Thesis for the Degree
of Doctor

New Methodology for measuring Equipment Performance and Managerial Effect in TPM

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李弘哲 教授 指導

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Abstract

This dissertation presents the newly designed calculation methodologies on the TPM (Total Productive Maintenance) effect measuring indices for promoting the output performance and maturity of TPM that the numerous companies have introduced for strengthening the manufacturing competitiveness.

The first purpose of this research is to present a new calculation methodology for the equipment performance indices based on a modified time loss structure different from the existing ones on the TPM literatures. With the time loss structure for the processing type equipment, the equipment efficiency indices such as time availability, performance efficiency, good quality rate and overall equipment efficiency (OEE) can be calculated. But, this methodology cannot provide the sufficient information in view of the whole equipment performance appraisal, and also is insufficient to calculate the equipment productivity, reliability, efficiency and maintainability indices from one time loss structure all together. This dissertation suggests a new methodology capable of calculating the equipment productivity, reliability, efficiency and maintainability indices with a newly designed universal metrics and also the definitions of losses based on a modified time loss structure different from the existing ones.

The second purpose of this research is to present a new calculating methodology for estimating a quantitative monetary managerial effect as a result of TPM activities. The suggested methodology is to calculate the total contributive managerial effect composed of the contribution profit and saved manufacturing cost that are obtained by improving the OEE of processing type equipment. The managerial effect as the unit contributive

managerial effect acquired by keeping the OEE at the 1% upraised condition during a given period can be calculated by the following equation; "Contributive managerial effect acquired by 1% upraised OEE = Additive contribution profit + Saved manufacturing cost". Based on this unit additive contributive managerial effect, the total monetary effect amount corresponding to the total upraised value of OEE during the same period can be calculated. This suggested calculation methodology can be demonstrated by applying to a Coke filler as a processing type manufacturing equipment.

These new suggested methodology models will contribute to improving the maturity of TPM activities by grasping the equipment performance indices such as the equipment efficiency, productivity, reliability and maintainability, and the monetary quantitative managerial effects on a periodical monthly and/or yearly basis.

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Chapter 1. Introduction

1.1 Background of Research

In order to achieve the world-class manufacturing performance, the more and more companies are undertaking the efforts to improve the quality and productivity, and to reduce the manufacturing costs by means of the equipment performance improvement based on the Total Productive Maintenance (TPM) (Mckone et al., 1999; Hipkin and Cock, 2000; Takahashi, 1996). TPM has been adopted in order to strengthen the manufacturing business performance and to achieve the world-class manufacturing competitiveness since 1971 (Demeter, 2003; Shirose, 1996; Swanson, 2001).

The purpose of TPM is to secure the physical improvement of personnel and equipment, and also that of the manufacturing company. The major target among TPM effect indices is to make the improvement of Overall Equipment Efficiency (OEE) and labor productivity, eventually to secure the equipment failure to zero, defects and rework to zero and industrial accident to zero (Shirose, 1996; Nakajima, 1996; Takahashi, 1992a & 1992b; Suzuki, 1997).

As the concrete means to achieve the equipment failure to zero, defects and rework to zero, and industrial accident to zero, the eight major elements of TPM activities such as individual improvement, autonomous maintenance, planned maintenance, skill-up education & training, quality maintenance, Maintenance Prevention (MP), safety & environment and office TPM are implemented, and the set-up and goal-setting of TPM effect measuring indices are required for the effect measurement in advance (Shirose, 1996; Suzuki, 1997; Mckone et al., 1999; JIPM, 1996 & 1998; KSA, 2000; Nakajima, 1996; Okamoto, 1994).

At a preparation stage of TPM deploying program, the basic TPM policy and effect improvement target must be settled. As a goal setting of TPM, the bench mark review of TPM effect indices and improvement increment goal setting are performed. To grasp an activity performance from the introduction stage to the steady application stage, the index of OEE as the effect measuring indices in TPM is normally used (Shirose, 1996; Suzuki, 1997; JIPM, 1998; Swanson, 2001).

From now on, on the basis of the equipment time loss structure, the OEE for the processing type equipment and Overall Plant Efficiency (OPE) for the plant type equipment, and also time availability, performance efficiency and good quality rate as the components of OEE and OPE have been used for the equipment efficiency indices.

OEE is widely adopted as an important means among the equipment performance measurement indices for the appraisal of TPM activities' results available in the processing type equipment (Schroeder and Cua, 2001). Up to now, there are no standardized calculation models of OEE (Oechsner et al., 2002). The successful analysis on OEE only is not sufficient because no machine is isolated in a factory, but operates in a linked and complex environment. A wider approach has to focus also on the performance and utilization of whole equipment in a factory during a given calendar time and the effective measurement of contributive managerial effect resulted from TPM activities.

The calculation methodology of OEE based on an equipment loss structure in the processing type and plant type equipment has been shown by several researchers such as Oechsner et al. (2002); Schippers (2001); Chand and Shirvani (2000); Wang and Lee

(2001); Shirose (1996); Nakajima (1996); JIPM (1998); Mckone (1996) and Cua (2000), and that on the equipment productivity was shown by Oechsner et al. (2002); Jung (2001) and KSA (2000).

We intend to control and improve the equipment efficiency by using the OEE in case of the processing type equipment such as batch type, independent production type, non-continuously working type as the equipment efficiency indices among the TPM effect indices (Shirose, 1996; Nakajima, 1996; Takahashi, 1992b).

The studies on TPM effect appraisal indices to meet the requirements of diversified manufacturing business types seem to be insufficient. Especially, the studies on the effective and practical methodologies capable of measuring TPM managerial effect quantitatively seem to be insufficient also.

This dissertation presents the more systematic and informative calculation methodologies for the equipment efficiency, productivity, reliability and maintainability indices based on a newly designed universal equipment time loss structure different from the existing ones on the TPM literatures to promote the equipment performance and to strengthen the TPM effectiveness.

TPM is called as "money-earning PM activities" and oriented for "Total Profit-able Maintenance" or "Total Productive Management". Therefore, TPM activities shall contribute to the managerial profit directly and to the profit-producing result practically (Suzuki, 1989; Swanson, 2001). To make the additive profit quantitatively by the TPM activities, the calculation of additive contribution profit and saved manufacturing cost must be performed to measure how much TPM activities contribute to the profit-producing improvement (Kwon and Lee, 2004).

However, the well-known TPM effect indices are insufficient in view of appraising “money-earning PM activities”. In view of Top’s interest on TPM effect indices, it has been pointed that the contributive profit is more important rather than the other tangible effects.

In this dissertation, to show the calculation methods of managerial effect as the summed-up value of additive contribution profit and saved manufacturing cost resulted from the TPM activities, a calculating methodology example for the processing type in the manufacturing industry is presented.

1.2 Purpose and Importance of Research

The purpose of TPM effect measurement is to extract the important problems hindering the equipment and production losses, to remove the problems promptly, and to heighten the manufacturing business performance (Demeter, 2003). The TPM effect indices capable of realizing the exact and effective measurement on the result of TPM activities must be the ones capable of judging whether the ordinary TPM activities contribute to the improvement of effect indices, to the induction of the countermeasures and improvement points on the problems and finally to the contributive managerial effect.

Because the equipment productivity, reliability, efficiency and maintainability become the critical issues in the capital-intensive operations, the strategic importance of productive maintenance in a manufacturing business must be recognized (Tsang, 2002).

The individual equipment efficiency indices such as time availability, performance efficiency, good quality rate and OEE calculated by the time loss structure for the processing type equipment seem to act a good role on reducing the related losses as the integrated equipment efficiency indices (Nakajima, 1996). But, these indices cannot provide the sufficient information in view of the whole equipment performance appraisal, and this methodology based on an existing loss structure is insufficient to calculate the equipment productivity, reliability, efficiency and maintainability indices together with the equipment efficiency indices from one loss structure.

The first purpose of this research is to present a new calculation methodology model for measuring the equipment productivity, reliability, efficiency and maintainability indices based on a new and modified time loss structure designed differently from the existing ones on the TPM literatures.

This new calculation methodology for the equipment efficiency indices capable of enabling the more systematic and informative index analysis based on a new universal equipment time loss structure different from the existing ones on the TPM literatures will contribute to the improvement of manufacturing competitiveness. And also the calculation methodology on the additional TPM effect indices such as the equipment productivity, reliability and maintainability indices will help to produce the higher performance of equipment.

The maintenance cost is often regarded as a necessary expense that belongs to the operating budget. However, it is a common item on the hit list of cost-reduction programs. Because the reliability and maintainability become the critical issues in the capital-intensive operations, the strategic importance of maintenance cost reduction and maintenance quality improvement in a manufacturing businesses must be recognized (Takahashi, 1996; Suzuki, 1997).

The targets of TPM activities must be contributed to the managerial profit of a company. To realize the profit-producing TPM activities, and to measure the TPM effects about how much they contribute to the managerial effect such as contribute managerial profit, the calculation of additive contribution profit and saved manufacturing cost shall be performed (Kwon and Lee, 2004; Ham, 1998).

If TPM activities do not contribute to the managerial profit practically, the reconsideration on the TPM deploying methodology shall be made, and the improvement activities on the insufficient elements shall be strengthened (Mckone et al., 2001).

TPM has been emphasized that it must be contributed to the profit-producing management as its result, but the standardized and/or generalized methodology capable of calculating a contributive managerial profit matched for the accounting system of a company quantitatively has not been shown.

The second purpose of this research is to present the new calculation methodology model for estimating the quantitative contributive managerial effects such as additive contribution profit and saved manufacturing cost as a result of TPM activities to measure what degree of contribution to the managerial profits corresponding to the accounting system of a company directly.

The possibility of grasping how much the result of TPM contributes to the managerial profit is to incur the good recognition of related participating division in a company on the TPM, and also it helps to improve the degree of autonomous participation of related divisions on TPM. Additionally, it can convert the current recognition on TPM from the top management class, and also can help to secure the top management's financial assistance to the improvement activities for the more systematic TPM deployment.

1.3 Method of Research

The first purpose of this research is to suggest the new calculation methodologies for the equipment efficiency, equipment productivity, reliability and maintainability indices among TPM effect indices on the basis of a new universal time loss structure, and additionally for the contributive managerial effect enabling the quantitative calculation for the purpose of improvement of manufacturing performance and the setting-up of effective countermeasures on the equipment losses.

Therefore, this research draws on the methodologies that are suitable for the theoretic-cally driven empirical research. Weick (1989) suggested that the theories should be developed by use of three systematic processes involving the literature review, use of data, and use of intuition and assumptions (Cua, 2000). In building the business operations management theories and purposes, the principle of Weick's suggestion can be used. Levis (1998) pointed that the processes of theory development are not meant to be the sequential trial & error, and Eisenhardt (1989) pointed that those must be used in conjunction and in balance (Cua, 2000).

Traditionally, the business Operations Management has been dominated by the deduct-ive approaches, and the mathematical modeling and simulation analysis has been the common tools of analysis (Cua, 2000). In the 1990's, an attention was drawn to the potentiality of empirical research involving cross-technical and longitudinal data analysis. The recent case study is considered as an indispensable complement to the quantitative analysis (Cua, 2000).

In this dissertation, the methodologies of literature reviews, suggestion of new models, case studies and reviews are used in conducting this research. These four methodologies are not conducted in strict sequence. Instead, they are used complementarily to develop, enhance, and empirically verify the new calculation models on the equipment efficiency and contributive managerial effect.

To illustrate the research question of this dissertation, the literature reviews on the TPM and TPM effect indices, equipment productivity, equipment efficiency indices such as OEE and OPE, equipment reliability and maintainability, managerial effect indices in TPM, contributive managerial profit and saved manufacturing cost as the managerial effect are conducted.

This research is theoretically grounded on the factory management principles such as the concepts of equipment management, equipment efficiency, equipment productivity, production economics, production innovation engineering, plant productive maintenance engineering, equipment reliability engineering and cost accounting.

The use of literature reviews on the equipment management and monetary effect principles can be helpful for establishing a theoretical framework for a set of practical and effective TPM effect measurement practices.

In this dissertation, to provide a "reality validation" of the relevance about the theoretically developed framework, the first case study used the collected data for the OSRK company's fluorescent lamp manufacturing and the second case study used the collected data for the DSB company's Coke filler equipment suitable for the processing type equipment during the given period.

Yin (1994) pointed that the case studies can also serve a source of analytic generalization to the theory, hence the information obtained from the case studies is used to enhance the theoretical framework (Cua, 2000). Case analysis helps to answer the "why" and "how" questions in the natural setting of phenomena under observation and also provides the direction for a subsequent research.

To illustrate the suggested theoretical framework and its associated definitions systematically, the first case study on the new TPM effect appraisal indices such as the equipment productivity, equipment efficiency composed of OEE and TEEP (Total Effective Equipment Productivity), equipment reliability and maintainability on the basis of universal equipment time loss structure newly defined on this dissertation is performed with the collected data for the OSRK company's fluorescent lamp manufacturing during the given period . And the second case study on the contributive managerial effect is performed with the collected data for the DSB company's Coke filler equipment suitable for the processing type equipment (Kwon and Lee, 2004).

Above of all, the new TPM effect measurement indices must be able to be used for the practical TPM effect measurement methodologies. And these new methodologies will be more effective and useful in TPM performance measurement practice. Hence these two case studies and illustrations have been performed about the theoretical framework to investigate the empirical validation and the feasibility of utilization in TPM practices.

1.4 Scope of Research

This dissertation is to present the new methodologies for the TPM effect measurement indices for improving the TPM performance and manufacturing competitiveness. As the TPM effect measurement indices, the nine spheres of them can be defined as follows; ① managerial effect, ②plant and equipment efficiency, ③equipment reliability and maintainability, ④maintenance work efficiency and maintenance cost, ⑤MP (Maintenance

Prevention) & initial control, ⑥safety, hygiene and environment, ⑦quality and energy, ⑧education and morale and ⑨office productivity (Shirose, 1996; Suzuki, 1997; JIPM, 1998; Takahashi, 1992a & 1992b).

This dissertation is confined only to the three effect measurement indices such as ① managerial effect, ② plant and equipment efficiency and ③ equipment reliability and maintainability among the above nine spheres.

Firstly, this dissertation presents a new methodology model on the plant and equipment efficiency, equipment reliability and maintainability. An index used as a representative effect measurement index in a production division is the OPE (Overall Plant Efficiency) in case of plant type equipment and the OEE (Overall Equipment Efficiency) in case of processing type equipment. The equipment reliability is defined as "the characteristics that the equipment does not incur the failure"(Lee, 2002). And, the equipment maintainability is defined as "the characteristics capable of completing the repair maintenance within the specified interval under the given condition" (Lee, 2002).

For calculating the plant and equipment efficiency, and the equipment reliability and maintainability, this dissertation presents a newly suggested model for calculating the equipment performance indices such as productivity, reliability, efficiency and maintainability that can be derived from a new universal time loss structure hindering the equipment performance in the processing type equipment, and also on the definitions of seven major time losses.

Secondly, on the managerial effect, this dissertation presents a new methodology model capable of calculating the contributive managerial effect as a result of TPM activities quantitatively.

The managerial effect measurement index is the one as a result that all TPM activities have been synthesized. All sorts of TPM activities' results must be reflected to the managerial effect index finally and must be contributed to the achievement elevation of divisional tasks in charge.

For the managerial effect measurement indices, although the managerial effect measurement indices by TPM activities are composed of the value-added productivity, labor productivity, manufacturing cost per unit, contribution profit, and so on, above of all, the additive contribution profit as the quantitative contributive managerial effect by TPM corresponding to the accounting system of a company seems to be very important. Hence in this dissertation a new methodology model for the contribution profit as the monetary contributive managerial effect is presented.

As a methodology for grasping the monetary contributive managerial effect as a result of TPM activities, in a different way from the above researchers, this dissertation presents the calculation model and example in the processing type equipment that the quantitative contributive managerial effect corresponding to the total upraised value of OEE during a given period can be calculated.

1.5 Contents of Research

To present these two new models for the TPM effect measurement, this research is conducted on the basis of the literature reviews on the TPM and TPM effect indices, equipment productivity, equipment efficiency indices such as OEE and OPE, equipment reliability and maintainability, managerial effect indices in TPM, contribution profit and saving cost as the managerial effect.

Firstly, this dissertation presents a new model for the calculation methodology on the equipment productivity indices such as equipment utilization rate, planned availability, equipment operation rate and total effective equipment productivity (TEEP), the equipment reliability indices such as time availability, mean time between failure (MTBF), failure intensity rate and failure frequency rate, the equipment efficiency indices such as performance efficiency, good quality rate, OEE and net equipment efficiency (NEE), and the equipment maintainability index such as mean time to repair (MTTR) (Kwon and Lee, 2003).

