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Building energy saving performance indices for cleaner semiconductor manufacturing and an empirical study

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ABSTRACT

In recent years, global climate change has caused worldwide severe disasters. Countries started to convene CO_2 reduction meetings, but they failed to achieve expected outcome. With global greenhouse effect getting worse, governments have more actively made energy saving policies. In 2010, Ministry of Economic Affairs in Taiwan adapted many energy saving strategies, which pushed semiconductor enterprises to take it seriously.

Semiconductor industry is both technology and energy intense; therefore, using effective ways to reach energy saving goal has become an important issue. This study aims to establish a Fab energy efficiency assessment model for the semiconductor industry based on SMART decision analysis structure, which used multiple energy saving methods to measure energy cost management efficiency, and considered both theoretical and practical conditions to give suggestions to each indicator to improve the decision making on energy expenditure and distribution. In addition, this study took a Fab in Taiwan as an example to demonstrate the inspection of energy efficiency and construct OPE (Overall Power Energy Effectiveness) indicators, which can help managers to understand the execution of each decision-making unit and properly deploy the resource. The results showed that a Fab must additionally evaluate the energy saving design in expansion and concretely explain energy saving effect and energy management, analyzed the encountered energy difficulties and solutions in 8-inch Fab system, provided a reference for future expansion. The results demonstrated the practical viability of this approach.

1. Introduction

Energy conservation has become a popular issue in the recent years. Furthermore, energy is a critical driver for economic growth but it is also a key driver for climate change (Battaglini, Lilliestam, Haas, & Patt, 2009). Faced with the trend of low-carbon economy, the development of energy industry now is critical to the well-being of the human future as well as the national economic growth. Therefore, the governments have started to work on the policy of energy conservation.

Semiconductor industry is one of the most complicated industries in which productivity enhancement, yield enhancement, continual cost reduction, and cycle time reduction are the important ways for operational excellence (Chien, Hsu, & Chang, 2013; Chien & Wu, 2003; Wu & Chien, 2008). Driven by Moore's Law (Moore, 1965), the semiconductor industry has strived for continuous technology migration via capital investments and cost reduction to maintain competiveness. In particular, capital effectiveness and productivity are critical for reducing the costs and maintaining competitive advantages (Chien et al., 2013). In addition, the semiconductor industry in Taiwan not only requires a high standard on the stability and quality of electricity supply, but also has obviously consumed more electricity than other industries like the steel or petrochemical. If the high-tech industries cannot put more efforts on energy conservation, aside from paying high electricity expenses, they could even face trade sanctions. Therefore, if the semiconductor industry in Taiwan can provide specific performance indicators in energy management of the Fab, the energy conservation policy could be implemented more efficiently.

Overall Equipment Effectiveness (OEE) is a productivity management tool for Total Productive Maintenance (TPM) that considers equipment availability, utilization, and output quality for identifying and analyzing hidden performance losses including equipment failure, setups/adjustments, idling/minor stoppages, reduced speed, defects in process, and yield loss (Jeong & Phillips, 2001; Nakajima, 1988). To capture the overall equipment performance for identifying and analyzing hidden performance

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losses, OEE was developed as an industry standard (SEMI E79-0200, 2000). Furthermore, SEMI E79-0200 (2000) defines OEE as the fraction of total time that equipment is producing effective units at theoretically efficient rates. In particular, effective units denote the number of units processed by the equipment during production time that were of acceptable quality. OEE indices and SEMI E10-0701 (2000) have been widely accepted as a set of industry-wide standards for measurement of equipment productivity among equipment buyers, suppliers, and manufacturers in semiconductor manufacturing (Chien et al., 2013). For example, Chien, Chen, Wu, and Hu (2007) proposed the Overall tool Group Efficiency (OGE) indices to evaluate the performance of tool groups with statistical efficiency control charts for continuous control, in which the subgroups of the tools should be determined for backups for the reentrant processes of semiconductor manufacturing (Chien & Hsu, 2006). Huang et al. (2002) integrated the productivity metrics such as OEE, OTE (overall throughput effectiveness), and CTE (cycle time effectiveness) and the theory of constraints to improve the productivity of a leading glass manufacturer. Muthiah and Huang (2006) proposed the OEE and Overall Throughput Effectiveness (OTE) metrics to identify bottleneck and diagnose system productivity problems for complex-connected manufacturing systems including series, parallel, assembly, and expansion subsystems. Wudhikarn, Smithikul, and Manopiniwes (2010) proposed the overall equipment cost loss indicator based on OEE for evaluating the production loss in monetary value to prioritize problematic machines. Furthermore, in order to evaluate the factory performance, SEMI E124-1107 (2007) defined a set of metrics for overall factory efficiency (OFE) via multiplying the volume efficiency and the yield efficiency. In particular, the production metrics access the volume efficiency including the performance of throughput rate, cycle time efficiency, and WIP efficiency with respect to the process efficiency. The quality metrics access the yield efficiency including the performance of line yield and test yield with respect to the overall material efficiency. For example, data mining approaches were developed to extract wafer bin map patterns for yield improvement (Hsu & Chien, 2007; Liu & Chien, 2013). Similarly, the cycle time efficiency and throughput rate efficiency can be measured. For example, Kuo, Chien, and Chen (2011) employed data mining and manufacturing Intelligence to exploit the production and tool big data to reduce cycle time and enhance the production performance. Also, Chien, Chen, and Hsu (2015) proposed an advanced control approach to hedge and compensate the variations of critical dimensions of the short processing loop of development and etching for yield enhancement, while maintaining productivity. In order to enhance the productivity of the wafer resource, Chien et al. (2013) proposed the Overall Wafer Effectiveness (OWE) indices to identify different types of wafer area losses owing to equipment, lithography technology, exposure pattern, and production variation. Chien and Hsu (2014) developed a data mining approach to generate the optimal IC feature designs that can bridge the gap between Integrated Circuits (IC) design and wafer fabrication by providing IC designer the optimal IC feature size in the design phase to increase gross dies for enhancing OWE and reduce the required shots for increasing throughput and cost reduction. Focusing on the resources of materials used for wafer fabrication, Chien, Diaz, and Lan (2014) designed the overall usage effectiveness (OUE) indices and developed a data mining framework that integrates the data for fault detection and classification (FDC) and the data from the Manufacturing Execution System (MES) to enhance OUE for cost reduction. Furthermore, Chien, Chu, and Zhao (2015) proposed a set of novel indices for Overall Resource Effectiveness (ORE) to thus drive various improvement directions for total resource management.

