actual operating time to loading time represented in (2).

$$P = \frac{Net\ operating\ time}{Operating\ time} \tag{2}$$

where, net operating time is the time during which equipment is producing at the standard production rate. To calculate net operating time, subtract performance time losses from the operating time. Performance time losses consist of normal production losses (production rate reduction due to start-up, shutdown, and changeover) and abnormal production losses (production rate reductions due to abnormalities). Net operating time is the processed amount multiplied by the actual cycle time.

The last element is quality rate. It considers the proportion between number of good products and total production amount. The calculating formula of quality rate is given as (3).

$$Q = \frac{Processed\ amount - defect\ amount}{Processed\ amount} \tag{3}$$

where, processed amount refers to the number of items processed per time period (day, month or etc.). The defect amount represents the number of items rejected due to quality defects of one type or another, which require rework or become scrapped.

Combining equations (1) to (3), the OEE for given equipment operation is determined from (4)

$$\text{OEE} = A \times P \times Q \tag{4}$$

As mentioned, the OEE depends on three main element and these elements are definitely specified with equivalent weight. The OEE is in direct proportion to all these three elements. Rising in the availability rate positively affects to the reduction of buffer inventories leading to a decreasing in lead times. This shortened lead times could enhance the organization's competitive capability in term of flexibility and delivery, since these increasing performance leads to deliver various products in a shorter lead time. Moreover, an increasing in term of performance efficiency, also, reduces the requirements for the buffer inventories, together with enhances the effective capacity. Finally, an increment of quality rate can be implied that scrap and rework are reduced, which both reduces the costs of product, and also delivers a higher capability of quality rate [11], [12].

Although OEE is recognized as a complete measurement indicator for measuring equipment performance, however several researches still argued its originally inappropriate approach. They improved the original OEE by adapting other terminologies. For example, Garza-Reyes *et al.* [13] proposed overall resource effectiveness which extensively considers both efficiency of material and also alterations in material and process cost. Braglia *et al.* [14] presented OEE accounting the whole production line performance and Raouf [15] and Wudhikarn [16] proposed a modified method assigning unequal weight for OEE's element, since generally losses are not equal in all elements. Furthermore, Kwon and Lee [17] developed the calculating method calculating increasing profits or decreasing costs from an incremental percentage of OEE. Its outcome is represented in monetary unit allowing easier ranking of the problem priorities. This study put efforts on improving the OEE's weaknesses to prevent a wrong decision making. It was still, however, inappropriately developed, thus, a new indicator has been proposed by Wudhikarn *et al.* [18]. This modified method is called an overall equipment cost loss indicator (OECL). After that Wudhikarn [19] also extended the OECL by considering it with cost of quality (COQ) and named as overall equipment and quality cost loss (OEQCL). The last three mentioned methods, nevertheless, require the operating information accompanied with the financial information and some of developed methods require much more information than original OEE, which put these indicators too complicated to calculate in shop floor level. As a conclusion, the original OEE or the weighted OEE is more suitable for the operational process.

As mentioned previously, Raouf [15] proposed a weighted OEE and this methodology assign different weight to each OEE's element by applying analytic hierarchy process (AHP). Nevertheless, the AHP assumes that there is no dependency among the concerning elements. Therefore, it is not suitable to apply AHP to identify the weight of OEE's elements which generally interrelate to each other. Hence, this research applied another alternation called analytic network process (ANP) for calculating weight of element.

B. *Analytic Network Process*

ANP is an improved method of AHP applied in MCDM. It was developed in the late of 1990s by Saaty [20]. The ANP extended the traditional AHP scope by accounting with dependency among criteria and alternatives, and then occasionally it is called as a generalization of AHP. Since, the AHP assume that each concerning element in hierarchy model is specified to be independent. However, generally, decision problems are unable to be structured in hierarchy model totally, and, moreover, problems may involve with the dependence between upper-level elements and lower-level elements in a hierarchical model, since the AHP is not suitably applied with these interrelation problems. Therefore, Saaty proposed the ANP to solve the mentioned problem. The ANP can be conducted in four main steps as follows.

1) Model the problem as a dependency network

The problem will be constructed to a network model consisting of elements and clusters. Each element in a cluster can depend on some or whole of the elements of any cluster, and this relationship is called outer dependence represented by arc connecting to other nodes in any other cluster. In the other hand, an interrelationship among elements within cluster is named inner dependence represented by a looped arc.

2) Calculating priorities among elements and establishing original or unweighted supermatrix

The second step concerns with prioritizing elements among inner elements and also outer elements. These priorities are obtained by making pairwise comparisons. In order to make a comparison, a generic question that must be encountered with is: How much more does one element influence on another element than the others? The process to perform pairwise comparisons and to obtain priority vectors of ANP is similar to the AHP. The relative importance values are described in Table II.