And secondly, this dissertation presents a newly suggested methodology for calculating the contributive managerial effect corresponding to the total monetary amount of effect composed of the additive contribution profit and saved manufacturing cost that can be obtained by the improvement of OEE in the processing type equipment.

The contributive managerial effect that is regarded as the total monetary managerial effect calculated on the basis of unit contributive managerial effect earned by keeping the OEE at the 1% upraised condition for a given yearly period can be calculated by the following equation; "Contributive managerial effect acquired by 1% upraised OEE = Additive contribution profit + Saved manufacturing cost" (Kwon and Lee, 2004).

Based on the above unit contribution managerial effect, the total monetary managerial effect amount corresponding to the total upraised value of OEE during the same period can be calculated as the unit contribution managerial effect is multiplied by the total upraised value of OEE. The suggested calculation methodology can be demonstrated by applying to a Coke filler as a processing type manufacturing equipment as shown on the case study.

1.6 Contributions of Research

From now on, the equipment efficiency indices such as OPE, OEE, time availability, performance availability and good quality rate based on a time loss structure of equipment have been known and used already in the TPM practices.

However, the methodology capable of calculating all indices such as equipment efficiency, productivity, reliability, maintainability and also work readiness measurement all together from one equipment time loss structure has not been known and used.

This new methodology capable of calculating the equipment productivity, reliability, maintainability and also work readiness measurement additionally from one equipment time loss structure together with equipment efficiency can help the various views of TPM effect grasping works for extracting the higher performance of TPM. And this contributes to the removal of equipment losses concretely, and it contributes to the improvement of manufacturing competitiveness.

The various indices on TPM activities of diversified manufacturing business types can be measured additionally, but grasping how much TPM contributes to the managerial effect as its performance can be considered as the more important thing.

The possibility of calculating the contributive managerial effect by OEE as TPM effect measurement methodology enables to grasp the quantitative contributive managerial effect as a TPM activities' result. And also, it will enable to heighten an interest on TPM, and to extract the financial assistance about the innovative activities from the top management.

The possibility of calculating the contributive managerial effect by OEE is not confined to only the processing-type industry, but can be applied to the plant type, too. Hereafter, we hope that the research on this methodology for the plant type industry and equipment will be conducted more actively, and that by this the maturity of TPM will be able to be more improved.

1.7 Composition of Dissertation

The remainder of this dissertation is organized by the literature reviews on TPM effect measurement composed of TPM for strengthening the manufacturing competitiveness, the literature reviews on the equipment productivity, equipment efficiency, reliability and maintainability indices, the managerial effect indices in TPM, the contribution profit and saving cost as the managerial effect, a model on the equipment performance indices, a model on the contributive managerial effect and the conclusions in sequence.

Chapter 2. Literature Reviews on TPM Effect Measurement

2.1 TPM for Strengthening the Manufacturing Competitiveness

2.1.1 TPM as a Means of Manufacturing Competitiveness Strengthening

The inner environment where a today's manufacturing company is placed in the extreme oppression on the manufacturing cost reduction and the productivity improvement for striving under the low growth times. And each manufacturing company has met with the times that it must put an interest on the product quality innovation by producing the consumer-oriented products.

Since UR which is the eighth multilateral trade negotiation, the international environment where the manufacturing companies are placed in has met with the wide market opening of industrial products, and also has met with the unlimited competition times because of getting out of a local competition or a domestic competition circumstance owing to the launching of WTO, that is, World Trade Organization, too.

This implies that a company without manufacturing competitiveness cannot be protected any more, and that it meets with the situation of crisis. Also, this implies that the importance of coping with an environmental change by means of deploying the management innovation action program contributing to the improvement of basic physical constitution by letting this crisis turn into a blessing must be recognized.

To improve a company's competitiveness, the managerial innovative activities for the improvement of productivity and quality and the cost reduction are more necessary than any other times. The realization of productivity improvement by the effective utilization of available resources, product development for improving the functional quality of product, quality innovation enabling the customer satisfaction by eliminating the quality defects, and cost reduction by the eradication of all kinds of losses impeding the manufacturing efficiency of a factory is more important than ever (Swanson, 2001).

The manufacturing companies have been endeavoring in order to improve the manufacturing competitiveness by the innovative activity solutions and/or tools for the effective factory innovation such as TPM, 6 Sigma, TCR (Total Cost Reduction), RCM (Reliability-Centered Maintenance), TOC (Theory of Constraints), and also by the e-Business solutions for the company-wide innovation such as ERP (Enterprise Resources Planning), CRM (Customer Relationship Management), SCM (Supply Chain Management), SEM (Strategic Enterprise Management), and so on.

As for the manufacturing activities of nowadays, the tendency of dependence on equipment element is growing larger than on human element among the 4Ms (Man, Machine, Material, Method) that are the four elements of manufacturing process in view of productivity and quality on account of the development of technology. In addition, because the trend that equipment's status influences the quality of a product grows larger, an efficient operation scheme of equipment is considered as an important countermeasure of manufacturing competitiveness.

The manufacturing companies pay attentions to the innovative activity programs for the productivity improvement and cost reduction to secure the correspondence ability under the company's disadvantageous environment and for the improvement of physical constitution of company.

The number of manufacturing companies to which TPM have been introduced as an innovative action tool was increased greatly after the middle of 1980's (Shirose, 1996; Suzuki, 1997; Nakajima, 1996; JIPM, 1996 & 1998; Takahashi, 1992a & 1992b). TPM has been recognized as an effective and strong tool for the competitiveness elevation of manufacturing company. And the innovative success rewards have been reported through TPM activities for more than 40 years since a Japanese Nippon Denso Co. introduced the TPM for the efficiency of production in 1964 (Takahashi, 1992a & 1992b).

TPM pursues the overall efficiency of manufacturing equipment, and it is the activity good for eliminating all kinds of losses impeding the equipment efficiency effectively. In particular, TPM activities are conducted under the company-wide participation of all divisions in a company. That is, TPM is an innovative company's scheme not only to let the maintenance men of special maintenance divisions in charge perform the inherent special maintenance but also to let the operators of equipment utilization divisions perform the autonomous maintenance.

In TPM, the following activities are performed. The operators of equipment utilization divisions are to be required for conducting the autonomous maintenance, the individual improvement for the equipment efficiency to eliminate all sorts of equipment losses and furthermore the quality maintenance to reduce the quality defect loss caused by the poor maintenance, malfunctions of equipment, and inappropriate condition setting and control to zero (Shirose, 1996; Nakajima, 1996; Takahashi, 1992a & 1992b).

And also, MP design & initial control by the equipment planning division are conducted to eliminate (debug in other word) all sorts of anticipated problems during the initial interval for the introduction and installation of new equipment in advance before the normal operation, too (JIPM, 1998).

Additionally, the office TPM is conducted by the indirect and administrative divisions in order to support the TPM activities effectively and to elevate the office productivity through the removal of business losses in charge of the divisional duties.

Finally, for each equipment operator in order to acquire an equipment maintaining ability, the skill-up education & training is conducted. This activity enables to bring up the skilled equipment operator on the equipment. Through the characterized small overlapping groups, all classes of the company from the top management to the front-line operators are participated in TPM activities in charge (JIPM, 1998).

The introduction purpose of TPM activities in a manufacturing company is to accomplish improving the physical constitution of company and acquiring the profit-producing activity result through improving the physical constitution of employees and equipment (Takahashi, 1992b). Also, TPM is performed in order to aim at the improvement of overall equipment efficiency and labor productivity, and eventually the equipment failure to zero, the quality defect to zero, the accident and environmental disaster to zero (Shirose, 1996).

Above of all, TPM activities must be contributed to the contribution profit on the accounting system of company directly and quantitatively. To extract the profit-producing result effectively, a new effect measuring methodology capable of calculating the contributive managerial effect is necessary.

A new calculating methodology of contributive managerial effect will help the conversion to the favorable recognition on TPM from the top management, and will contribute to improving the quality and maturity of TPM activities.

2.1.2 Definition, Necessity and Features of TPM

TPM is an acronym of "Total Productive Maintenance" in which "involving all employees for the top managements to the front-line operators". Recently, "P" connotes "Productivity or Profit", while "M" connotes "Management" for the purpose of the reinforcement of manufacturer's competitiveness (Shrose, 1996; Nakajima, 1996).

The definition of TPM can be described as the following five elements (JIPM, 1998).

① Aiming at forming a manufacturing company's culture which can pursue the maximum efficiency of production system (overall efficiency).

② Establishing the system at the existing local site and equipment which can prevent the various losses and achieve such "reduction to zero" targets as "zero accident", "zero defects" and "zero failure" in every equipment life-cycle in the production system.

③ In all aspects of production, development, marketing and administration.

④ All employees involving from the top management to the front-line operators.

⑤ Achievement of losses to zero level through the activities of overlapping small groups.

In order to have the essence of TPM understood, the definition, necessity and features of TPM are presented as the following (Takahashi, 1992a & 1992b, Shirose, 1996).

The necessity of TPM can be described as the following items.

① The economic environment surrounding the companies becomes severe, and the thorough elimination of wastes is required for the survival of company. Therefore, the wastes caused by the failure shutdown of equipments built with the huge investment, and the wastes such as defective products should be absolutely eliminated.

② Requirements for the product quality become stringent, and only one defective product may not be allowed. Quality-assured delivery of total products is now taken for granted.

③ With the needs diversified, the small lot production on the various kinds of products and a shorter delivery period have been strongly required. That is to say, TPM enabling to reduce the eight major losses of equipment to zero is recognized as necessary for the survival of manufacturing company.

④ In the company's environment related to the human resources, such tendencies as the avoidance of 3Ds (Difficult, Dirty and Dangerous), tertiary industry orientation and working hour shortening can be seen to a large extent and the secure of sufficient work force becomes hard. On the other hand, as the aging society and higher education society have been advancing, the maintenance of conventional types of production activities becomes difficult.

Accordingly, the necessity of introducing TPM has been recognized so that the manufacturing company can survive under the world-wide competition, with the sixteen major production losses composed of equipment, personnel and jig & energy losses to zero (Shirose, 1996; Nakajima, 1996; Lee, 1993).

On the other hand, the features of TPM can be described as the following items.

① Economic efficiency (" Profitable productive maintenance ")

② Tota1 maintenance system (Maintenance prevention + Preventive maintenance + Corrective maintenance)

③ Autonomous maintenance by operators (Small group activities)

The first feature of economic efficiency is common to TPM and PM (Productive Maintenance and/or Preventive Maintenance). And the second feature of total maintenance system is common to TPM and productive maintenance. Especially, it can be said that the feature of AM (Autonomous Maintenance) by operators is unique to TPM (JIPM, 1998). Even though the features can be classified in this way, the features of the above ① and ③ items have not been so far pursued to their limits in the production activities of each manufacturing company.

To attain the goals of TPM effect indices, the systematic approach on the eight spheres of activities must be implemented. TPM is performed by the total participation of all divisions such as the equipment planning, utilization, maintenance and supporting & administrative divisions in a company.

In concrete, TPM activities are composed of MP (Maintenance Prevention) design & initial control by the equipment planning division, autonomous maintenance, individual improvement and quality maintenance by the equipment utilization division, planned maintenance by the equipment maintenance division, safety and hygiene by the safety division, environment management by the environmental division, office TPM by the equipment supporting & administrative division.

In particular, to expedite these spheres of TPM activities effectively, the skill-up education & training and the activities of overlapping small groups are performed. TPM aims at improving the physical constitution of a company through the improvement of physical constitutions of employees and equipments, and pursues the improvement of OEE and labor productivity as the major effect indices, ultimately intends to attain the equipment failure to zero, the quality defects to zero, and the accident & disaster to zero (Shirose, 1996; Nakajima, 1996; Lee, 1993).

On the other hand, the key points on the eight spheres of TPM as the characteristics on the deploying methodology of each sphere of TPM activity can be presented as follows (JIPM, 1998; Takahashi, 1992a & 1992b; Nakajima, 1996; Shirose, 1996; Suzuki, 1989 & 1997).

Firstly, the “Autonomous maintenance” aims at maintaining one’s own equipment by oneself, keeping the fundamental conditions of equipment such as cleaning, lubricating and retightening, bringing-up of skilled operator on the equipment, and it is composed of the following key activities.

① An autonomous maintenance is progressed step by step according to the deploying program composed of the seven steps (for about four to five years).

② An autonomous maintenance is composed of seven steps such as Step 1 (Initial clean-up), Step 2 (Countermeasures for the causes of dirt equipment and difficulties of equipment operation), Step 3 (Preparing the tentative cleaning, oiling and checking standards), Step 4 (Equipment general inspection), Step 5 (Autonomous inspection; in case of the processing type, Process general inspection; in case of the plant type), Step 6 (Standardization; in case of the processing type, Systemization of autonomous maintenance; in case of the plant type) and Step 7 (Autonomous control).

Secondly, the “Individual improvement” aims at elevating the efficiency of equipment and production by the reduction, restoration and eradication on the defects and deterioration of equipment, and the losses hindering the equipment efficiency, and it deploys the reducing or eradicating activities on the six big losses such as equipment failure loss, set-up and adjustment loss, cutting blade and jig change loss, yield (start-up) loss, minor stoppage and idling loss, reduced speed loss and defects & rework loss hindering the equipment efficiency.

Thirdly, the "Planned maintenance" aims at maximizing the time availability by the periodical maintenance and predictive maintenance as a specialized maintenance, and it is composed of the following key activities.

① Planned maintenance is progressed step by step according to the deploying program composed of the six steps (for about four to five years), and the specialized maintenance system can be completed by these six steps.

② Planned maintenance is composed of six steps such as Step 1 (Evaluation of equipment and grasp of present status), Step 2 (Restoration of deterioration and improvement of weakness; Support of autonomous maintenance and prevention of recurrence in the similar defects and troubles), Step 3 (Set-up of maintenance information management system), Step 4 (Set-up of periodical maintenance system), Step 5 (Set-up of predictive maintenance system), Step 6 (Overall evaluation of planned maintenance).

③ Major elements of planned maintenance are composed of the equipment grade control, failure grade system, maintenance record system, effect measurement indices system in the planned maintenance, supporting system of autonomous maintenance, corrective maintenance system, CMMS (Computerized Maintenance Management System), maintenance budget control, spare parts control, standardization of maintenance activity, maintenance interval and plan, maintenance tool control, lubrication control, maintenance precision control, utility control, predictive maintenance and equipment diagnosis technique, and so on.

Fourthly, the “TPM education & training” aims at improving the employee’s mind, maintenance skill and employee’s deploying skill on TPM, and it is composed of the following key activities.

① Education & training on the TPM deploying methodology; managers, staffs, leaders and operators in order.

② Education & training on the maintenance technique are conducted in view of the function, principle and maintenance, general inspection manuals on each part of equipment, and the component and unit of equipment.

③ One point education and training on the fundamental knowledge, examples on the equipment failure, examples on the quality defects, and examples on the equipment improvement are conducted by OPL (One Point Lesson) sheet.

Fifthly, the “MP (Maintenance Prevention) design and initial control” aims at conducting the MP design of new introducing equipment appropriately, and it is composed of the collection of MP information, preparation of MP design standard, set-up of debugging system on the step by step initial control activities from the introduction of new equipment to the initial floating period (before the normal operation in other words), and set-up and improvement actions of initial floating control system.

Sixthly, the “Quality maintenance” aims at the set-up and control of equipment condition not to cause the quality defects. It is composed of the set-up of manufacturing process condition, reduction and/or eradication of quality defects loss, and quality maintenance analysis by means of QM (Quality Maintenance) matrix technique.

Seventhly, the “Safety, hygiene and environment” aims the attainment of accident and disaster to zero, and it is composed of the following key activities.

① Settlement of each system on the spheres of safety and hygiene, control of local site based on the safety and hygiene manuals, improvement action plan on the defects and items necessary for the remedial and/or improvement in view of safety and hygiene.

② Settlement of each system on the spheres of environment, control of local site based on the working environment manuals, implementation of autonomous maintenance and improvement action on the environmental equipment for the waste water treatment (WWT), air pollution protection and soil contamination protection.

Eighthly, the "Office TPM" aims at the improvement of office productivity and office environment, and it is composed of 5S (Seiri, Seidon, Seiso, Seiketz, Sitzke in Japanese words) in office, document filing system, office efficiency and standardization on TPM.

The systematic step by step development on these spheres of TPM activities based on TPM deploying master plan enables to attain the improvement of TPM effect indices, and furthermore to contribute to the large increase of contributive managerial profit.

2.1.3 Purpose and Target of TPM

What TPM aims at is "to reform the manufacturing company's constitution through the improvement of human resources and plant equipment". The improvement of human resources means that the employees are educated and fostered to be able to respond to the new demands of factory automation and to bring up the strong manpower capable of handling the equipment and manufacturing process in charge (JIPM, 1998; Takahashi, 1992a & 1992b; Nakajima, 1996; Shirose, 1996; Suzuki, 1989 & 1997).

