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Inventory write-down prediction for semiconductor manufacturing considering inventory age, accounting principle, and product structure with real settings

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ABSTRACT

The International Financial Reporting Standards (IFRS) No. 2 has been the worldwide accounting principle for the reduction of inventory to market allowance since January 1, 2005. Using make-to-stock manufacturing strategies and inventory accounting for only approximately 14% of the total costs, integrated device manufacturers have found maintaining robust records for financial statements increasingly difficult. For example, one company in the case study conducted in this study must write-down losses of 2–100% of the total inventory costs for products with inventory ages of 18 months–3 years. However, the average cycle time for producing flash memory is approximately 3 months. In other words, when the system variation and safety stock policy are considered, the company must write-down the reduction of inventory to market allowance for most of work-in-process inventory. However, little research has been done to addressing the practical management of operations according to inventory aging processes. This study develops a polynomial-time-based model to obtain significant features, including inventory ages, accounting principles, and product structures (bill of material), for the accurate prediction of inventory write-downs to reduce the impact of the carrying value fluctuation of inventory. An empirical study was conducted on a Taiwanese semiconductor manufacturer. The results show that predicting 3-month inventory write-downs of a complete flash memory production line comprising approximately 8500 product types can be conducted in less than 10 s, with the mean absolute percentage error (MAPE) less than 3.5%. Discussions regarding the sensitivity analysis and cost tornado diagrams suggest the priority of affecting factors. The results show the viability of implementing the proposed model to predict inventory write-downs in the semiconductor manufacturing industry.

1. Introduction

The semiconductor industry is continuously growing with extensive applications in medical electronics, green energy, car electronics, computers, communication, and consumer electronics (MG + 4C). The Semiconductor Industry Association (SIA) reports a double-digit growth of all major semiconductor product categories in 2010 compared to 2009. The global semiconductor chip sales reached a record US$298.3 billion with a nearly 32% annual increase (SIA, 2011). However, numerous semiconductor memory companies have been exposed to the risk of excess inventory levels and frequent inventory write-downs (Chen, Ramnath, Rangan, & Rock, 2010). The reason can be ascribed to industry characteristics, including high capital intensity, rapid technology development, and severe supply chain competition (Aizcorbe, 2002; Chien, 2007; Chien et al., 2011; Leachman, Ding, & Chien, 2007). Specifically, high capital expenditure prompts semiconductor manufacturers to fully use capacity, which leads to high levels of inventory accumulation during low-demand periods. Following Moore's law, the new generation product will dominate prior generations regarding the cost-per-function. This technology migration will accelerate the price decline and replacement of prior generation products, rendering the existing inventory obsolete. Additionally, the increasingly fierce competition has commodified chip sales. The continuous and significant price decline leads to a market value lower than the manufacturing costs, which is another cause of inventory write-downs.

On January 1, 2005, the International Financial Reporting Standards (IFRS) Foundation Trustees declared the IFRS No. 2 (2010) the accounting principle for the reduction of inventory to market allowance. However, since its implementation, integrated device manufacturers have experienced even greater difficulty maintaining robust records for financial statements. Inventory write-downs are recorded as part of cost of goods sold that led to

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disadvantageous gross profit. Semiconductor manufacturing is complex and lengthy. For example, the average cycle time of flash memory is approximately 3 months, including the 50 days for wafer fabrication, 5 days for circuit probing, 7 days for chip assembly, and 22 days for final tests. The average cycle time of semiconductor manufacturing varies across products because of a number of manufacturing strategic decision settings, including demand planning (Chien, Chen, & Peng, 2010a), new product ramping schedule and allocation (Chien, Wu, & Wu, 2011), capacity planning (Chien & Zheng, 2011), wafer start plan, work-in-process (WIP) level, tool availability (Kuo, Chien, & Chen, 2011), outsourcing strategy and order allocations (Chien, Wu, & Weng, 2010b; Wu & Chien, 2008a), and scheduling (Wu & Chien, 2008b).

In addition, three months to 1 year of safety stocks are typically established depending on the product market and customer satisfaction level. In these cases, most of the WIP and end products become the amortization item to be written down. Additionally, variations in financial performance may further cause overreactions in the stock market when a significant amount of reduction of inventory to market is reported at once. This overreaction is typically nonreversible. That is, no compensation will be provided even after written-down inventories are sold thereafter.

The timing and magnitude of inventory write-downs are crucial to earning management (Chen et al., 2010). However, knowing that prior research addressed inventory write-down estimation primarily based on economic factors and temporal history data, this study develops a multi-period inventory write-down prediction model that captures specific company features, including accounting principles, inventory ages, and product structures. An empirical study was conducted on a semiconductor manufacturer located in the Hsinchu Science Park in Taiwan to demonstrate the viability of the proposed model.