3) Calculating priorities among clusters and establishing weighted supermatrix

The supermatrix is constructed according to the dependency network model and after that this matrix is processed to the weighted supermatrix. The weighted supermatrix can be obtained by determining a cluster comparison to acquire a priority vector. These comparisons indicate a relative importance of influences between each cluster. Subsequently, the perceived priority vector is multiplied to relating segments of the unweighted supermatrix. The obtaining vector will be applied to weight the relative matrix segments. For example, the first entry of priority vector is used to multiply with all concerning elements in the first matrix segment. Following this process for all columns, finally, weighted supermatrix can be obtained.

TABLE II: SCALE OF ANALYTIC NETWORK PROCESS PREFERENCE [20]

Intensity of importance	Definition	Explanation
1	Equal importance	two activities contribute equally to the objective
3	Moderate importance	experience and judgment slightly favor one over another
5	Strong importance	experience and judgment strongly favor one over another
7	Very strong importance	activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	used to represent compromise between the priorities listed above

4) Calculating limit super matrix and obtaining final priorities

After the weighted super matrix is acquired, then multiplying the matrix by itself until every column in the matrix is totally similar. This process derives the limit supermatrix which the final priorities can be obtained from the corresponding columns. Then, read off the highest priority alternative or the desired mix of alternatives.

As presented, the ANP accounts the dependencies between considered elements by replacing the hierarchical model with the network model [21], so in recent years, many ANP studies have been highly applied in various fields. For instance, in research and development process [22], [23], in environmental impact assessment process [24], [25] and in logistic and supply chain management process [26], [27]. Even though the ANP has been extensively applied in many fields, its approach still has not been used with OEE. One of the nearest hierarchical decision process has been applied with OEE ever was the AHP. However, as mentioned, AHP represents a framework with one way direction hierarchical relationship. Therefore, in this research, a model that adopts ANP is proposed to solve the weaknesses of original OEE and some of modified OEE.

III. Proposed Methodology

As mentioned already, this research goal is to find the way to improve the original OEE and also other improved OEE. To do so, this paper applies the ANP approach to identify the weight of OEE's element. First, the OEE elements are still computed as in the original calculation, following (1), (2) and (3) for A, P and Q respectively. As previously noted, the significance of every single OEE's element is completely dissimilar to the others. However, even in the same element, if the comparable machines are different in the matter of machine type, capacity and also operating cost and so on, the intensity of incurred losses is also different. For instance, at the same number of reject, a machine producing expensive product has higher losses than a machine manufacturing cheaper goods. Therefore, the ANP is selected for handling with these independent issues. It is applied to determine the weight of equipment and also elements. The concerning weights are specified by following the weighted supermatrix following supermatrix formation and transformation step illustrated previous section. Afterward, the final OEE is calculated as the following formula.

$$\text{OEE}_j = w_{Aj}A_j + w_{Pj}P_j + w_{Qj}Q_j \tag{5}$$

Assuming that a weight of A element of machine j is w_{Aj}, a weight of P element of machine j is w_{Pj} and a weight of Q element of machine j is w_{Qj}, where $0 \leq w_{Aj}, w_{Pj}, w_{Qj} \leq 1$ and $w_{Aj} + w_{Pj} + w_{Qj} = 1$.

IV. Conclusion

Performance measurement seems to be a general matter in organization, but it is still a crucial part for manufacturing firms. It concerns with several decisions contributing to successfulness of company. Hence, a good measurement methodology is mostly required for assessing business performance. OEE is one of widely used metrics of performance in the manufacturing, especially, for firms already applying the TPM. However, the original OEE method does not appropriately prioritize problematic equipment especially when the comparable machines are different in term of capacity, produced product, production cost, etc. This weakness was realized and improved by specifying weight for different element of OEE. Nevertheless, these weights are calculated using AHP approach assuming that the OEE's elements and equipment are independent in spite of involving with the dependent interaction. Therefore, this research proposes an improved calculation method applying ANP approach to identify the weight of interactive elements and equipment. However, this paper aims to present concepts and initial work in term of developing how to calculate weighted OEE. Hence the implementation, discussion and verification of this proposed method will be done in the further works.

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Ratapol Wudhikarn is a lecturer and also Ph.D. candidate in the College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand. In 2004, He earned his Bachelor of industrial engineering from Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand, and, in 2008, he received his studies towards a Master degree of industrial engineering at Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand. Now, he is studying Doctoral degree in knowledge management at College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand.

He has five years' work experiences as System Development Engineer and Production Engineer as well as three years academic work experience in modern management and information technology during his Ph.D. study. His research interests include: production engineering, management system, operations management, manufacturing systems, supply chain management, operations research, maintenance engineering, decision making, and so on.