Master Production Schedule and System for Excelling Enterprise Resources (SEER) in the LED Industry

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Abstract—Every enterprise is pursuing energy conservation and carbon reduction development. Under this trend, light-emitting diodes (LEDs) are becoming the focus of the lighting industry. Because of the different levels or types of chips and substrates, the characteristics of products will be different. LED products are categorized according to characteristics such as luminescence efficiency, wavelength (color), and the reference voltage level. Traditionally, lack of good communication channels for production and sales department led to excessive inventories, even though the demand was satisfied. These products face the risk of being unsalable due to the short product life cycle. Therefore, this study developed a system for excelling enterprise resources (SEER) for LED manufacturing that optimizes chip procurement and production planning by linear programming. The system considered the deviation of the output distribution during the production to allocate the amount of chip and process to maximize profit. This study chooses the LED packaging company in Taiwan Hsinchu Science Park as an empirical case. We analyzed the different planning criteria to find some management rules and let this system become a communication tool between the production and sales department.

I. INTRODUCTION

In recent years, because of the growing environmental awareness, energy price volatility, and emerging countries in Asia and elsewhere, the prices and demands of energy have been increasing. People have paid more and more attention to energy conservation and alternative energy. Since these technologies are extensively researched and developed, the green-related industries have been growing globally. With the advantages of mercury-free, energy saving, carbon reducing, and long life, LEDs have become the optimal choice for the new generation lighting source. Because of rapid technological advance and various innovative applications, LEDs have gradually replaced traditional light sources. Additionally, the promotion of favorable policies by various governments has created more impressive business and growth opportunities. The LED manufacturing process is similar to integrated circuits (ICs). Because of its unique capabilities and well-developed industrial groups, Taiwan's semiconductor industry is well positioned to support the development of the LED industry. In recent years, the mutual cooperation in LED development between the government and private company has led to the establishment of a complete hierarchical value chain, which involves upstream IC design, midstream chip manufacturing, downstream packaging, and lighting applications. Therefore, Taiwan's LED manufacturing industry was the No.1 producer of LEDs in the world in 2010; its total output value is No. 2 in the world.

However, during LED packaging process, because of different manufacturing process and materials, products must be sorted into different bins (product level). In the LED industry, the term “binning” refers to sorting LED products according to various criteria, such as luminescence efficiency, wavelength, and the reference voltage level. Then, products are selected according to the customer’s requirements. For example, the downstream TFT-LCD Industry required similar substrates (TFT) and color filter (CF) to improve yield during the assembly. Thus, procurement, production, and order-fulfillment decisions should be integrated. When the chip is packaged into a product, the price is based on its luminescence efficiency, wavelength. However, only some product bins can be allocated for customers’ order, and the remaining products are saved as the inventory. This not only increases inventory processing costs, but also, if the inventory cannot be sold, further wastes raw materials and production costs, thereby affecting the overall financial performance of the company.

This study developed a system for excelling enterprise resources (SEER) to optimize LED master production schedule by linear programming. The system optimizes chip procurement and production planning by considering the output distributions generated by variations in the production process, the ordering behavior of various customers, and the handling costs for inventories of various durations. After considering these elements, the system determines the amount required for mass production, which matches the combination of chips and processes, to maximize the company’s profit. This study chooses the LED packaging company in Hsinchu Science Park as an empirical case. We analyzed the different planning criteria to find some management rules and let this system become a communication tool between the production and sales department.

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II. LITERATURE REVIEW

Most studies related to production planning and demand fulfillment used methods such as system simulation, mathematical programming, and algorithms. Sahin et al. [1] investigated the relationship between manufacturers and suppliers in a make-to-order environment, using a system simulation construction model to conduct experimental analysis of the entire factory. Sahin et al. observed three main production design factors: planning horizon length, frozen interval length, and re-planning frequency, and observed four environmental factors: ordering cycle length, supplier flexibility, demand limitations, and demand lumpiness. These factors affect the master production scheduling, advance order commitment, and influence design strategies. Vollling and Spengler [2] used a system simulation to determine the factors influencing the design costs under the time interval policy of various master production scheduling strategies in a supply chain, including non-frozen interval policy, planning horizon length, frozen interval length, and re-planning frequency. These four factors are the main factors affecting master production scheduling design. Besides, order cycle length, supplier flexibility, demand limitations, and demand lumpiness are four environmental factors affecting master production scheduling costs and instability.