However, little research has been done to address energy expenditure management from the perspective of the Fab energy conservation. Moreover, there is a lack of measurement for evaluation of energy efficiency, yet just use of the energy consumption. This study aims to fill this gap by proposing a novel index, namely Overall Power Energy Effectiveness (OPE), for measuring overall energy expenditure effectiveness. In particular, constructing OPE indicators for energy conservation will be the main topic of this study. The objective of this study is base on the UNISON framework for decision analysis (Chien, 2005) and employ the SMART methodology (Edwards, 1977) to establish a Fab energy efficiency assessment model for the semiconductor industry, as well as use multiple energy saving methods to measure energy cost management efficiency. Additionally, this study considered both theoretical and practical conditions to identify directions and provide suggestions with respect to each indicator to improve the decision making on energy expenditure and distribution. In particular, this study took a Fab of semiconductor enterprise in Taiwan as an example to inspect the energy efficiency and employ the proposed OPE indicators to help the managers understand the execution of each decision-making unit and properly deploy the resource for energy saving and sustainability.

2. Approach

Manufacturing strategic decisions for capital-intensive industries involve the interrelated elements of the PDCCCR framework (Chien, Chen, & Peng, 2010) including pricing strategies (P), demand forecast and demand fulfillment planning (D), capacity planning and capacity portfolio (C), capital expenditure (C), and cost structure (C), that will affect the overall return (R) of a company, as shown in Fig. 1. In particular, the effectiveness of utilizing various resources is critical to enhance productivity and improve cost structure for profitability.

This study proposed an approach for optimizing energy consumption in the semiconductor fabrication (Fab) plant. The research framework is shown as Fig. 2. Firstly, the top executive of the company needs to declare their concern on the carbon reduction issue and to explicitly make related policies for execution. In the meantime, it is also necessary to establish an energy management department and formulate supporting performance indices for motivating employees and base on the "top-down" concept to bring the energy-saving ideas to employees at all levels. Then, we collect related data and make classifications to sort out the energy consumption ratio and propose energy-saving plans; besides, through the SMART method, we can find the optimal alternative for making a detailed energy-saving plan and figure out the optimal energy consumption based on the effective energy outputs of the whole plant. Finally, we construct OPE indicators and energy management systems based on the results of the optimal energy consumption.

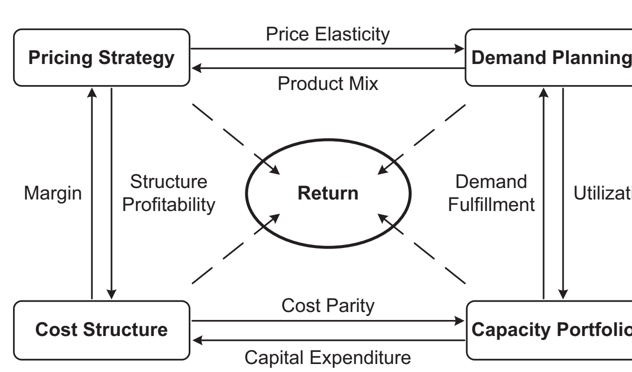

Fig. 1. PDCCCR framework of manufacturing strategy (Chien et al., 2010).

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