The employees are required for the education & training in order to acquire the following abilities.

① Operator : Ability to perform the autonomous maintenance.

② Maintenance man : Ability to perform the high-quality special maintenance.

③ Production engineer : Ability to execute the maintenance-free equipment plan.

TPM activities aim at improving the overall efficiency of plant equipment through the improvement of human resources. To reform the plant equipment performance, the following items are required.

① Increase of total efficiency through the improvement of existing plant equipment performance.

② LCC (Life Cycle Cost) design of new equipments and their minimum trouble occurrence during the launching and normal operation stage.

As mentioned above, TPM aims at reforming the manufacturing company's culture through the improvement of both human resources and plant equipment, and the following is its basic concept.

To promote TPM as a part of policy and target management by clarifying the integration of basic business policy and mid/long term business plan into TPM and by integrating the TPM target into the manufacturing company's business target for the fiscal year, the goals or targets of TPM tangible effects are determined.

Annual targets are determined by year in order to attain the TPM tangible effects at the settlement or completion stage of TPM as shown on the Table 2-1 (JIPM, 1998).

TPM tangible effects can be attained to a degree of each result as shown on the Table 2-1 in most manufacturing companies with TPM activities if the divisional programs of TPM have been performed adequately step by step in accordance with the TPM master plan.

Table 2-1. The examples for TPM tangible effects at the stage of completion

P	··· * Value-added productivity improvement : 1.5 to 2 times
	* Reduction in number of failures : 1/250
	* Overall Equipment Efficiency (OEE) : 1.5 to 2 times
Q	··· * Reduction in quality defects : 1/10
	* Reduction in customer claims : 1/4
C	··· * Maintenance costs : reduced by 30%
D	··· * Reduction in product inventories : reduced by 50%
S	··· * No accidents
E	··· * Elimination of pollution

Remarks; P, Q, C, D, S & E indicate the abbreviated symbols that P is Productivity, Q is Quality, C is Cost, D is Delivery, S is Safety and E is Environment.

2.1.4 Spheres on the Effect Measurement Indices in TPM

The mid/long term goal setting of TPM indices is performed as one activity of introduction preparation stage on TPM development program. The goal setting is to perform the grasp of bench mark status and to set up the goal about the effect measurement indices. It is necessary for setting up the TPM effect measurement indices and for managing the process control of them in order to grasp the yearly and monthly TPM performance results from the introduction stage to the completion stage.

As a classification method of TPM effect measurement indices, there are two methods such as the effect measuring indices by the business areas and the ones by the cause and result.

Firstly, the effect index based on the business areas can be divided into the nine spheres of effect indices such as ① managerial effect, ② plant and equipment efficiency, ③ equipment reliability and maintainability, ④ maintenance work efficiency and maintenance cost, ⑤ MP (Maintenance Prevention) and initial control, ⑥ safety, hygiene and environment, ⑦ quality and energy, ⑧ education and morale and ⑨ office productivity (Shirose, 1996; Suzuki, 1997; JIPM, 1998).

Secondly, the effect index based on the cause and result is to measure the TPM effect for the TPM activity index such as M (Morale) that is the cause and/or means side index, and also for the TPM performance indices such as P (Productivity), Q (Quality), C (Cost), D (Delivery), S (Safety) and E (Environment) that are the result and/or purpose side indices.

The measuring indices for grasping the managerial effect are the integrated results of all TPM activities. The results of several activities by TPM are to be contributed to the managerial effect indices first of all, and consequently to the improvement of manufacturing business achievements and/or managerial profit. After issuing the TPM policy according to the managerial policy, TPM targets harmonized with the managerial policy must be settled (Cua, 2000; McKone, 1996). And after the divisional responsibilities are identified exactly, the performance targets that the divisional responsibilities are reflected must be settled.

As the managerial effect measurement indices, the ones such as value-added productivity, productivity per direct employee, contribution profit, manufacturing cost per unit, opportunity loss amount caused by production line stoppage, effect amount by individual improvement, order deficiency loss rate, equipment investment efficiency and rate of equipment to labor are used (Takahashi, 1992a & 1992b).

The effect measurement indices for the plant and equipment efficiency are the ones to measure the overall efficiency of plant and equipment. The OPE multiplied by the four components of utilization rate, time availability, performance efficiency and good quality rate is used in the plant type equipment (Takahashi, 1992a), and the OEE multiplied by the three components of time availability, performance efficiency and good quality rate is used in the processing type equipment (Takahashi, 1992b).

The equipment measurement indices for equipment reliability and maintainability are the indices to measure the reliability, that is, to connote how long the equipment has operated without the failure shutdown during the given net loading time, and also the maintainability, that is, to connote how fast the equipment repair maintenance has been completed under the failure loss time. As the reliability measurement indices, MTBF, failure frequency rate, failure intensity rate, time availability, equipment failure times and process trouble times are used. And as the maintainability measurement indices, MTTR is used (Lee, 1993).

The effect measurement indices for the maintenance work efficiency and maintenance cost are the indices to measure the efficiency of maintenance work and the maintenance cost, and also the indices to judge the economics of maintenance activity in TPM. As the maintenance work efficiency measurement indices, the fulfillment rate of preventive maintenance, curtailed hours of SDM (Shutdown Maintenance) and starting trouble times of SDM are used. And as the maintenance cost measurement indices, the total maintenance cost rate, maintenance cost per product are used (Shirose, 1996; Takahashi, 1992a).

The effect measurement indices for MP & initial control are the indices to measure the adequate MP design of new introduction equipment and the efficiency of initial floating control. As the MP & initial control measurement indices, the decreased rate of initial floating time in contrast with the previous similar equipment, decreased rate of emergency failure times are used (Kwon, 1997; Shirose, 1996; Takahashi, 1992a & 1992b).

The effect measurement indices for safety, hygiene and environment are the indices to measure the effectiveness of safety, hygiene and environment management system. As the safety & hygiene measurement indices, the one thousand times of injured employees to total employees, disaster frequency rate (one million times of disaster times to total working hours), disaster intensity rate (one thousand times of working loss days to total working hours), working environment measurement indices related with illumination, harmful gas, noise and dust are used. And as the environment measurement indices, the water pollution measurement indices such as pH, COD, BOD, SS and N-He, and the air pollution degree such as dust, SOx, NOx, CO, bad smell and sooty smoke, and the noise and vibration are used (Kwon, 1997; Shirose, 1996; Takahashi, 1992a & 1992b).

The effect measurement indices for quality and energy are the indices to measure the degree of quality and the effectiveness of energy usage. As the quality measurement indices, the customer claim numbers, poor quality rate during the production process. And as the energy measurement index, each energy cost per product on the electric power, cooling water, fuel, steam and lubricant are used (Kwon, 1997; Shirose, 1996; Takahashi, 1992a & 1992b).

The effect measurement indices for education and morale are the indices to measure the TPM activity indices related with M (Morale) that is the cause and/or means side index. As the education & training measurement indices, the TPM education hours per employee, OPL preparation numbers, OPL education hours are used. As the TPM effect measurement indices in view of morale, the meeting times of small groups, theme completion numbers by individual improvement, numbers of improvement proposal, finding numbers of defect items, repair numbers of defect items, repair numbers and rate supported by maintenance men on the defects found by operators, autonomous maintenance rate by operators, preparation numbers of improvement sheet, etc. are used (Kwon, 1997; Shirose, 1996; Takahashi, 1992a & 1992b).

The office productivity measurement indices are the ones related with the office efficiency. As for this purpose, the reduction rate of hours required for the office work, hours required for finding out the necessary document, lead time required for delivering the required material to a company are used (Kwon, 1997; Suzuki, 1989; Takahashi, 1992a & 1992b).

It is necessary to set up the goals of the TPM effect measurement indices in advance, and to perform the periodical process control by month or year under the TPM activities in order to grasp the monthly or yearly TPM performance results for these effect measurement indices.

2.1.5 New Viewpoints in the TPM Effect Measurement

TPM activities are called as the "money-earning or profit-producing PM activities" that are the ones to improve the manufacturing competitiveness. To judge the above money-earning or profit-producing PM activities, the effect measurement indices that enable to calculate the quantitative monetary amount, that is, how much the results of TPM activities have contributed to the managerial effect of a manufacturing company are required.

The contribution profit among the previously showed managerial effect measurement indices can be regarded as the relevant index related with the "money-earning or profit-producing PM activities". The development of methodology for the easy calculation of contributive managerial effect as a TPM effect measurement index is required in view of TPM and effect measurement practice (Kwon and Lee, 2004).

This dissertation intends to present a new effective methodology capable of measuring the quantitative contributive managerial profit as a managerial effect that can be calculated by OEE as the overall efficiency index of equipment.

In addition, as a representative overall efficiency index in view of equipment productivity among TPM effect measurement indices, OPE is calculated in case of the plant type equipment, and OEE is calculated in the processing type equipment.

As an index in view of equipment productivity, a calculating methodology capable of grasping the diversified equipment productivity, reliability, maintainability and work readiness control all together in addition to the OEE as an index of equipment productivity seems to be meaningful in view of improving the manufacturing competitiveness.

For this purpose, in this dissertation, with the new definitions of losses based on a newly designed universal time loss structure of equipment, the new effect measuring methodology capable of calculating the equipment productivity, reliability and maintainability additionally in addition to the OEE is presented.

The possibility of measuring the contributive managerial profit, OEE and additive relevant TPM effect indices calculated on the basis of the new universal equipment time loss structure can elevate the participation degree of all employees and divisions in charge of TPM, and can contribute to the improvement of manufacturing competitiveness resulted from the TPM activities with the eradication of equipment and production losses.

2.2 Literature Reviews on the Equipment Productivity

The equipment productivity as a measuring index of equipment performance is reviewed. The improvement of equipment productivity as well as factory productivity involves the metrics to measure and compare the efficiency, productivity, cost reduction, and effectiveness of equipment and manufacturing line (Mckeown and Philip, 2003).

The generally defined productivity refers to the ratio of output to input. In case of the production equipment, the equipment productivity can be measured by the following Equations (2-1) to (2-3) (Jung, 2001).

$$\text{Equipment productivity} = \frac{\text{Added value}}{\text{Cost required for the equipment}} \qquad (2\text{-}1)$$

$$= \frac{\text{Processed products' quantity(or Monetary amount)}}{\text{Book value for plant and equipment}} \qquad (2\text{-}2)$$

$$= \frac{\text{Labor productivity}}{\text{Rate of equipment to labor}} \qquad (2\text{-}3)$$

On the Equation (2-1), the added value refers to the increment of value by the processing work. The cost required for the equipment refers to the cost for the purchase, installation operation, and maintenance of equipment. And on the Equation (2-3), the labor productivity is given as in Equation (2-4), and the rate of equipment to labor is given as in Equation (2-5) (Jung, 2001).

$$\text{Labor productivity} = \frac{\text{Processed products'quantity(or Monetary amount)}}{\text{Employee' s number}} \quad (2\text{-}4)$$

$$\text{Rate of equipment to labor} = \frac{\text{Book value for plant and equipment}}{\text{Employee's number}} \quad (2\text{-}5)$$

The equipment productivity changes according to the processed products' quantity and operated time, and it rises as the processed products' quantity increases. The improvement of equipment productivity refers to, in other words, "that the equipment is used to the extreme capacity" or "that the processed products' quantity is raised without the increase of equipment capacity" (KSA, 2000).

On the other hand, SEMI E79 Specification provides the metrics of OEE as a means of measuring the equipment productivity (Oechsner et al., 2002). It is important to note that "equipment productivity" is largely impacted by various factors far beyond the equipment itself, including operator, recipe, facilities, material availability, scheduling requirements, and so on. The effective application of this standard is required that the equipment performance is followed by using the metrics for equipment reliability, availability and maintainability (RAM) established in SEMI E10. This means that all state changes of analyzed equipment have to be automatically tracked.

Additionally, the Automated Reliability, Availability and Maintainability Standard (ARAMS) SEMI E58 can be used for the equipment with ARAMS capability. The productivity metrics for the fixed and flexible-sequence cluster tools requires the tracking of SEMI E10 equipment states and recipes at the level of individual processing modules.

This SEMI E79 document is currently limited to measuring the equipment productivity by using overall equipment efficiency (OEE) as the metrics and does not address the impact of productivity changes on the cost, cycle time or other measures (Oechsner et al., 2002).

This dissertation does not follow the above Equations (2-1) to (2-3) and SEMI E79 metrics for calculating the equipment productivity, but follows a newly defined calculating methodology based on a new universal time loss structure hindering the equipment performance in the processing type equipment.

2.3 Literature Reviews on the Equipment Efficiency Indices

2.3.1 Equipment and Plant Efficiency as TPM Activities' Effects

In TPM, the effect indices for measuring the overall efficiency of plant and equipment are emphasized. The principal measuring indices in the production division among TPM effect measuring indices are OEE in case of processing type equipment (Shirose, 1996; Takahashi, 1992b), and OPE (overall plant efficiency) in case of plant type equipment (Shirose, 1996; Takahashi, 1992a; Kwon & Lee, 2003).

The processing type equipment mainly corresponds to the batch type production equipment, individual processing equipment, non-continuously processing equipment such as motors, vehicles, motor component, machinery, electric home appliances, semi-conductors, metal goods and wood product industries.

And the plant equipment mainly corresponds to the continuously operating equipment such as steel, nonferrous metal, chemical, fiber/textile, rubber, plastics, food, medicine, paper/pulp, print, cement, ceramics, gas and petroleum industries (Shirose, 1996; Nakajima 1996; Takahashi, 1992b).

OEE used in case of processing type equipment can be calculated by multiplying the following three indices that are the components of OEE. That is, the OEE is an index multiplied by its three components such as the time availability for judging the equipment failure loss, set-up & adjustment loss and cutting blade & jig change loss, the performance efficiency for judging the yield (start-up) loss, minor stoppage & idling loss and reduced speed loss, and the good quality rate for judging the quality defects and rework loss (Takahashi, 1992b; Kwon & Lee, 2003).

OPE used in case of plant type equipment can be calculated by multiplying the following four indices that are the components of OPE. That is, OPE is an index multiplied by its four components such as the equipment utilization rate for judging the degree of SD loss and production adjustment loss, the time availability for judging the degree of equipment failure loss and process failure loss, the performance efficiency for judging the degree of normal production loss and abnormal production loss, and the good quality rate for judging the quality defect loss and rework loss (Takahashi, 1992a; Kwon & Lee, 2003).

By the calculation of OEE and OPE, the profit-producing TPM can be realized by eradicating the problem elements and attempting the overall efficiency of equipment through the individual improvement of all sorts of losses hindering the OEE and OPE.

2.3.2 OEE in the Processing Type Equipment

OEE is an index used for measuring the overall efficiency of equipment. OEE is used as a representative effect measurement index in the goal setting at a preparation and/or introduction stage for deploying the TPM activities in the processing type equipment. For measuring the equipment efficiency, OEE is used as an important index in case of the processing type equipment (Takahashi, 1992b; Kwon & Lee, 2003). On the other hand, OPE is used as an effect measurement index of plant type equipment (Takahashi, 1992a; Kwon & Lee, 2003), and this is the one that the equipment utilization rate and OEE are multiplied by.

To show the calculating methodology of equipment efficiency indices in the processing type equipment, firstly; the time loss structure and definitions of times to judge the equipment efficiency, secondly; the definitions on the seven major losses hindering the equipment efficiency, and thirdly; the calculation methodology of equipment efficiency indices are presented in sequence.

Firstly, the time loss structure and definitions of times to judge the equipment efficiency are presented. To grasp where the losses hindering the equipment efficiency are located and how much the amount of losses are, the time loss structure of processing type equipment and the major seven losses (from ① to ⑦) hindering the equipment efficiency are shown as on the Figure 2-1 (Kwon & Lee, 2003).

The equipment losses in the processing type equipment are composed of the four big losses such as shutdown loss, downtime loss, performance loss and defect quality loss from the time loss structure (Shirose, 1996; JIPM, 1998; Schippers, 2001; Takahashi, 1992b; Kwon & Lee, 2003).