Robinson et al. [3] used make-to-order and order-oriented planning approaches of strategic modeling used by automobile manufacturers to build a mathematical model for the order commitment and master production scheduling processes. Because of the complex dynamic interaction between the two models, factors such as capacity utilization, available capacity, capacity utilization derived contribution, and the capacity/demand ratio must be considered. ANOVA was conducted using the unavailability of resources, transfer costs, and the amount of average inventory as the measurement targets to select the best strategy. Körpeoglu et al. [4] used the multi-level stochastic programming approach for master production scheduling under conditions of uncertainty and capacity limitations to maximize profit by controlling manufacturing time. Ram et al. [5] used food manufacturing as an example and explained that under the material demand planning, unexpected inventory problems can be better managed with a flexible bill of material (allowing the number of dependent demand items to fluctuate within a certain range) compared to a fixed bill of material. A linear programming model is also used to minimize fluctuation range.

Sawik [6] used a hierarchical integer programming model of the high-tech manufacturing industry under limited capacity during a planning interval to satisfy the order distribution using various delivery schedules. Sawik used a lexicographic approach to obtain the optimal solution by minimizing delays as the primary target, maximizing the use of the inventory from the previous period, and minimizing the inventory of the current period as the secondary target. Vieria and Riba [7] used fractional factorial experiment to screen important parameters to construct simulated annealing method to resolve problems regarding multi-objective master production scheduling, such as maximizing capacity utilization, customer service quality, and minimizing the inventory level. Soares and Vieria [8] planned a master production schedule using a genetic algorithm (GA) and considered multiple objectives, such as maximizing service quality and resource utilization and minimizing inventory levels. Chem and Hsieh [9] proposed the use of a heuristic algorithm for the master planning of supply chain networks by considering three goals, namely minimizing the penalty for delayed delivery, outsourcing, and total costs (including production, transportation, and inventory holding costs), under limited production capacity and delivery requirements.

With the increasing complexity of manufacturing systems and advances in decision support systems, many companies are starting to use decision support systems for planning and operation. Eom et al. [10, 11] compiled studies on decision support systems from 1988 to 1994 and 1995 to 2001 and found an increasing trend in applications at the strategic level. At least half of the compiled studies applied decision support systems to help manage real problems. These problems related less to the work level and more to the planning, function, and operational levels. The areas of application and the methods used were also expanded, significantly increasing the use of these systems.

Jeong et al. [12] established an integrated decision support system to help businesses handle production line diagnoses, maintenance planning, and production scheduling. The system established a number of algorithms that determine the sampling program using conditional probability and considered the current status of machine maintenance planning and production scheduling within the minimum planning time. Cai et al. [13] and Lin et al. [14] established an optimal decision support system for energy management and considered the problem of uncertainty using a scenario analysis method. Mahdavia et al. [15] used simulation methods to analyze companies with flexible production and employ if-then rules to manage planning. Maria et al. [16] constructed a graphical decision support system for wind power generation, which observes the existing wind conditions of wind farms in the specific area, to provide sufficient information for decision making.

III. METHODOLOGY

A. Notation

**Indicators:**
- \( w \): chip type
- \( r \): production process type
- \( b \): product type
- \( O \): customers’ order
- \( t \): period
- \( a \): inventory age

**Parameters:**
- \( Price_{o,b,t} \): Selling price of product type \( b \) for order \( o \) during the period \( t \)
- \( C_{chip}^{w,t} \): Chip cost of chip type \( w \) during the period \( t \)
- \( C_{chip\_handling}^{w,a} \): Inventory handling cost for the type \( w \) of chip for inventory age \( a \)
C. Mathematical Model

This problem was formulated in the following linear programming model, which is designed for chip procurement and production scheduling under a known production allocation for various types of chips. The model is useful in determining the necessary quantity for chips and corresponding tape-out of process combination to maximize the company profits.

This problem focuses on profit maximization. Revenue earning covers the demand satisfaction level of customer orders and individual sales prices. The consideration of cost includes chip costs, production costs, inventory handling costs, and the penalty cost of unfilled orders. Inventory handling cost involves the cost of holding inventory and the risk of unsellable inventory. The settings of cost standards vary according to the inventory age; for example, an inventory with a high inventory age (an old inventory) can lead to correspondingly higher handling costs. The penalty cost of unfilled orders is several times the selling price.