The rest of this paper is organized as follows. Section 2 addresses the literature review of inventory models related to inventory write-downs; Section 3 elaborates features of inventory write-downs in semiconductor manufacturing and introduces the proposed model; Section 4 explains the proposed model; Section 5 presents the data collection and analytical results based on an empirical study; Section 6 addresses discussions on sensitivity analysis and applications of cost tornado diagrams; and lastly, Section 7 offers a conclusion.

2. Fundamentals

Semiconductor industry is very capital intensive, in which the chip makers strive to increase productivity and enhance capacity utilization for maintaining their capital effectiveness and competitive advantages (Chien, Chen, Wu, & Hu, 2007). Indeed, manufacturing strategic decisions of semiconductor companies involve the interrelated elements 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 their overall financial return (R), as illustrated in the PDCCCR conceptual framework of Fig. 1 (Chien et al., 2010a). On one hand, semiconductor companies have to forecast future demands to provide the basis for capacity strategic decisions including new fab construction, technology migration, capacity transformation and expansion, tool procurement, and outsourcing. On the other hand, given demand uncertainty and forecast errors, companies often carry a safety stock in terms of the days of in the semiconductor supply chain. As shown in the *Bullwhip Effect* (Lee, Padmanabhan, & Whang, 1997), the variations are amplified as moving upstream in the supply chain. Thus, it is critical for semiconductor companies to develop robust demand fulfillment strategies and manage the inventory to mitigate the

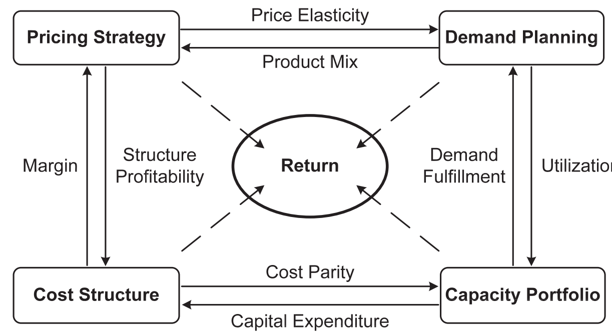

Fig. 1. Conceptual framework of PDCCCR (Chien et al., 2010a).

negative impacts of the *Bullwhip Effect*. However, the demand fluctuation due to shortening product life cycle and increasing product diversification in the consumer electronics era make the demand forecast problem increasingly difficult (Chien & Chen, 2011), which complicates the present problem for inventory write-down prediction considering inventory age, product characteristics, and cost structure, according to the accounting principle.

The characteristic of a product value decreasing over time has been studied in inventory management. Recent research has considered perishability, deterioration, and obsolescence, and developed optimal inventory policies accordingly. Agricultural goods are among the classic products facing this problem (Blackburn & Scudder, 2009; Lodree & Uzochukwu, 2008), and their perishability might affect the demand itself. Concerning supply chain management, obsolescence strongly affects reorder policies, which have been analyzed and compared (Deniz, Karaesmen, & Scheller-Wolf, 2010; Emsermann & Simon, 2007; Song & Zipkin, 1996). Ferguson and Koenigsberg (2007) suggested a two-period inventory model to determine the optimal production and price. The primary features for classifying these models include single/multiple items, static/varying demand, single/multiple periods, purchase/production models, with/without backordering, single/multiple buyers, and constant/changing deterioration rates (Raafat, 1991). However, inventory ages are occasionally not recorded to reflect the inventory value for a write-down.

Existing studies have explored echelon (stage) inventory policy aimed at optimizing the stock levels and order quantity of each echelon supply chain to reduce stock and inventory holding costs (Clark & Scarf, 1960; Cohen, Kleindorfer, & Lee, 1989; Graves & Rinnooy Kan, 1993). Regarding specific application areas, the inventory costs of electronic products can be divided into component devaluation costs, price protection costs, product return costs, obsolescence costs, and inventory holding costs. Different inventory costs have different proportions in different product categories. Therefore, different supply chain management policies should be used for inventory-driven cost reduction (Callioni, de Montgros, Slagmulder, Van Wassenhove, & Wright, 2005). Since a decline in product demand leads to a loss of orders, and thus, high stock levels, examining the product life cycle of electronic components and adjusting stock levels accordingly to reduce inventory overdue costs is necessary (Solomon, Sandborn, & Pecht, 2000). To further improve the evaluation of inventory management, effective information systems were suggested, including implementation of the Just-in-Time (JIT), material requirement planning (MRP), mass customization, and manufacturing flexibility and modularity strategies (Rabinovich, Dresner, & Evers, 2003). To obtain the structure of a significant bill of material (BOM), a flow-network approach was developed (Yenisey, 2006). However, the previous studies focused on ordering and production decisions to minimize total costs, which is not applicable to predicting inventory write-downs.