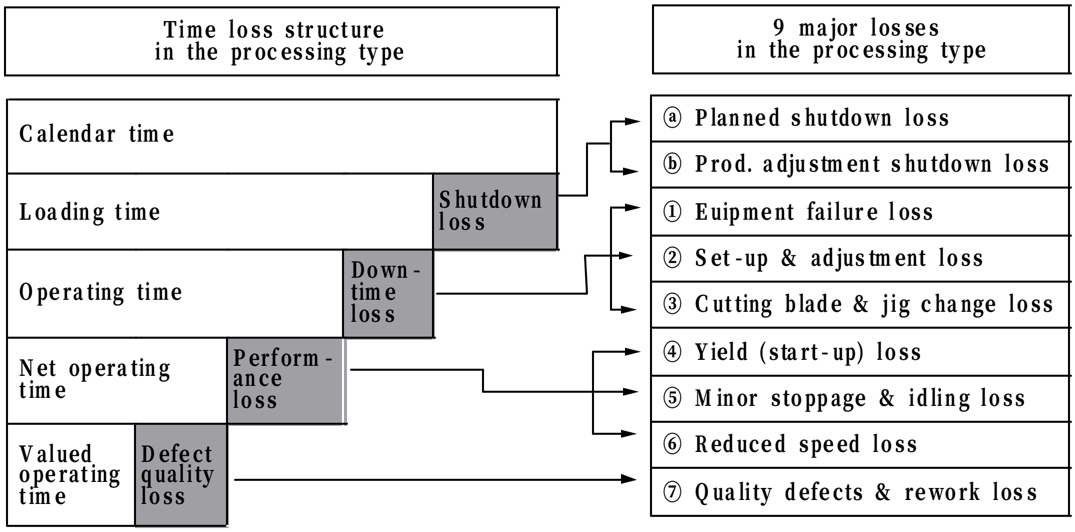

Figure 2-1. The time loss structure and nine major losses hindering the equipment utilization and equipment efficiency in the processing type equipment

The four big losses are subdivided into the nine major losses such as planned shutdown loss, production adjustment shutdown loss, equipment failure loss, set-up & adjustment loss, cutting blade & jig change loss, yield (start-up) loss, minor stoppage & idling loss, reduced speed loss and quality defects & rework loss when reviewed from the calendar time to the valued operating time (Shirose, 1996; Chand and Shirvani, 2000; Takahashi, 1992b; Kwon & Lee, 2003).

But in the processing type equipment, the equipment utilization loss such as planned shutdown loss and production adjustment shutdown loss is not considered for calculating the OEE and only the equipment efficiency loss such as residual seven losses (from ① to ⑦ on the Figure 2-1) essential for calculating the OEE is considered (Shirose, 1996; JIPM, 1998; Takahashi, 1992b; ; Kwon & Lee, 2003) on account of the characteristics of processing type equipment.

To reduce these time losses, the equipment efficiency indices are calculated. By these indices the loss amount can be grasped and the barometer on the improvement degree of equipment efficiency can be determined.

The definitions of loss times to judge the equipment utilization and efficiency based on the Figure 2-1 are as the following (Oechsner et al., 2002; Schippers, 2001; Chand and Shirvani, 2000; Wang and Lee, 2001; Shirose, 1996; Nakajima, 1996; JIPM, 1998; Mckone, 1996; Cua, 2000; Takahashi, 1992b).

The calendar time is determined monthly by the calendar (e.g., the times for one month are '30×24' hours in case that one month is composed of 30 days).

The loading time is the one that the equipment has to be operated during a given period, or can be operated. This time is the one that the equipment is to be operated or can be produced, and the one that the shutdown loss such as planned shutdown loss caused by the periodical maintenance, electric power failure, inevitability (e.g., labor strike, etc.), new increase of equipment and replace of equipment and the production adjustment shutdown loss caused by the lack of order, shortage of material and excess of stock is subtracted from the calendar time.

The operating time is the one that the equipment is operated actually, and the one that the downtime loss such as the equipment failure loss caused by the mechanical or electric power failure, the set-up & adjustment loss caused by the work preparation, product exchange and process condition adjusting and the cutting blade & jig change loss is subtracted from the loading time.

The net operating time is the one that is operated practically on a normal speed during the operating time. This time is the one that the performance loss such as yield (start-up) loss, minor stoppage & idling loss and reduced speed loss caused by the gap between the design speed and normal speed is subtracted from the operating time.

The valued operating time is the one that is served on making the good products practically, and the one that the quality defects & rework loss is subtracted from the net operating time.

Secondly, the definitions on the nine major losses hindering the equipment utilization and equipment efficiency are presented. The definitions and examples on the nine major losses hindering the equipment utilization and equipment efficiency in the processing type equipment can be presented as on the Table 2-2 (Shirose, 1996; Takahashi, 1992b; JIPM, 1998; Nakajima, 1996; Kwon & Lee, 2003).

To show the calculating methodology of OEE as the equipment efficiency index in the processing type equipment, the definitions on the seven major losses hindering the equipment efficiency are required.

The seven major losses (from ① to ⑦ on the Figure 2-1) hindering the processing type equipment efficiency are the equipment failure loss, set-up & adjustment loss, cutting blade & jig change loss, yield (start-up) loss, minor stoppage & idling loss, reduced speed loss and defects & rework loss (Shirose, 1996; Nakajima, 1996; JIPM 1998; Cua 2000; Takahashi, 1992b).

Thirdly, the calculation methodology of equipment efficiency indices is presented. According to the time loss structure as shown on Figure 2-1, the calculation methodology of equipment efficiency indices such as time availability, performance efficiency, good quality rate and OEE can be presented (Shirose, 1996; Nakajima, 1996; JIPM, 1998; Cua, 2000; Kwon, 1997; Takahashi, 1992b).

Table 2-2. The definitions on the nine major losses hindering the equipment utilization and equipment efficiency in the processing type equipment

9 major losses	Definitions of losses	Unit	Examples
Planned shutdown loss	Shutdown loss which is caused by the shutdown of equipment for its planned annual maintenance and periodical equipment adjustment	Hour	Planned shutdown loss for the planned maintenance, and non-planned shutdown loss caused by the interruption of electrical power, water stoppage, fire & inevitability
Production adjustment shutdown loss	Adjustment time loss which is caused by the production plan to adjust the supply and demand balance	Hour	Adjustment time loss caused by the lack of order, shortage of material and excess of stock
Equipment failure loss	Production stoppage time loss owing to the abrupt equipment failure	Hour	Equipment failure losses owing to the mechanical or electrical factors for 5 minutes and above
Set-up & adjustment loss	Production stoppage time loss owing to the set-up and adjustment at initial starting, production starting for the next product, closing for the stoppage	Hour	Time losses for the production preparation, product component and jig change, adjustment for the good quality condition and closing work
Cutting blade & jig change loss	Time loss owing to the periodical exchange and short time exchange of cutting blade or jig, and quality loss occurring before and/or after exchange owing to the defects	Hour Kg	Tip exchange time, grinder exchange time, work measuring time after tip exchange, rework quantity and time owing to the tip breakage
Yield (Start-up) loss	Time and quantity loss which is considered during the start-up, running-in and settlement of machining conditions	Hour Kg	Time and quantity loss caused by start-up after periodical maintenance, long-term shutdown, holiday, or lunch time
Minor stoppage & idling loss	Time and performance loss owing to the temporary equipment trouble different from the equipment failure	Hour	Production stoppage time loss for under 5 minutes, equipment idling time loss for the abnormal condition
Reduced speed loss	Time and performance loss owing to the gap between designed speed and actual working speed	Kg Ton	Performance loss owing to the equipment deterioration or reduced production
Quality defects & rework loss	Quality loss caused when defects are found and have to be reworked	Kg Ton	Quantity loss owing to the defects or rework, and time loss to make the good product condition after rework

For the calculation convenience, from the calendar time to the valued operating time in order, the relevant indices can be calculated as in the following procedures.

Step 1. **Time availability**; this index is the value to measure the degree of time availability without the downtime loss of equipment, and calculated as in Equation (2-6).

$$\text{Time availability} = \frac{\text{Operating time}}{\text{Loading time}} \tag{2-6}$$

Step 2. **Performance Efficiency**; this index is to judge the equipment performance. It is composed of the net operating rate and speed operating rate and defined as the Equation (2-7). The net operating rate indicates the persistence degree of equipment and the loss degree caused by the minor stoppage. This index is used to identify whether the equipment can be operated at the designated speed within the given time or not. It is not used to indicate whether the actual speed is faster or slower than the theoretical speed, but used to check whether the equipment can be operated at a stable speed over a longer speed regardless of the speed or not. The speed operating rate indicates the speed difference between the theoretical speed and normal speed.

$$\text{Performance efficiency} = \underbrace{\frac{\text{Processed products} \times \text{actual C/T}}{\text{Operating time}}}_{\text{Net operating rate}} \times \underbrace{\frac{\text{Theoretical C/T}}{\text{Actual C/T}}}_{\text{Speed operating rate}} \tag{2-7}$$

On the Equation (2-7), the theoretical cycle time (C/T) can be selected among the following three criteria; ① the cycle time designated on a design specification, ② the theoretical cycle time on an ideal condition and ③ the shortest cycle time hitherto, according to a given equipment condition (Shirose, 1996; JIPM, 1998; Takahashi, 1992b). The performance efficiency can be transformed from the above Equation (2-7) to the following Equation (2-8) as a generally used formula.

$$\text{Performance efficiency} = \frac{\text{Theoretical C / T} \times \text{Processed products}}{\text{Operating time}} \tag{2-8}$$

Step 3. **Good quality rate**; this index is used to judge the degree of good quality products that the equipment produces, and calculated as in Equation (2-9).

$$\text{Good quality rate} = \frac{\text{Good products}}{\text{Processed products}} \tag{2-9}$$

Step 4. **OEE**; this equipment efficiency index is the value used to measure the overall equipment efficiency and performance (Shirose, 1996; Nakajima, 1996; Wang and Lee , 2001; JIPM, 1998; Takahashi, 1992b).

The OEE is useful for judging whether the present equipment has contributed to the added value or not under the total consideration of what the condition of equipment has been in view of time and speed, and what the condition of good quality rate has been. The OEE is the value multiplied by three of time availability, performance efficiency and good quality rate (Kwon & Lee, 2003).

Based on the above Equations (2-6), (2-8) and (2-9), OEE can be calculated as in Equations (2-10) to (2-11) (Shirose, 1996; Nakajima, 1996; JIPM 1998; Takahashi, 1992b; Kwon & Lee, 2003).

OEE (Overall equipment efficiency)

$$= \text{Time availability} \times \text{Performance efficiency} \times \text{Good quality rate} \qquad (2\text{-}10)$$

$$= \frac{\text{Operating time}}{\text{Loading time}} \times \frac{\text{Theoretical C/T} \times \text{Processed products}}{\text{Operating time}} \times \frac{\text{Good products}}{\text{Processed products}}$$

$$= \frac{\text{Theoretical C/T} \times \text{Good products}}{\text{Loading time}} \qquad (2\text{-}11)$$

According to the calculating formula of OEE, among the losses on Figure 2-1 the improvement action activities for the seven major equipment losses are taken to reduce the losses because the time availability is related with ①equipment failure loss, ②set-up & adjustment loss and ③cutting blade & jig change loss, the performance efficiency is related with ④yield (start-up) loss, ⑤minor stoppage & idling loss and ⑥reduced speed loss, and the good quality rate is related with ⑦quality defects & rework loss (Kwon, 1997; Takahashi, 1992b; Shirose, 1996; Nakajima, 1996; Kwon & Lee, 2003).

On the other hand, in case that the processing type equipment is composed of the several dependent equipment, OEE for one production line must be calculated by using the theoretical cycle time (C/T) of one bottleneck equipment among the several equipment in one production line (Kwon & Lee, 2003).

2.3.3 OPE in the Plant Type Equipment

OPE is an index to measure the overall efficiency of plant type equipment (Takahashi, 1992a). OPE is used as a representative effect measurement index in the goal setting at a preparation and/or introduction stage for deploying the TPM activities in the plant type equipment.

The major losses hindering the overall plant efficiency are composed of the following losses such as ①planned shutdown (SD) loss, ②production adjustment shutdown loss,

Table 2-3. The definitions on the eight major losses in the plant type equipment

8 major losses	Definitions of losses	Unit	Examples
Planned shutdown loss	Shutdown loss which is caused by the shutdown of the plant for its planned annual maintenance and periodical plant adjustment	Hour	Planned shutdown loss for the planned maintenance, and non-planned shutdown loss caused by the interruption of electrical power, water stoppage, fire and inevitability
Production adjustment shutdown loss	Adjustment time loss which is caused by the production plan to adjust the supply and demand balance	Hour	Adjustment time loss caused by the lack of order, shortage of material and excess of stock
Equipment failure shutdown loss	Time loss which is caused by sporadic shutdown of the facility or equipment owing to the malfunctions	Hour	Equipment failure shutdown loss caused by the mechanical or electrical factors
Process failure shutdown loss	Time loss which is caused by the plant shutdown owing to improper chemical or physical properties of the substances handled, some other improper equipment operation or external factors	Hour	Process failure shutdown loss caused by the leakage, clogging and improper operation of equipment
Regular production loss	Time loss which is caused by set-up and adjustment at the start-up, shutdown and/or stoppage, or jig changes	Rate-downed time	Initial operating time loss caused by the catalyst exchange, material exchange, etc.
Irregular production loss	Time loss which is caused by the reduce of the production rate owing to the plant malfunction or abnormality	Rate-downed time	Time loss caused by the reduced load operation and abnormal operation condition
Quality defects loss	Time and material losses which are generated by the defective products	Hour Ton	Time and material loss caused by the defective products
Reprocessed loss	Time loss which is caused by reworking	Hour	Time loss caused by the re-work of processed products

③equipment failure shutdown loss, ④process failure shutdown loss, ⑤regular production loss, ⑥irregular production loss, ⑦quality defects loss and ⑧reprocessed loss. These losses are called as the eight major losses of plant type equipment (Takahashi, 1992a; JIPM, 1998; Nakajima, 1996; Kwon, 1997; Kwon & Lee, 2003).

The definitions and examples on the eight major losses in the plant type equipment are showed as on the Table 2-3 (Shirose, 1996; Takahashi, 1992a, JIPM, 1998; Nakajima, 1996; Kwon, 1997, Kwon & Lee, 2003).

To grasp where the losses hindering the plant type equipment efficiency are located and how much the amount of losses is, the time loss structure of plant type equipment and the eight major losses hindering the plant efficiency are showed as on the Figure 2-2 (Suzuki, 1997; Takahashi, 1992a; Kwon & Lee, 2003).

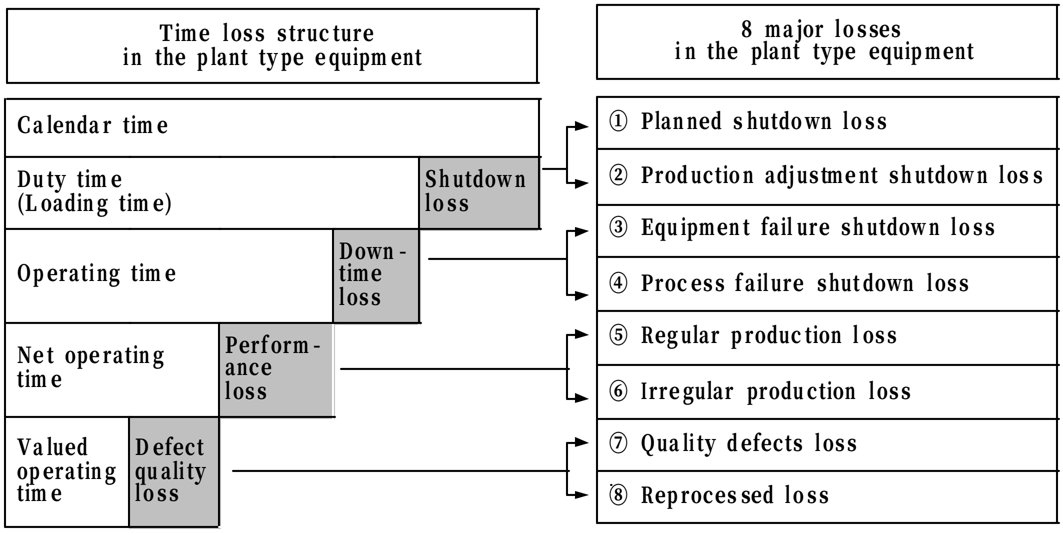

Figure 2-2. The time loss structure and eight major losses hindering the plant efficiency in the plant type equipment

The loss structure of plant type equipment is composed of the shutdown loss, downtime loss, performance loss and defect quality loss when reviewed from the calendar time to the valued operating time. To reduce these losses, the plant efficiency indices are calculated, and by these indices the loss amount can be grasped and the barometer for the improvement can be determined (Kwon and Lee, 2003).

The calendar time is determined monthly by the calendar (e.g., the times for one month are ‘30×24’ hours in case that one month is composed of 30 days).

The duty time (in other words, loading time) is the one that the plant is operated or can be operated during one year, one month or one day. This time is the one that the equipment or plant can be operated or can be produced. And also this time is the one that the shutdown loss composed of both ① planned shutdown loss such as scheduled downtime owing to the planned maintenance, electric power failure, inevitability (such as labor strike, etc.), new increase of equipment and replace of equipment and ② production adjustment shutdown loss such as lack of order, shortage of material and excess of stock is subtracted from the calendar time.

The operating time is the one that the plant is operated actually. This time is the one that the downtime loss caused by the plant failure and process trouble is subtracted from the loading time.