Objective function:

\[
\begin{align*}
\sum_{w} \sum_{b} \sum_{o} \sum_{t} \sum_{a} \sum_{t} z_{w,b,o,t,a} \times Price_{b,t} \\
- \sum_{w} \sum_{t} x_{w,t} \times C_{chip} \\
- \sum_{r} \sum_{t} \sum_{a} y_{r,t,a} \times C_{r} \\
- \sum_{w} \sum_{t} \sum_{o} \sum_{a} v_{w,t,o} \times C_{chip \_holding} \\
- \sum_{w} \sum_{b} \sum_{t} \sum_{a} \sum_{r} i_{w,b,t,a} \times C_{product \_holding} \\
- \sum_{o} \sum_{t} nsd_{o,t} \times C_{nsd}
\end{align*}
\]

Constraint:

\[
\begin{align*}
x_{w,t} & \leq UW_{w,t} & \forall w, \forall t \\
x_{w,t} & = v_{w,t} + \sum_{r} \sum_{a} y_{r,t,a} & \forall w, \forall t \\
v_{w,t,1} & = v_{w,t,1} + \sum_{r} \sum_{a} y_{r,t,2} & \forall w, \forall t \\
v_{w,t,1} + v_{w,t,2} & = v_{w,t,3} + \sum_{r} \sum_{a} y_{r,t,3} & \forall w, \forall t \\
Yield_{b,t} & \times \sum_{a} y_{r,t,a} = product_{r,b,t} & \forall r, \forall t \\
product_{r,b,t} & = \sum_{a} z_{r,b,a,t} + v_{r,b,t,1} & \forall r, \forall b, \forall t \\
\ell_{r,b,t,1} & = \sum_{a} z_{r,b,a,t} + v_{r,b,t,1} & \forall r, \forall b, \forall t
\end{align*}
\]
Equation (2) represents the upper and lower limits of supply for various chips. The upper limit represents the production capacity or inventory of the supplier, and the lower limit is determined by long-term supply contracts or supplier relationship maintenance. Equations (3), (4), and (5) are balance constraints on the chip side, which can be produced using chips purchased from vendors and previous inventory. These chips may enter the production line or be stored for the next period. The inventory age of chips purchased in the current period is divided into three types: chips purchased in the previous month, inventory chips purchased within the past two months, and chips purchased more than three months previously. Inventories old more than three months mainly include the chips that are less frequently used and facing elimination from the market. Thus, their handling cost is higher. Equation (6) represents the balance constraints on the production side, in which the production of chips follows the production distribution table for product output. The table assumes that the production ratio of various outputs is close to historical data; the total percentage of production is listed as yield in the distribution table.

\[
D_{st} + nsd_{s,t-1} = \sum_{x} \sum_{y} x_{y} \cdot \sum_{z} z_{x,y,z} + nsd_{x,y} \quad \forall s, \forall t
\]

Figure 2. Welcome screen of the system

Equations (7), (8), and (9) represent the balance constraints of the product side, which are divided into three periods of the inventory age similar to those of the chip side, with relatively higher product inventory handling costs for inventories older than three months. Although chips can change the output ratio through different manufacturing processes, products eliminated from the market cannot be sold. Equation (10) represents balance constraints on the customer side, which records the product specifications demanded by the customer in the purchase order. Some customers have a higher acceptance level for various specifications, whereas other customers specify that the products must be produced with a particular chip because of stability or manufacturing process characteristics.

D. System structure

Operational issues can be divided into long-term, medium-term, and short-term problems, which affect the consideration of various lengths of time, objectives, programs, and resources. Different problems involve different decision-makers, which can lead to decision-making bias because of personal preference and experience. A system for excelling enterprise resources (SEER) can play a rational role to provide a high quality advice. However, not all problems can be resolved objectively. Some problems still require personal judgment. Decision makers can use expert knowledge to make a balanced final decision that considers quality and feasibility.