The net operating time is the one that is operated practically on a standard production rate. This time is the one that the performance loss such as the normal production loss caused by the decreased speed owing to the plant abnormality is subtracted from the operating time.

The valued operating time is the one that is served on making the good products practically. This time is the one that the defect quality loss is subtracted from the net operating time.

OPE (Overall Plant Efficiency) is the value multiplied by four components of operation rate, time availability, performance efficiency and good quality rate. This is the index to grasp whether the present plant contributes to the added value or not under the total consideration of what condition of the present plant is in respect of time and speed, and what the degree of quality rate is (Suzuki, 1997; Kwon & Lee, 2003).

Unlike the processing type equipment, the plant type equipment is characterized by the consecutive operation during one year and the plant loss time structure is different from the one of processing type equipment.

The calculating methodology of OPE in the plant type equipment can be showed as the following procedure (Suzuki, 1997; Kwon, 1997; Takahashi, 1992a; Kwon & Lee, 2003).

Step 1. **Operation rate**; this index is the value dividing the duty time (in other word, loading time) by the calendar time, the index to measure how much the plant had contributed to the production activities during a given period.

$$\text{Operation rate} = \frac{\text{Calendar time - Shutdown loss}}{\text{Calendar time}} = \frac{\text{Duty time}}{\text{Calendar time}} \qquad (2\text{-}12)$$

Step 2. **Time availability**; this index is the value that the operating time except for the downtime loss such as the equipment failure and process trouble is divided by the duty time (or loading time), and is the index to measure how much the plant had been operated during a given period for a plant operation.

$$\text{Time availability} = \frac{\text{Duty time} - \text{Downtime loss}}{\text{Duty time}}$$

$$= \frac{\text{Operating time}}{\text{Duty time}} \qquad (2\text{-}13)$$

Step 3. **Performance efficiency**; this index is to measure the performance of plant, and can be calculated with the theoretically processed products and actual average processed products as the following Equation (2-14).

$$\text{Performance efficiency} = \frac{\text{Actual average processed products}}{\text{Theoretically processed products}} \qquad (2\text{-}14)$$

In the Equation (2-14), the actual average processed products are the value calculated by the following Equation (2-15).

$$\text{Actual average processed products} = \frac{\text{Actual processed products}}{\text{Operating time}} \qquad (2\text{-}15)$$

And also the Performance efficiency of plant can be calculated with the theoretical cycle time (C/T) and processed products as the following Equation (2-16).

$$\text{Performance efficiency} = \frac{\text{Theoretical C/T} \times \text{Processed products}}{\text{Operating time}} \qquad (2\text{-}16)$$

Step 4. **Good quality rate**; this index is the ratio that the accepted good quality products are divided by the processed products, and is described as the following Equation (2-17).

$$\text{Good quality rate} = \frac{\text{Processed products} - \text{Defect quality loss}}{\text{Processed products}}$$

$$= \frac{\text{Good products}}{\text{Processed products}} \qquad (2\text{-}17)$$

Step 5. **Overall plant efficiency (OPE)**; this index is the value to measure the overall plant efficiency in the plant type equipment, and it can be calculated as the following Equations (2-18) and (2-19) (Kwon, 1977; Takahashi, 1992a; Suzuki, 1997; JIPM, 1998; Kwon & Lee, 2003).

$$\begin{aligned}
&\text{OPE (Overall plant efficiency)}\\
&= \text{Operation rate} \times \text{Overall equipment efficiency}\\
&= \text{Operation rate} \times \text{Time availability} \times \text{Performance efficiency}\\
&\quad \times \text{Good quality rate} \qquad (2\text{-}18)
\end{aligned}$$

$$\begin{aligned}
&= \frac{\text{Duty time}}{\text{Calendar time}} \times \frac{\text{Operating time}}{\text{Duty time}}\\
&\quad \times \frac{\text{Theoretical C / T} \times \text{Processed products}}{\text{Operating time}} \times \frac{\text{Good products}}{\text{Processed products}}\\
&= \frac{\text{Theoretical C / T} \times \text{Good products}}{\text{Calendar time}} \qquad (2\text{-}19)
\end{aligned}$$

In case that the plant type equipment is characterized by the continuously processing production and composed of the several, large and long processes, and that the total grasping of plant efficiency is insufficient in view of measuring the output of TPM activities concretely, the overall plant efficiency can be measured respectively after being divided into the several processes (Kwon & Lee, 2003).

In the above case the performance efficiency as one element of overall plant efficiency can be calculated with the theoretical C/T of one bottleneck process among the several processes.

2.4 Literature Reviews on the Reliability and Maintainability

The equipment reliability and maintainability as the measuring indices of equipment performance are reviewed. The equipment reliability is defined as "the characteristics that the equipment does not incur the failure"(Lee, 2002; Lee, 1993). When the net loading time (i.e., the time that is secured for the equipment to run actually) is composed of the operating time (i.e., the one that is secured in order to produce the products practically without the equipment failure, and that the time loss such as minor stoppage & idling loss and reduced speed is included) and equipment failure loss, the measuring indices for equipment reliability based on the equipment time loss structure can be shown that the time availability is as in the Equation (2-20), and MTBF (mean time between failure) is as in the Equation (2-21). The equipment maintainability is defined as "the characteristics capable of completing the repair maintenance within the specified interval under the given condition". MTTR (mean time to repair) is defined as in the Equation (2-22) (Lee, 2002; Lee, 1993; Kwon, 2003).

$$\text{Time availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \tag{2-20}$$

$$\text{MTBF} = \frac{\text{Operating time}}{\text{Failure times}} \tag{2-21}$$

$$\text{MTTR} = \frac{\text{Failure downtime}}{\text{Failure times}} \tag{2-22}$$

We have to pay attentions when MTBF as the reliability index and MTTR as the maintainability index in connection with the equipment loss structure are calculated. The loading time is calculated as the following equation "Loading time = Operating time + Downtime loss", on the basis of the time loss structure for the processing type equipment as shown on the Figure 2-1 and the one for plant type equipment as shown on the Figure 2-2 in order to calculate the efficiency indices of equipment.

MTBF and MTTR related with the time availability shall be calculated only by using the operating time that the downtime loss composed of the equipment failure loss, set-up & adjustment loss and cutting blade & jig change loss is subtracted from the loading time and the only equipment failure loss in the downtime loss on the equipment time loss structure. That is, in consideration with the equipment time loss structure, the MTBF and MTTR can be calculated on the basis of the following equation "Net loading time = Operating time + Equipment failure loss".

The Equation (2-20) for calculating the time availability of equipment can be calculated by two components such as MTBF as the mean value of operating time and MTTR as the mean value of equipment failure loss. After MTBF and MTTR are calculated on the basis of the equipment time loss structure for calculating the reliability and maintainability indices of equipment, the time availability can be calculated by using these MTBF and MTTR (Lee. 1993; Kwon, 2003).

The time loss structures for the processing and plant type equipment which have been known previously hitherto are very effective in view of calculating the equipment efficiency indices. However, when MTTR and time availability are calculated, they seem to be easy to violate errors that MTTR is calculated by the total downtime loss without separating the total downtime loss into the equipment failure loss time and the other downtime loss as the non-equipment failure loss time (Lee, 1993; Kwon, 2003).

Therefore, this dissertation presents the new universal time loss structure as the next Figure 3-1 capable of calculating the equipment efficiency, MTBF and time availability all together.

2.5 Literature Reviews on the Managerial Effect Indices in TPM

It is necessary that how much the results of TPM activities contribute to the managerial profit quantitatively. As the managerial effect measurement indices, the value-added productivity, productivity per direct employee, contribute profit, manufacturing cost per unit, opportunity loss amount caused by production line stoppage and effect amount by individual improvement are used in TPM (Kwon and Lee, 2004).

Although the managerial effect measurement indices resulted from TPM activities are composed of the value-added productivity, labor productivity, unit manufacturing cost and contribution profit, above of all, the contribution profit as the monetary managerial effect corresponding to the company's accounting system seems to be very important (Kwon and Lee, 2004).

Some major examples of managerial effect measurement are presented as on the Table 2-4 (Kwon & Lee, 2004).

Table 2-4. The measurement indices of managerial effects resulted from TPM activities

Indices	Formula	Rank[a]	Division in charge	PQCD SM[b]
Value-added productivity	$\frac{\text{Added value}}{\text{Employee's number}}$	B	Production	P
Productivity	$\frac{\text{Processed products' quantity(or Monetary amount)}}{\text{Gross labor times of direct employees}}$	A	Production	P
Contribution profit	Sales Variable Cost	C	Planning	P
Unit manufacturing cost	$\frac{\text{Manufacturing cost}}{\text{Processed products}}$	B	Production	C
Order deficiency loss rate	$\frac{\text{Plant shutdown time owing to order deficiency}}{\text{Planned shutdown time}}$	B	Marketing	P
Equipment invest efficiency	$\frac{\text{Standard processed products}}{\text{Book value for plant and equipment}}$	C	Production technology	P
Rate of equipment to labor	$\frac{\text{Book value for plant and equipment}}{\text{Employee's number}}$	C	Planning	C

[a] Refers to the important degree that A is the very important index, B is the important index and C is recommendable index.

[b] Indicates the abbreviated symbols that P is productivity, Q is quality, C is cost, D is delivery, S is safety and M is morale.

2.6 Contribution Profit and Saving Cost as the Managerial Effect

It is important that the overall equipment efficiency can be improved as a result of TPM deployment. However, in view of grasping the managerial effect as a result of TPM, it is not enough that we know only the increased numerical value of overall equipment efficiency (Kwon and Lee, 2004).

It is important for us to manage so that these tangible effect indices can be improved to a higher level. The relevant effect indices related with P (Productivity), Q (Quality), C (Cost), D (Delivery), S (Safety) and E (Environment) which are used as the performance indices of TPM are the tangible effect indices, but they are not corresponded directly and quantitatively to the accounting system of a company.

The necessity for the development and control of index capable of being corresponded to the accounting system directly as a result of TPM has been emphasized steadily in the companies. By the way, the generalized managerial effect measurement methodology that the result of TPM can be corresponded to the accounting system of a company directly and grasping the monthly managerial effect resulted from TPM activities can be grasped quantitatively has not been developed yet. The grasp of contributive managerial profit earned by the good product amount corresponding to the increased value of OEE in view of the measurement of managerial effect seems to be the most meaningful among the managerial effect measurement tasks.

OEE corresponding to the result of TPM activities as the overall efficiency index of equipment is given as an index multiplied by the three components such as the time availability, performance efficiency and good quality rate. If OEE has been increased, the additive good products corresponding to the increased value of OEE can be acquired. These additive good products are the ones capable of being sold. In this dissertation, a new methodology capable of calculating the contributive managerial profit quantitatively is presented.

The calculation methodology of the contributive managerial effect corresponding to the increased value of OEE is the one that the total amount of contributive managerial effect can be calculated by multiplying the contributive managerial effect corresponding to the additive one percent of OEE by the increased total percent value of OEE (Kwon and Lee, 2004). To calculate the managerial effect by keeping the OEE at the 0.01(1%) upraised condition for a given period, at first, the following accounting principles and concepts in connection with this dissertation must be defined (Lee, 1999; Kwon & Lee, 2004).

The cost accounting methods are divided into the merging cost accounting and direct cost accounting in accordance with whether the fixed manufacturing indirect cost is involved in the inventory cost or not. The direct cost accounting is called as the variable cost accounting, and used for the inner accounting planning and control of a company. The total cost accounting is called as the merging cost accounting, and used for the outer publication (or outer report). The managerial effect in this research is calculated by the direct cost method as the cost accounting method (Kwon & Lee, 2004). The accounting principles and concepts of direct cost accounting used in this research are shown as the following.

Firstly, the concept of cost as a basis of calculation on the contributive managerial effect resulted from the TPM activities is as follows. The composition of gross cost and the concept on the individual cost helping to grasp the concept on the cost saving which is related with the profit structure are shown as on the Table 2-5 (Lee, 1999).

Secondly, the comparison between the merging cost accounting and direct cost accounting is as follows. The difference between these two methods can be shown as on the Table 2-6 (Lee, 1999; Kwon and Lee, 2004).

The merging cost accounting is the methodology that all manufacturing costs are the product cost and the costs except for the manufacturing cost are the period cost. That is, the merging cost accounting is the methodology that all of the material cost, labor cost and

Table 2-5. The composition and related concepts on the costs

☐ Total cost = Manufacturing cost + Selling and administration cost where, ◯ Manufacturing cost = Direct cost + Manufacturing expense ◯ Direct cost = Direct material cost + Direct labor cost + Direct expense ◯ Manufacturing expense = Fixed manufacturing expense + Variable manufacturing expense ◯ Selling and administration cost = Fixed selling and administration cost + Variable selling and administration cost

Table 2-6. The difference between the merging cost accounting and direct cost accounting

Description	Merging cost accounting	Direct cost accounting
Purpose	Outer report (for the outer publication)	Inner report (for the inner planning and control)
Product cost	Variable and fixed manufacturing cost	Variable manufacturing cost
Period cost	Variable selling and administration cost Fixed selling and administration cost	Fixed manufacturing indirect cost Variable selling and administration cost Fixed selling and administration cost
Preparation method of income statement	Functional classification Gross profit = Sales -Cost of sales Term net profit = Gross profit - selling and administration cost	Cost behavioral classification Contribution profit (or margin) =Sales - Variable cost Term net profit = Contribution profit-Fixed cost
Effect(or Relationship) on net profit Production>Sales Production=Sales Production<Sales In view of long term	 Increasing Equivalent Decreasing Equivalent	 Decreasing Equivalent Increasing Equivalent

manufacturing cost (variable manufacturing indirect cost and fixed manufacturing indirect cost) are the product cost, and especially including the fixed manufacturing indirect cost also are the product cost.

The direct cost accounting is called as the variable cost accounting, occasionally called as the marginal cost accounting or the contributive approach cost accounting. The direct cost accounting is the one that only the variable manufacturing cost is the product cost, and that the other costs such as fixed manufacturing indirect cost, variable selling and administrative cost, and fixed selling and administrative cost are the interval cost. In particular, this method considers only the variable manufacturing cost except for the fixed manufacturing cost in the product cost (Lee, 1999).

In the direct cost accounting method, the cost items on the income statement are divided into the variable cost and the fixed cost, and instead of the gross profit the contribution profit (or called as the marginal income) is calculated. The income statement made by this direct cost accounting method is called as the contribution income statement, and indicated as the contribution approach income statement. The income statement by the direct cost accounting method is the one made after the cost is divided into the variable cost and fixed cost in accordance with the cost characteristics.

Thirdly, the comparison of correlation between the contribution profit and gross profit is as follows. The contribution profit and gross profit are used for the cost accounting, but these two profit terminologies are different each other in meaning. The contribution profit is the one that the variable cost is subtracted from the sales. The variable cost for the contribution profit includes the variable costs on both the selling and administrative cost as well as the manufacturing cost. The gross profit is the one that the cost of sales is subtracted from the sales (Okamoto, 1994; Lee, 1999; Kwon & Lee, 2004).

Basically, the contribution profit is the concept of managerial accounting, and the gross profit is the one of financial accounting. The contribution profit is the useful concept for the top management to carry out the managerial decision-making. For example, it is useful for the Cost-Volume-Profit (CVP) analysis, direct cost accounting and special decision-making (Lee, 1999).

The gross profit is essential for the financial accounting process and listed first on the income statement. This gross profit is the first index to appraise the profitability earned by the goods selling or products selling. This is the one different from the operating profit, ordinary profit and net profit calculated on the income statement (Kwon & Lee, 2004).

Finally, the calculation method of managerial profit by the profit-and-loss method and cost method is as follows. The general managerial profit for each one-year budget is calculated periodically by the profit-and-loss method and cost method. For the outer publication, the calculation method of profit with the profit-and-loss method can be shown as the formulas on the Table 2-7 (Lee, 1999; Kwon, 1996; Kwon & Lee, 2004).

Table 2-7. The calculation of profit by the profit-and-loss method

□ Term net profit = Profit before taxes - Corporation tax, etc.

where,

○ Profit before taxes=Ordinary profit + Extraordinary profit   Extraordinary loss expenses

○ Ordinary profit = Operating profit + Non-operating revenue   Non-operating expenses

○ Operating profit = Gross profit - Selling and administration cost

○ Gross profit = Sales   Cost of sales

For the inner control, the full costing (or merging costing) method and direct (or variable) costing method as the calculating method of profit by the cost method can be shown as follows. The profit calculation method with the full costing (or merging costing) can be shown as the formulas on the Table 2-8 (Lee, 1999; Kwon & Lee, 2004).

Table 2-8. The calculation of profits by the full (merging) costing

☐ Term net profit = Gross profit - Selling and administration cost

where,

○ Gross profit = Sales   Cost of sales

○ Cost of sales = Direct material cost + Direct labor cost +Variable manufacturing expense + Fixed manufacturing expense   Ending inventory

○ Ending inventory = Total cost×Stock

○ Selling and administration cost = Variable selling and administration cost + Fixed selling and administration cost

The profit calculation method with the direct (or variable) costing can be shown as the formulas on the Table 2-9 (Lee, 1999; Kwon & Lee, 2004).

Table 2-9. The calculation of profits by the direct (variable) costing

☐ Term net profit = Contribution profit   Fixed cost

where,

○ Contribution profit = Sales   Variable cost

○ Variable cost = Direct material cost + Direct labor cost +Variable manufacturing expense + Variable selling and administration cost - Ending inventory

○ Fixed cost = Fixed manufacturing expense + Fixed selling and administration cost

Among the prescribed profit concepts, to measure the contribution degree in the managerial profits by TPM activities, the managerial profit corresponding to the contribut-ion profit as the TPM effects must be calculated in accordance with the direct cost accounting method used for the purpose of inner control (Kwon & Lee, 2004).

Chapter 3. A Model on the Equipment Performance Indices

3.1 Suggesting Model on the Equipment Performance Indices

The generally known equipment efficiency indices have played good roles on the individual improvement action activities, but insufficient in view of measuring the equipment performance indices such as equipment productivity, reliability, efficiency and maintainability all together.

Therefore, this dissertation suggests a new methodology model for calculating the equipment productivity indices such as equipment utilization rate, planned availability, equipment operation rate and total effective equipment productivity (TEEP), the equipment reliability indices such as time availability, mean time between failure (MTBF), failure intensity rate and failure frequency rate, the equipment efficiency indices such as performance efficiency, good quality rate, OEE and net equipment efficiency (NEE), and the equipment maintainability index such as mean time to repair (MTTR) additionally (Kwon and Lee, 2003).

To show the calculating methodology of equipment performance indices, firstly; a modified time loss structure and the definitions of loss times to judge the equipment performance, secondly; the definitions on the seven major losses hindering the equipment efficiency and equipment productivity; and thirdly; the calculation methodology of equipment efficiency and equipment productivity indices are presented respectively (Kwon and Lee, 2003).

Firstly, the time loss structure and definitions of times to judge the equipment performance are presented. To calculate the equipment performance indices, a modified time loss structure and the definitions and examples on the seven major losses hindering the equipment performance are presented. In order to grasp where or how much the losses hindering the equipment performance are, the loss structure shall be defined. A seven major time losses' structure hindering the equipment performance can be shown as on the Figure 3-1 (Kwon and Lee, 2003).

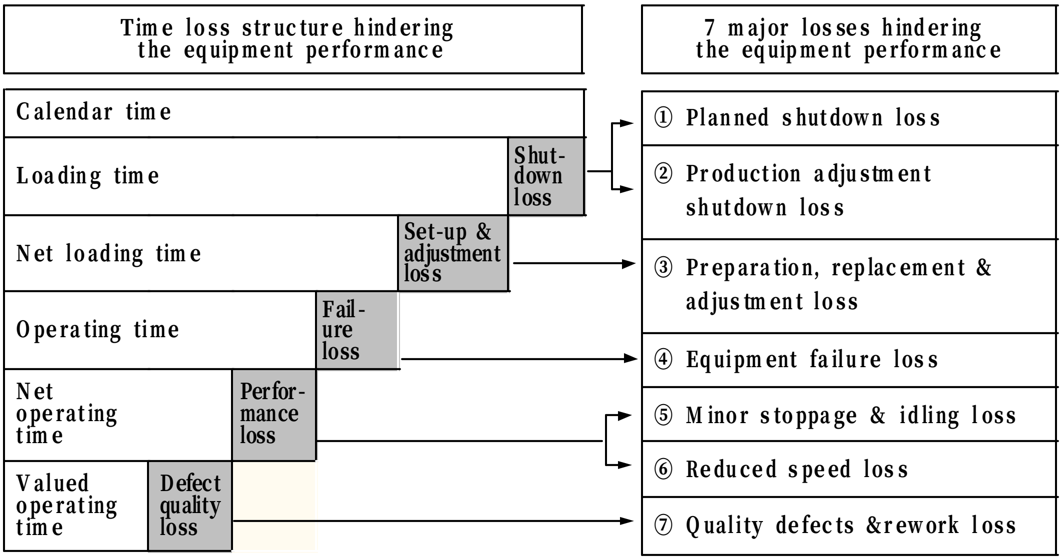

Figure 3-1 A modified time loss structure and the seven major losses hindering the equipment performance

The equipment losses for a suggesting model are composed of the five big losses such as shutdown loss, set-up & adjustment loss, failure loss, performance loss and defect quality loss as shown on the Figure 3-1. These five big losses are subdivided into the seven major losses such as planned shutdown loss, production adjustment shutdown loss, preparation, replacement & adjustment loss, equipment failure loss, minor stoppage & idling loss, reduced speed loss and quality defects & rework loss when reviewed from the calendar time to the valued operating time. To reduce these time losses, the equipment performance indices such as equipment productivity, reliability, efficiency and maintain-ability are calculated (Kwon & Lee, 2003). By these indices the loss amount hindering the equipment performance can be grasped and the barometer on the improvement degree of equipment productivity, reliability, efficiency and maintainability can be determined.

In this suggested model, the terminologies on the loss times based on a time loss structure hindering the equipment performance are suggested differently from the existing ones for the previously mentioned processing and/or plant type equipment defined by Shirose (1996), Suzuki (1997) and JIPM (1998), etc.

The significant difference among the Figure 2-1, Figure 2-2 and Figure 3-1 is the one that the methodology on the basis of Figure 3-1 is capable of calculating the equipment performance indices such as equipment productivity, reliability, efficiency and maintain-ability all together by separating the operating time as shown on the Figure 2-1 and Figure 2-2 into the net loading time and operating time as shown on the Figure 3-1. The definitions of times to judge the equipment performance such as equipment productivity, reliability, efficiency and maintainability are shown as on the Table 3-1 (Kwon & Lee, 2003).

The calendar time (i.e., the time available) is determined monthly by the calendar (e.g., the times for one month are '30×24' hours in case that one month is composed of 30 days).

Table 3-1 The definitions on the seven major losses hindering the equipment performance

7 major losses	Definitions of losses	Unit	Examples
Planned shutdown loss	Shutdown loss which is caused by the shutdown of the plant for its planned annual maintenance and periodical plant adjustment	Hour	Planned shutdown loss for planned maintenance, and non-planned shutdown loss caused by the interruption of electrical power, water stoppage, fire and inevitability, etc. Planned shutdown loss determined by company (festive day, official holiday and Sunday, etc)
Production adjustment shutdown loss	Adjustment time loss which is caused by the production plan to adjust the supply and demand balance	Hour	Adjustment time loss caused by the lack of order, shortage of material and excess of stock
Preparation, replacement & adjustment loss	Production stoppage time loss caused by the set-up and adjustment at initial starting, production starting for next product and closing stoppage	Hour	Time losses for production preparation, component and jig change, adjustment for good quality condition and closing work
Equipment failure loss	Production stoppage time loss caused by the abrupt equipment failure	Hour	Equipment failure losses owing to the mechanical losses or electrical factors for 5 minutes and above
Minor stoppage & idling loss	Time and performance loss caused by the temporary equipment trouble different from the equipment failure	Hour	Production stoppage time loss for under 5 minutes, equipment idling time loss for the abnormal equipment condition
Reduced speed loss	Time and performance loss owing to the gap between designed speed and actual working speed	Kg Ton	Performance loss caused by the deterioration or reduced production
Quality defects & rework loss	Quality loss caused when quality defects are found and have to be reworked	Kg Ton	Quality loss caused by the defects or rework, and time loss to make the good product condition after rework

The loading time is the one that the equipment has to be loaded during a given period, or can be operated. This time is the one that the shutdown loss such as the planned shutdown loss caused by the periodical maintenance, electric power failure, water stoppage, fire, inevitability (e.g., labor strike, etc.), new increase of equipment and replace of equipment and the production adjustment shutdown loss such as lack of order, shortage of material and excess of stock is subtracted from the calendar time.

The net loading time is the one that the equipment is secured to run actually. This time is the one that the set-up & adjustment loss such as preparation, replacement & adjustment loss is subtracted from the loading time.

The operating time is the one that is secured in order to produce the products practically without the equipment failure, and that the performance loss such as minor stoppage (e.g., stoppage under five minutes) & idling loss and reduced speed loss is included. This time is the one that the equipment failure loss such as the production stoppage time loss is subtracted from the net loading time.

The net operating time is the one that is secured to produce practically without the equipment failure, minor stoppage and reduced speed. In other words, it is the one that the performance loss which the equipment is operated normally, but do not contribute to the production on account of poor equipment condition is subtracted from the operating time. The performance loss time can be defined as “(Theoretical processed products Actual processed products)×Theoretical C/T” (Kwon & Lee, 2003).

The valued operating time is the one that is served to produce the good products. If the processed products are the poor quality because of the quality defects, it means that the equipment is operated on a mechanically normal condition during producing the defect products, but it serves to produce the non-valued products (i.e., the defect products). This time is the one that the defect quality loss is subtracted from the net operating time.

Secondly, the definitions on the seven major losses hindering the equipment performance are presented. To show the calculating methodology of equipment performance indices such as equipment productivity, reliability, efficiency and maintainability for a suggesting model, the definitions on the seven major losses such as planned shutdown loss, production adjustment shutdown loss, preparation, replacement & adjustment loss, equipment failure loss, minor stoppage & idling loss, reduced speed loss and quality defects & rework loss are presented. The definitions and examples on the seven major losses hindering the equipment performance can be presented as on the Table 3-1 (Kwon & Lee, 2003).

Thirdly, the calculation methodology of equipment performance indices such as equipment productivity, reliability, efficiency and maintainability is presented. According to the time loss structure as shown on the Figure 3-1, the calculation methodology of equipment productivity indices such as equipment utilization rate, planned availability, equipment operation rate and total effective equipment productivity (TEEP), the equipment reliability indices such as time availability, mean time between failure (MTBF), failure intensity rate and failure frequency rate, the equipment efficiency indices such as performance efficiency, good quality rate, OEE and net equipment efficiency (NEE), and the equipment maintainability index such as mean time to repair (MTTR) additionally.

For the calculation convenience, from the calendar time to the valued operating time in order, all of relevant indices can be calculated only by the time elements as in the following procedures (Kwon and Lee, 2003).

Step 1. **Equipment utilization rate**; this equipment productivity index is the barometer to measure how much the equipment has served on the equipment utilization during a given period. This index can be calculated as in Equation (3-1).

$$\text{Equipment utilization rate} = \frac{\text{Calendar time} - \text{Shutdown loss}}{\text{Calendar time}}$$

$$= \frac{\text{Loading time}}{\text{Calendar time}} \tag{3-1}$$

Step 2. **Planned availability**; this equipment productivity index is the barometer to measure how well the equipment has been prepared to operate during a given period. This index can be calculated as in Equation (3-2).

$$\text{Planned availability} = \frac{\text{Loading time - Set - up \& adjustment loss}}{\text{Loading time}}$$

$$= \frac{\text{Net loading time}}{\text{Loading time}} \tag{3-2}$$

Step 3. **Time availability**; this equipment reliability, productivity and efficiency index is the one to measure how much the equipment has operated actually without the equipment failure. This index can be calculated as in the Equation (3-3).

$$\text{Time availability} = \frac{\text{Net loading time - Failure loss}}{\text{Net loading time}}$$

$$= \frac{\text{Operating time}}{\text{Net loading time}} \tag{3-3}$$

Step 4. **MTBF**; this equipment reliability index is the one to measure the reliability how long the equipment has been operated without the failure shutdown during the given net loading time. This index can be calculated as in the Equation (3-4).

$$\text{MTBF} = \frac{\text{Operating time}}{\text{Failure times}} \tag{3-4}$$

Step 5. **MTTR**; this equipment maintainability index is the one to measure the maintainability how fast the equipment repair maintenance has been completed during the failure loss time. This index can be calculated as in the Equation (3-5).

$$\text{MTTR} = \frac{\text{Failure loss time}}{\text{Failure times}} \tag{3-5}$$

Step 6. **Failure intensity rate**; this equipment reliability index is the one to measure the reliability how long the period of equipment failure has been during the net loading time. This index can be calculated as in the Equation (3-6).

$$\text{Failure intensity rate} = \frac{\text{Failure loss time}}{\text{Net loading time}} \tag{3-6}$$

Step 7. **Failure frequency rate**; this equipment reliability index is the one to measure the reliability how frequent the equipment failure has occurred during the net loading time. This index can be calculated as in the Equation (3-7).

$$\text{Failure frequency rate} = \frac{\text{Failure times}}{\text{Net loading time}} \tag{3-7}$$

Step 8. **Performance efficiency**; this equipment efficiency index is the one to measure the performance efficiency of equipment under the consideration of performance loss such as minor stoppage & idling loss and reduced speed loss. This index can be calculated as in the Equation (3-8).

$$\text{Performance efficiency} = \frac{\text{Operating time - Performance loss}}{\text{Operating time}} = \frac{\text{Net operating time}}{\text{Operating time}} \tag{3-8}$$

where,

Performance loss

$$= (\text{Theoretical processed products} \quad \text{Actual processed products}) \times \text{Theoretical C/T} \qquad (3\text{-}9)$$

$$= (\text{Theoretical processed products} \quad \text{Actual processed products}) \div \text{Theoretical processed products} \qquad (3\text{-}10)$$

Step 9. **Good quality rate**; this equipment efficiency index is the one to measure how much the equipment has produced the good quality or accepted products except for the defect, obsolete and/or rework products. This index can be calculated as in the Equation (3-11).

$$\text{Good quality rate} = \frac{\text{Net operating time} - \text{Defect quality loss}}{\text{Net operating time}}$$

$$= \frac{\text{Valued operating time}}{\text{Net operating time}} \qquad (3\text{-}11)$$

where,

Defect quality loss

$$= \text{Defect quality products} \div \text{Theoretical capacity} \qquad (3\text{-}12)$$

Step 10. **Equipment operation rate**; this equipment productivity index is the one to measure the equipment productivity, and can be given by the times of time availability and production readiness rate. This index can be calculated as in the following Equations (3-13) & (3-14).

Equipment operation rate

$$= \text{Planned availability} \times \text{Time availability} \tag{3-13}$$

$$= \frac{\text{Net loading time}}{\text{Loading time}} \times \frac{\text{Operating time}}{\text{Net loading time}}$$

$$= \frac{\text{Operating time}}{\text{Loading time}} \tag{3-14}$$

Step 11. **Net equipment efficiency (NEE)**; this equipment efficiency index is the one to indicate the net efficiency of equipment how much the equipment has served to produce the good products by using the net loading time given in order to produce practically, and can be calculated as in the Equations (3-15) & (3-16). This is the index to indicate what the machine is doing during the net loading time (Chand and Shirvani, 2000).

Net equipment efficiency (NEE)

$$= \text{Time availability} \times \text{Performance efficiency} \times \text{Good quality rate} \tag{3-15}$$

$$= \frac{\text{Operating time}}{\text{Net loading time}} \times \frac{\text{Net operating time}}{\text{Operating time}} \times \frac{\text{Valued operating time}}{\text{Net operating time}}$$

$$= \frac{\text{Valued operating time}}{\text{Net loading time}} \tag{3-16}$$

Step 12**. Overall equipment efficiency (OEE)**; this equipment efficiency index corresponds to the overall efficiency of equipment how much the equipment has served to produce the good products by using the loading time given in order to produce. This is the index to indicate what degree of efficiency during the loading time is, and can be calculated as in the Equations (3-17) and (3-18).

Overall equipment efficiency (OEE)

$$= \text{Equipment operation rate} \times \text{Performance efficiency} \times \text{Good quality rate} \quad (3\text{-}17)$$

$$= \left(\frac{\text{Net loading time}}{\text{Loading time}} \times \frac{\text{Operating time}}{\text{Net loading time}} \right)$$

$$\times \frac{\text{Net operating time}}{\text{Operating time}} \times \frac{\text{Valued operating time}}{\text{Net operating time}}$$

$$= \frac{\text{Valued operating time}}{\text{Loading time}} \quad (3\text{-}18)$$

Step 13. **Total effective equipment productivity (TEEP)**; this equipment productivity and efficiency index corresponds to the total productivity and efficiency of equipment how much the equipment has served to produce the good products by using the calendar time given in order to produce. This index indicates the operation environment and machine condition (Chand and Shirvani, 2000), and also indicates what degree of total productivity and efficiency during the given calendar time is. This index can be calculated as in the Equations (3-19) and (3-20).