A system for excelling enterprise resources (SEER) comprises four modules. The data module is responsible for integrating information from various sources and providing the other modules with required information, such as data for input and calculation; the analysis module uses expert knowledge from the organization's existing knowledge database or from an analysis of the information provided by the data module to strengthen proposals generated by the system; the optimization module is responsible for calculations, including the proposed linear programming in this study, and calculation rules for items such as cost and financial indicators; and the interface module is the actual module that users employ, which uses a graphical interface for data maintenance, pattern computation, and result observation.

IV. EMPIRICAL STUDY

A. Empirical Case

This study used a firm located in Hsinchu Science Park as a case study. With the effects of environmental awareness and energy conservation in recent years, the company established an LED division in 2009. Their main business is high-power light-emitting diode (LED) packaging OEM by providing flexible customized packaging services according to the needs of customers.

Although the production capacity of this company was limited, under the fledgling development of the LED industry, its production capacity was sufficient to meet the demand. The data dimensions tested include 11 types of chips, 18 processes, and 32 product types. The scheduled period is for the current and following months because of the lead time of the make-to-order wafer fabrication. Although packaging production is rapid, chip procurement requires a longer production period.

B. System for Excelling Enterprise Resources (SEER)

This study established a system for excelling enterprise resources (SEER) to assist companies in scheduling chip procurement and tape-out. Users can import order, process, chip, and product information in Microsoft Excel format.
After importing the data by Excel format, users can check the information of order, chip cost, yield, chip inventory and product inventory. Then press the optimize button to start the analysis. Finally, various reports will be generated by the system and users can export the reports to Excel file.

Figure 6 shows that the calculation of the entered data using system optimization and database modules can generate various reports for use and reference by every department, and obtain various types of detailed information using the export function.

Users have to enter the order information include customer, demand, product type and sales price; the cost information include cost of chip, upper purchase limit and process cost; the yield information include the product output distribution; the inventory information include the initial inventory of chip and product with different ages.

The system start to optimize the linear programming model based on the imported data to maximize the company profits by using Lingo.

C. Analysis

In product classification, when the quantity of one product cannot meet the order demand, an alternative product can be used. For example, for the purpose of lighting, customers can accept replacement products with high brightness instead of low brightness, which is referred to as a downgrade. High-end products are believed to have higher costs, and replacing a low-end product with a high-end product reduces company profits; thus, downgrades are rarely implemented.

However, the establishment of a mechanism in the optimization module that permits downgrades can improve company profit by as much as 17.40 % according to the verified data. This is because if downgrades are not permitted, attempts to satisfy orders for low-end products result in the purchase of chips used in most low-end products, producing additional unnecessary product inventory.

Another improvement is the generation of orders. Traditionally, when an order is received from the customer, we first confirm if there is any inventory before the production of a single work order. This method often produces unnecessary product inventory while ignoring products produced by other work orders that meet the customer’s specifications.

The establishment of a multi-work order hybrid production and delivery mechanism within the system can increase profits by 14.28 %. Considering customer usage, the implemented production mechanism that requires each order to exceed 50,000 units before the hybrid work order can increase profits by 7.90 %. This is because of complementarities between various orders.
V. CONCLUSION

With increasing environmental awareness and the rapid development of the LED industry, this study developed a decision support system to optimize LED operations, using linear programming for chip procurement and production planning optimization. By considering the output distribution created by the changing production process, the ordering behavior of each type of customer, and the handling cost for inventories of various ages, the system facilitates decision-making of the required chip quantity and corresponding tape-out in the manufacturing process to maximize the company profits.

This case study was conducted in a company located in Hsinchu Science Park, which analyzed the results generated from various scheduling criteria. These results show that a downgrade in shipments is not negative for the company, but can improve profits by 17%. Though hybrid work order production must place greater emphasis on managing the production process, it can improve profits by 7 to 14%. In addition, when two programs are running in parallel, they only increase profit by approximately 19%. This is because a single program can only reduce the inventory of unnecessary products. Most businesses view this system to be useful for production scheduling to analyze and discuss the benefits of various planning guidelines. However, the data for purchase orders currently used in this study represent the sample data from the company. In the future, when the system is fully implemented within the company, more complete testing results can be obtained by conducting further situational analysis to identify applications during the changing economic conditions.

ACKNOWLEDGMENT

This research is supported by the National Science Council, Taiwan (NSC99-2221-E-007-047-MY3; NSC100-2628-E-007-017-MY3), and the Advanced Manufacturing and Service Management Research Center of National Tsing Hua University (101N2074E1).

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