Total effective equipment productivity (TEEP)

$$= \text{Equipment utilization rate} \times \text{Equipment operation rate} \times \text{Performance efficiency}$$

$$\times \text{Good quality rate} \quad (3\text{-}19)$$

$$= \frac{\text{Loading time}}{\text{Calendar time}} \times \frac{\text{Operating time}}{\text{Loading time}} \times \frac{\text{Net operating time}}{\text{Operating time}} \times \frac{\text{Valued operating time}}{\text{Net operating time}}$$

$$= \frac{\text{Valued operating time}}{\text{Calendar time}} \quad (3\text{-}20)$$

All suggested equipment performance indices such as productivity, reliability, efficiency and maintainability in this model do not directly consider the manufacturing costs.

The metrics for OEE is widely used, but not sufficient to characterize a complex manufacturing system because OEE is calculated only on the basis of time loss structure. Including the cost analysis with OEE would require the use of metrics for the characterization of overall factory effectiveness (OFE) in order to obtain a factory productivity and manufacturing cost competitiveness (SEMI E79-0200, 2002).

Many parameters have an influence on OFE composed of OEE, capacity utilization, cycle time, efficiency, on-time delivery, yield, ramp-up time and performance, etc. (Oechsner et al., 2002). Therefore, to achieve the cost competitiveness with the lower manufacturing cost under the competitive pressures on manufacturing organisms, the additional studies on the manufacturing cost and contributive managerial effect analyses in connection with the OEE are necessary hereafter.

Therefore, the additional methodology for the calculation of quantitative monetary contributive managerial effect as a result of TPM activities based on the concepts of manufacturing cost and cost accounting is presented in Chapter 4 on this dissertation.

3.2 Comparison on Each Type of Equipment Efficiency Indices

To investigate and analyze the relationship among the processing type, plant type and suggested universal type, the following summarized comparison result on each type of equipment efficiency indices can be presented as shown as on the Table 3-2.

Table 3-2. The comparison on each type of equipment efficiency indices

Descriptions	Suggested universal type equipment efficiency	Plant type equipment efficiency	Processing type equipment efficiency
Operation rate (Equipment utilization rate)	Loading time ÷ Calendar time	Duty time ÷ Calendar time	(Not applicable)
Planned availability	Net loading time ÷ Loading time	(Not applicable)	(Not applicable)
Time availability	Operating time ÷ Net loading time	Operating time ÷ Duty time	Operating time ÷ Loading time
Performance efficiency	Net operating time ÷ Operating time	(Theoretical C/T × Processed products) ÷ Operating time	(Theoretical C/T × Processed products) ÷ Operating time
		Actual average processed products ÷ Theoretical processed products	
Good quality rate	Valued operating time ÷ Net operating time	Good products ÷ Processed products	Good products ÷ Processed products
Equipment operation rate	Planned availability × Time availability	(Not applicable)	(Not applicable)
	Operating time ÷ Loading time		
N E E	Valued operating time ÷ Net loading time	(Not applicable)	(Not applicable)
O E E	Equipment operation rate × Performance efficiency × Good quality rate	Time availability × Performance efficiency × Good quality rate	Time availability × Performance efficiency × Good quality rate
	Valued operating time ÷ Loading time	(Theoretical C/T × Good products) ÷ Duty time	(Theoretical C/T × Good products) ÷ Loading time
T E E P (O P E)	Equipment utilization rate × Equipment operation rate × Performance efficiency × Good quality rate	Operation rate × Time availability × Performance efficiency × Good quality rate	(Not applicable)
	Valued operating time ÷ Calendar time	(Theoretical C/T × Good products) ÷ Calendar time	

In the plant type equipment with the continuously running characteristics during a given year, OEE is calculated on the basis of the time availability, performance efficiency and good quality rate, and OPE is calculated by multiplying the utilization rate to OEE. Thus, in the plant type equipment, these OPE and OEE indices are used the principal indices for the overall plant and equipment efficiency measurement.

Differently from the plant type equipment, in the processing type equipment without the continuous running characteristics during a given year, OEE is calculated on the basis of the time availability, performance efficiency and good quality rate. Thus, in the processing type equipment, this OEE index is used the principal index for the equipment efficiency measurement.

The calculation methodology of suggested universal type equipment efficiency that can be applied to the plant type and processing type equipment commonly different from these plant and processing types' methodologies has the merit that the more systematic and informative indices can be calculated than the ones on the basis of above two methodologies and calculated only by the time elements.

In view of the comparison result on the Table 3-2, we can apprehend that the newly suggested universal methodology capable of calculating the additional productivity-related equipment efficiency indices is the more systematic and informative method because the new universal calculating methodology is more detailed and can be measured only on the basis of time elements on the equipment productivity, reliability and maintainability indices additionally by the transformation of the previously known and existing loss structure. And also this new model can help the systematic eradication activities for the losses hindering the equipment productivity and efficiency.

3.3 Case Studies and Reviews on the Suggested Model

The collected data for equipment performance indices during the given period from the OSRK Company's fluorescent lamp manufacturing are as follows. The period for calculating the equipment efficiency indices is given as one month composed of 31 days, and the scheduled downtime is given as 216 hours (9 days). The processed products are 5 items (P1 to P5) and the theoretical capacity (the inverse is the theoretical C/T) of all products is given as on the Table 3-3.

Table 3-3 The production and time loss data for calculating the equipment performance indices

Product	Unit	P1	P2	P3	P4	P5	Total
Loading time	Hr	120	72	120	96	120	528
Theoretical capacity	EA/Min	0.5	0.4	0.6	0.3	0.5	0.47[a]
Theoretical processed products	EA	3,600	1,728	4,320	1,728	3,600	14,976
Actual processed products	EA	3,470	1,630	4,115	1,650	3,440	14,305
Defect quality products	EA	105	84	110	51	112	462
Good quality products	EA	3,365	1,546	4,005	1,599	3,328	13,853
Loading time	Min	7,200	4,320	7,200	5,760	7,200	31,680
Set-up & adjustment loss	Min	30	40	25	30	40	165
Equipment downtime	Min	0	0	20	10	40	70

[a] The value 0.47 as the theoretical capacity is the one that the theoretical capacity of each product is obtained by doing the weighed average on the basis of loading time as the following.

$(120\times0.5+72\times0.4+120\times0.6+96\times0.3+120\times0.5)\div(120+72+120+96+120) = 0.47$

Based on the above collected data, the prerequisite times and losses for calculating the equipment performance indices such as productivity, reliability, efficiency and maintainability can be calculated as follows (Kwon and Lee, 2004b).

(1) Calendar time = 31 Days = 44,640 Minutes (31×24×60)

(2) Loading time = Calendar time Shutdown loss = 44,640-12,960 = 31,680 Minutes

where, Shutdown loss = 9 Days = 12,960 Minutes (9×24×60)

(3) Net loading time = Loading time Set-up & adjustment loss

= 31,680 165 = 31,515 Minutes

where, Set-up & adjustment loss = 165 Minutes

(4) Operating time = Net loading time Failure loss = 31,515-70 = 31,445 Minutes

where, Failure loss = 70 Minutes

(5) Net operating time = Operating time Performance loss

= 31,445 1,428 = 30,017 Minutes

where, Performance loss

= (Theoretical processed products Actual processed products)

×Theoretical C/T

= (Theoretical processed products Actual processed products)

÷Theoretical processed products

= (14,976-14,305)÷0.47 = 1,428 Minutes

(6) Valued operating time = Net operating time Defect quality loss

= 30,017 983 = 29,034 Minutes

where, Defect quality loss = 462÷0.47= 983 Minutes

Based on the above prerequisite times and losses, the equipment performance indices such as productivity, reliability, efficiency and maintainability can be calculated as the following in sequence.

(1) Equipment utilization rate = Loading time ÷ Calendar time

= 31,680 ÷ 44,640 = 0.710

(2) Planned availability = Net loading time ÷ Loading time

= 31,515 ÷ 31,680 = 0.995

(3) Time availability = Operating time ÷ Net loading time

= 31,445 ÷ 31,515 = 0.998

(4) MTBF = Operating time ÷ Failure times = 31,445 ÷ 3 = 10,482 Min

(5) MTTR = Failure loss time ÷ Failure times = 70 ÷ 3 = 23.3 Min

(6) Failure intensity rate = Failure loss time ÷ Net loading time

= 70 ÷ 31,515 = 2.2×10^{-3} (0.22 %)

(7) Failure frequency rate = Failure times ÷ Net loading time

= 3 ÷ 31,515 = 9.5×10^{-5} Times/Min

(8) Performance efficiency = Net operating time ÷ Operating time

= 30,017 ÷ 31,445 = 0.955

(9) Good quality rate = Valued operating time ÷ Net operating time

= 29,034 ÷ 30,017 = 0.967

(10) Equipment operation rate = Planned availability × Time availability

= 0.995 × 0.998 = 0.993

= Operating time ÷ Loading time = 31,445 ÷ 31,680 = 0.993

(11) Net equipment efficiency (NEE)

= Time availability × Performance efficiency × Good quality rate

= 0.998 × 0.955 × 0.967 = 0.9216 (92.16 %)

= Valued operating time ÷ Net loading time

= 29,034 ÷ 31,515 = 0.921 (92.1 %)

(12) Overall equipment efficiency (OEE)

= Equipment operation rate × Performance efficiency × Good quality rate

= 0.993 × 0.955 × 0.967 × 0.967 = 0.917 (91.7 %)

= Valued operating time ÷ Loading time

= 29,034 ÷ 31,680 = 0.9165 (91.65 %)

(13) Total effective equipment productivity (TEEP)

= Equipment utilization rate × Equipment operation rate × Performance efficiency × Good quality rate

= 0.710 × 0.993 × 0.955 × 0.967 = 0.651 (65.1 %)

= Valued operating time ÷ Calendar time

= 29,034 ÷ 44,640 = 0.6504 (65.04 %)

As shown in the above case study on a suggested model, all equipment performance indices such as productivity, reliability, efficiency and maintainability can be demonstrated.

3.4 Implications on This Suggested Model

In order to attain the fruitful result of TPM, the periodical grasping of TPM effect measurement indices must be performed in parallel with the TPM deploying stage. In an equipment efficiency index in view of equipment productivity as the overall effect measurement index of TPM activities, OEE is used generally.

Based on the previously known and existing equipment time loss structure for the processing and plant type, OPE for the plant type and OEE for the processing type as an equipment efficiency index can be calculated easily. However, these calculation methodologies based on the previously known equipment time loss structures seem to be insufficient for the calculation of the additive effect measurement indices related with equipment productivity, reliability and maintainability except for the equipment efficiency indices.

This dissertation suggests a new model capable of calculating the equipment productivity, reliability, efficiency and maintainability indices with a different metrics based on a new universal time loss structure and also the definitions of losses.

This methodology can be a new methodology model for the calculating the equipment productivity indices such as equipment utilization rate, planned availability, equipment operation rate and total effective equipment productivity (TEEP), the equipment reliability indices such as time availability, mean time between failure (MTBF), failure intensity rate and failure frequency rate, the equipment efficiency indices such performance efficiency, good quality rate, OEE and net equipment efficiency (NEE), and the equipment maintainability index such as mean time to repair (MTTR) additionally.

On the other hand, the newly suggested time loss structure on this dissertation provides the exact information for calculating the MTTR and time availability. The loading time is calculated as the following Equation, that is, "Loading time = Operating time + Downtime loss" in accordance with the existing equipment time loss structure. Here, as a matter of remarkable attention, MTBF and MTTR related with the time availability shall be calculated only by using the operating time, that the downtime loss composed of the equipment failure loss and set-up & jig change loss is subtracted from the loading time, and the only equipment failure loss in the downtime loss on the equipment time loss structure (Kwon & Lee, 2003).

In these above methods based on the existing equipment time loss structure, when

MTBF, MTTR and time availability are calculated, they seem to be easy to violate errors that MTTR is calculated by the total downtime loss without separating the total downtime loss into the equipment failure loss time and the other downtime loss as the non-equipment failure loss time. Therefore, in this dissertation, a new definition on the equipment time loss structure is presented as a new methodology capable of calculating the equipment efficiency, MTBF and time availability indices all together (Kwon & Lee, 2003).

This newly suggested universal methodology can be commonly applied to the processing type and plant type equipment. And also this methodology can help to produce the higher result of performance-oriented TPM.

Chapter 4. A Model on the Contributive Managerial Effect

4.1 Structure of OEE as a Basis of Managerial Effect Calculation

The incremented value of OEE is not meaningful in view of the profit-producing or money-earning TPM activities. We need to grasp how much OEE has contributed to the managerial profit quantitatively. It is important to calculate the additive outrun as the good products corresponding to the OEE increment exactly and to calculate the contributive managerial profit about this additive increment (Hipkin and Cock, 2000). A new methodology capable of measuring the contributive managerial profit quantitatively corresponding to the cost system of a company directly as a result of TPM activities is presented (Kwon and Lee, 2004).

If the OEE has been increased as a result of TPM activities, the additive good products corresponding to the increased value of OEE will be acquired. These additive good products are the ones that can be sold. The total sales can be increased according to the sales of these additional products so much. And if the direct cost accounting is performed on the basis of these additive sales, the contributive managerial effect corresponding to these additive sales can be calculated. Thus, the grasp of additive good products corresponding to the increased value of OEE in order to measure the quantitative contributive managerial effect resulted from TPM activities is regarded as the meaningful effect measurement task above all (Kwon & Lee, 2004).

This dissertation is to present the calculation methodology of quantitative contributive managerial effect corresponding to the additive good products caused by the increased

OEE. To calculate the contributive managerial effect with the OEE increment in the processing type equipment for one example, the time loss structure hindering the OEE and the calculating methodology of OEE must be defined (Kwon and Lee, 2004).

When the losses of processing type equipment are reviewed in view of the time, the time structure and seven major losses hindering the equipment efficiency can be shown as on the Figure 2-1 in the paragraph 2.3.2.

OEE is the overall efficiency index to measure the operating efficiency on the basis of time loss structure for the processing type equipment, and is the value multiplied by three of time availability, performance efficiency and good quality rate.

This OEE index indicates whether the present equipment contributes to the added value or not under the total consideration of present equipment condition in view of the time and speed, and what the condition of good quality rate is (Shirose, 1996; Suzuki, 1997; JIPM, 1998; Oechsner et al., 2002; Kwon & Lee, 2004).

As shown in the paragraph 2.3.2, based on the Equation (2-6) Time availability, Equation (2-8) Performance efficiency and Equation (2-9) Good quality rate, OEE (Overall Equipment Efficiency) for the processing type equipment can be formulated by the Equation (4-1).

$$\text{OEE} = \frac{\text{Theoretical C / T} \times \text{Good products}}{\text{Loading time}} \tag{4-1}$$

To count the good products corresponding to the OEE increment and to calculate the contributive managerial profit corresponding to these good products, the OEE Equation (4-1) needs to be transformed to the following Equation (4-2) after the “Theoretical C/T” is transformed to the "Theoretical products per hour". Here, the unit of theoretical cycle time is the "hour/unit" and the unit of theoretical products per hour is the "unit/hour".

$$\text{OEE} = \frac{\text{Good products}}{\text{Loading time} \times \text{Theoretical products per hour}} \tag{4-2}$$

Generally, the calculation of OEE is performed by the Equation (4-1) involved with the theoretical cycle time (C/T). However, the OEE equation for calculating the contributive managerial effect corresponding to the increased value of OEE must be used in accordance with the Equation (4-2) involved with the "Theoretical products per hour" instead of the "Theoretical cycle time (C/T)". This is the reason for extracting the additive good products corresponding to the increased value of OEE effectively (Kwon & Lee, 2004).

And as a matter of paying an attention to the calculation of contributive managerial effect corresponding to the increased value of OEE, in case that the processing type equipment is composed of several dependent equipment, the calculation of OEE for one line must be done by using the "Theoretical products per hour" of one bottleneck equipment among the several equipment in one production line.

4.2 Suggesting Model on the Managerial Effect by OEE

The calculation methodology of contributive managerial effect corresponding to the increased value of OEE is the one that the total amount of contributive managerial effect can be calculated by multiplied the unit contributive managerial effect corresponding to the additive one percent of OEE by the increased total percent value of OEE (Kwon and Lee, 2004).

The good product increment that is the direct object to calculate the unit additive contributive managerial effect earned by keeping the OEE at the 1% upraised condition can be calculated according to the Equation (4-5) formulated on the basis of the Equations (4-3) and (4-4) (Kwon & Lee, 2004).

OEE (during a given period of bench mark year)

$$= \frac{\text{Good products } (x)}{\text{Loading time} \times \text{Theoretical products per hour}} \qquad (4\text{-}3)$$

OEE (during the same given period with the 1% upraised condition)

$$= \frac{\text{Good products } (y)}{\text{Loading time} \times \text{Theoretical products per hour}} \qquad (4\text{-}4)$$

The following Equation (4-5) can be acquired if in the above Equations (4-3) and (4-4) the operating time and theoretical products per hour are the same values during the comparative period (usually during one year) (Kwon & Lee, 2004).

$$y\text{-}x = (0.01) \times \text{Loading time} \times \text{Theoretical products per hour} \qquad (4\text{-}5)$$

The unknown unit quantity, y-x, as the good product increment corresponding to the extent of OEE increment at the 1% upraised condition can be acquired by the above Equation (4-5). Because the good products are the products capable of being sold to the customer, the good product increment is approximately the same value with the product increment capable of being sold to the customer (Kwon, 1996).

In case that all of the good product increment are sold, the additive unit contribution profit acquired by keeping the OEE at the 1% upraised condition during a given period (usually during one year) can be calculated by the Equation (4-6) (Kwon & Lee, 2004).

Additive contribution profit acquired by keeping the OEE at the 1% upraised condition

$$= \text{Good product increment being sold} \times \text{Contribution profit per unit} \qquad (4\text{-}6)$$

By the way, the calculating method of the total additive contribution profits by the OEE increment can be obtained by multiplying the unit additive contribution profit acquired by keeping the OEE at the 1% upraised condition by the total increased percent (%) of OEE. The contribution profit becomes more meaningful in view of the increase of TPM performance resulted from the equipment improvement activities.

The above contribution profit can be calculated exactly in case that the additive good product increment being sold can be anticipated without the influence of R&D and/or marketing divisions in a manufacturing company, or under the planned production system all of the outrun increment can be sold. Therefore, if OEE is increased, by this visible and direct production increment can the contribution profit be acquired.

The additive unit contributive managerial effect that is the total saved monetary effect, and that is acquired by keeping the OEE at the 1% upraised condition during a given period (usually during one year) can be calculated by the following Equation (4-7) in accordance with the direct costing method (Kwon & Lee, 2004).

Contributive managerial effect acquired by the 1% upraised OEE

$$= \text{Additive contribution profit} + \text{Saved manufacturing cost} \qquad (4\text{-}7)$$

where,

Additive contribution profit

$$= \text{Additive sales} \times \text{Contribution profit per unit} \quad (4\text{-}8)$$

Saved manufacturing cost

$$= \text{Saved labor cost} + \text{Saved utility cost} + \text{Saved maintenance cost} + \text{Saved depreciation cost} \quad (4\text{-}9)$$

Based on this unit additive contributive managerial effect, the total monetary effect amount corresponding to the total upraised value of OEE during the same period can be calculated.

Seeing these above equations, despite of the possibility to produce additionally to the extent of product increment, the equipment has been operated in the previous low grade of OEE. The labor cost, utility cost and maintenance cost corresponding to this product increment can be reduced, and furthermore the improvement effect can be obtained because the depreciation period based on the processed products amount can be elongated by the reappraisal of assets.

On the Equation (4-9), the unit cost of the labor cost, utility cost and maintenance cost that are the reduced costs corresponding to the product increment can be estimated by the past data (Kwon & Lee; 2004).

In addition, the above saved manufacturing cost composed of only four elements as in the Equation (4-9) among the manufacturing elements is the opportunity cost (Okamoto, 1994), that is, the additively charged cost owing to the wrong operation and the reducible cost that is charged owing to the ignored losses in spite that OEE can be raised to the extreme extent. Therefore, if the OEE is increased, this visible and direct product increment and also the reduction of opportunity cost attained additionally can be realized.

4.3 Case Study and Reviews on the Suggested Model

A case study on the calculation methodology of contributive managerial effect (that is, sum of additive contribution profit and saved manufacturing cost) acquired by keeping the OEE at the 1% upraised condition is presented for the DSB Company's Coke filler equipment as the processing type example (Kwon & Lee; 2004).

The DSB Company's Coke filler equipment is the bottleneck equipment in a No. 2 production line.

The example for the calculation of managerial effect acquired by keeping the OEE of the processing type equipment at the 1% upraised condition can be done by the following case study.

On the newly suggested calculation model, the data such as processed products, good products, calendar time, loading time and operating time are on the basis of one year data, and by these data, the OEE can be calculated. The good products must be substituted for the good products of final process in one production line. In case of the lack of data or the insufficient data, for example, only 10 months' data, the data converted to one year's data can be prepared for the convenience of result grasping policy.

The collected data for contributive managerial effect during one year from DSB Company's Coke filler equipment in a No. 2 production line as a bottleneck equipment are as follows (Kwon and Lee, 2004);

▶ Data collection for the OEE

* Product : Coke bottle

* OEE (During one bench mark year) : 82.1% (0.821)

* Processed products (During one bench mark year) : 4,484,000 Cases/Year

* Theoretical products per hour (based on a filler as bottleneck equipment); ⓐ : 2,500 Cases/Hr

* (During one bench mark year) Calendar time (Duty days × 24Hr) : 7,176 Hrs

* (During one bench mark year) Loading time; ⓑ : 2,183 Hrs

* (During one bench mark year) Operating time : 1,866 Hrs

▶ Data collection for the saved manufacturing cost corresponding to the additive production amount

▷ Labor cost data

* Labor wage rate; ⓒ : 2,500 Won/Hr

* Line working person; ⓓ : 24 Persons

▷ Utility cost data

* Electricity cost per hour; ⓔ : 75,000 Won/Hr

* Fuel cost per hour; ⓕ : 41,100 Won/Hr

* Water cost per hour; ⓖ : 33,000 Won/Hr

▷ Maintenance cost data

* Annual maintenance cost (Material + Subcontractor); ⓗ : 452,456,000 Won

* Maintenance cost per case ⓘ : 101 Won/case

▷ Depreciation cost data

* Purchase cost : 8,756,643,000 Won

* Period of depreciation : 10 Years

* Depreciation method : Fixed method

* Annual depreciation cost; ⓙ : 842,115,000 Won

▶ Data collection for contribution profit per case

* Sales per case; ⓚ : 8,496 Won/Case

* Variable manufacturing cost per case; ⓛ : 2,318 Won/Case

The calculation examples for the contributive managerial effect acquired by keeping the OEE of processing type equipment at the 1% upraised condition are presented according to the following sequence.

(1) Good products (During one year); ①

According to Equation (4-2), the calculated value can be presented as follows;

Good products = Overall equipment efficiency × Loading time × Theoretical products per hour (ⓐ)

= 0.821 × 2,183 × 2,500 = 4,480,608 Cases

(2) Additive good products acquired by the 1% upraised condition of OEE; ②

According to Equation (4-5), the calculated value can be presented as follows;

Additive good products acquired by the1% upraised condition of OEE

= (0.01) × Loading time (ⓑ) × Theoretical products per hour (ⓐ)

= 0.01 × 2,183 × 2,500 = 54,575 Cases

(3) Converted loading time corresponding to the additive good products; ③

= Additive good products acquired by the 1% upraised condition of OEE (②)

÷ Theoretical products per hour (ⓐ)

= 54,575 ÷ 2,500 = 21.83 Hrs

(4) Sub total of labor cost; ④

= Converted loading time corresponding to the additive good products (③)× Labor wage rate (ⓒ) × Line working person (ⓓ)

= 21.83×2,500×24 = 1,309,800 Won

(5) Saved electricity cost; ⑤

= Converted loading time corresponding to the additive good products (③)× Electricity cost per hour (ⓔ) = 21.83×75,000 = 1,392,000 Won

(6) Saved fuel cost; ⑥

= Converted loading time corresponding to the additive good products (③) × Fuel cost per hour (ⓕ) = 21.83×41,100 = 767,000 Won

(7) Saved water cost; ⑦

= Converted loading time corresponding to the additive good products (③) × Water cost per hour (ⓖ) = 21.83×33,000 = 616,000 Won

(8) Sub total of utility cost; ⑧

= Saved electricity cost (⑤) + Saved fuel cost (⑥) + Saved water cost (⑦)

= 1,392,000+767,000+616,000 = 2,775,000 Won

(9) Saved maintenance cost; ⑨

= Additive good products acquired by the 1% upraised condition of OEE (②) × Maintenance cost per case (ⓘ) = 54,575×101 = 5,512,075 Won

(10) Estimated depreciation cost; ⑩

= Annual depreciation cost (ⓙ)×Additive good products acquired by the 1% upraised condition of OEE (②)÷Good products during one year (①)

= 842,115,000×54,575÷4,480,608 = 10,257,185 Won

(11) Saved manufacturing cost corresponding to the additive good products; ⑪

= Sub total of labor cost (④)+ Sub total of utility cost (⑧)+Saved maintenance cost (⑨) + Estimated depreciation cost (⑩)

= 60,000+2,775,000 + 5,512,075 + 2,190,000 = 19,854,060 Won

(12) Sub total of contribution profit per case; ⑫

= Sales per case (ⓚ)-Variable manufacturing cost per case (ⓛ) = 6,178 Won

(13) Annual additional contribution profit; ⑬

= Additive good products acquired by the 1% upraised OEE (②)×Sub total of contribution profit per case (⑫)

= 54,575×6,178 = 337,164,350 Won

(14) Contributive managerial effect acquired by 1% upraised OEE

= Saved manufacturing cost corresponding to the additive good products (⑪) + Annual additive contribution profit (⑬)

= 18,604,260+337,164,350 = 357,018,410 Won

For the products as the data collection for the OEE on the above example, the individually calculating method by each product is the most desirable one. In case that the several types of products are produced from one equipment, for the values of processed products and good products the simple summed-up values are inserted, but the product-mix values of theoretical products per hour, sales per unit and variable manufacturing cost per unit are inserted with the weighted average values for the convenience of calculation and control. The weighted average methods for these can be given by the following Equations (4-10) to (4-12) (Kwon & Lee, 2004).

The theoretical products per hour are inserted by the weighted average value on the basis of processed products amount as the following Equation (4-10).

(Weighted average) Theoretical products per hour

= (Theoretical "A" products quantity × "A" products quantity +

Theoretical "B" products quantity × "B" products quantity +⋯)

÷ ("A" products quantity + "B" products quantity+⋯) (4-10)

The sales per unit and variable manufacturing cost per hour are inserted by the weighted average on the basis of products amount as the following Equations (4-11) and (4-12).

(Weighted average) Sales per unit

= ("A" products sales per unit × "A" products quantity +

"B" products sales per unit × "B" products quantity +⋯)

÷ ("A" products quantity + "B" products quantity +⋯) (4-11)

(Weighted average) Variable manufacturing cost per unit

= ("A" products variable manufacturing cost per unit ×

"A" products quantity + "B" products variable manufacturing

cost per unit × "B" products quantity +⋯)

÷ ("A" products quantity+ "B" products quantity+⋯) (4-12)

The above estimated values extracted by the weighted average method can be used as the approximate values. To extract the contribution profit corresponding to the extent of

1% upraised OEE, first, the additive good products on the basis of bottleneck equipment in each production line must be calculated.

However, because these good products must be contributed to the manufacturer's sales earned by serving to the customer, the only one equipment in each line must be applied to calculating the good products amount. For example, in case that one line is composed of numerous equipments and has one bottleneck equipment, the contribution profit correspon-ding to the additive good products of one line must be calculated on a basis of the bottleneck equipment.

4.4 Implications on This Suggested Model

Based on the increased value of OEE that is grasped as a result of TPM activities, a new calculating methodology for the summed-up values of additive contribution profit and saved manufacturing cost as the managerial effect of TPM has been presented.

This case study shows that the total contributive managerial effect can be calculated by adding up the reduced manufacturing cost corresponding to the decreased opportunity loss cost earned by the increase of OEE to the contributive managerial profit earned by the selling of additive good products corresponding to the increased value of OEE.

TPM has been regarded as the "profit-producing or money-earning PM activities" and also the importance on the effect measurement methodology of quantitative monetary managerial effect, that is, how much the result of TPM activities contributes to the managerial profit has been emphasized steadily (Kwon & Lee, 2004). However, because the development of calculation methodology on the contributive managerial profit as a result of TPM activities is based on the background about the comprehensive theories on the industrial engineering and cost accounting, the development on this methodology seems to be not proceeded so much.

It is important for managing so that OEE can be improved a result of TPM deployment. But, the quantitative monetary grasp of contributive managerial effect caused by the increased OEE corresponding to the cost accounting system of a company directly as a result of TPM activities is more important for judging the profit-producing or money-earning TPM.

This methodology will contribute to the recognition conversion on TPM. That is, the methodology capable of measuring the contributive managerial effect by improving the OEE with the effective TPM deploying program will contribute to the recognition conversion on the importance of TPM from the top management and related divisions in charge of TPM. And furthermore the capability of calculating the quantitative monetary contributive managerial profit corresponding to the increased OEE will help and speed up the systematic deployment of TPM.

In this dissertation, the contributive managerial effect corresponding to the increased value of OEE has been demonstrated on the basis of OEE for the processing type equipment as one example. But the contributive managerial effect corresponding to the increased value of OPE for the plant type equipment will also be able to be calculated similarly in accordance with the metrics for the processing type (Kwon & Lee, 2003). On this metrics for the plant type, the additional research project is expected hereafter.

Chapter 5. Conclusions

This dissertation aims at suggesting the new methodology models for the calculating the TPM effect measurement indices to appraise the result performance and maturity of TPM that the manufacturing companies have introduced for the purpose of strengthening the manufacturing competitiveness.

Firstly, a new methodology model for measuring the equipment productivity, reliability, efficiency and maintainability indices based on a newly suggested universal time loss structure different from the existing ones on the TPM literatures has been presented.

With the time loss structure for the processing type equipment in TPM literatures, the equipment efficiency indices such as time availability, performance efficiency, good quality rate and OEE can be calculated. But, this methodology in TPM literatures cannot provide the sufficient information in view of the whole equipment performance appraisal, and it is insufficient to calculate the equipment productivity, reliability, efficiency and maintainability indices from one time loss structure all together. This dissertation suggests a new methodology model capable of calculating the equipment productivity, reliability, efficiency and maintainability indices all together with a different metrics based on a modified time loss structure and also the definitions of losses.

In view of the comparison result between the literature reviews on the equipment efficiency indices in TPM and the suggesting first model for calculating the equipment performance indices, the latter method can be obtained on the additional productivity, reliability and maintainability indices additionally, and also it is more diversified and systematic for the effect measurement practices.

This methodology can help the systematic improvement activities for reducing the time losses hindering the equipment performance easily, and also can help to strengthen the manufacturing business performance. This model is expected to contribute to the maturity of TPM activities by grasping the equipment performance indices such as equipment productivity, reliability, efficiency and maintainability periodically, and also is expected to be the new countermeasures for the equipment improvement action plan.

All shown equipment efficiency and/or productivity indices in this suggested model do not directly consider the costs. The metrics for OEE is widely used, but not sufficient to characterize a complex manufacturing system because OEE is calculated only on a basis of time loss structure. Including the cost analysis in connection with OEE would require the use of metrics for the characterization of overall factory effectiveness (OFE) in order to obtain the factory productivity and manufacturing cost competitiveness.

Therefore, the additional second model for the calculation of quantitative monetary contributive managerial effect as a result of TPM activities based on the concepts of manufacturing cost and cost accounting has been suggested.

Secondly, a new calculating methodology for estimating the quantitative monetary managerial effects contributing to the managerial profits as a result of TPM activities has been suggested.

The calculation principle of unit contributive managerial effect acquired by keeping the OEE at the 1% upraised condition during a given period can be summarized by the following Equation; "Contributive managerial effect acquired by the 1% upraised OEE = Additive contribution profit + Saved manufacturing cost". For this suggested calculating methodology of contributive managerial effect, the OEE calculation Equation must be used with the Equation (4-2) instead of the Equation (4-1).

As a suggested model example for the calculation methodology of contributive managerial effect, this dissertation has presented the real industrial application example to the processing type equipment. The total contributive managerial effects acquired by the annual OEE increment can be calculated by "unit managerial effects acquired by keeping the OEE at the 1% upraised condition × Total increased percent (%) of OEE".

This newly suggested second model is expected to contribute to the maturity of TPM activities by grasping the quantitative monetary managerial effects periodically. The suggested second model has been demonstrated for the processing type equipment. This metrics will be able to be adapted to the plant type manufacturing equipment that OEE can be calculated. The methodologies on grasping the tangible monetary managerial effects corresponding to the company cost accounting system directly as the result of TPM activities among the several tangible effect indices are thought that they must be studied on the plant type equipment additionally hereafter to improve the maturity of TPM activities.

The capability of calculating the equipment efficiency indices and also the additive TPM effect measurement indices related with the productivity, reliability and maintainability in accordance with the newly designed equipment time loss different from the existing ones on the TPM literatures will help us to produce the more profit-oriented result of TPM.

Because the grasp on how much TPM contributes to the contributive managerial profit will help to let the related divisions' employees in charge for TPM hold a good recognition on TPM, and also help to improve the degree of participation in TPM. In addition, this can help the recognition conversion of top management on TPM and the security of monetary supporting system for the more systematic and effective TPM activities.

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