Int. J. Production Economics 147 (2014) 38–45

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Modeling cost benefit analysis of inspection in a production line

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ARTICLE INFO

Article history:
Received 23 November 2011
Accepted 10 May 2013
Available online 22 May 2013

Keywords:
Cost
Flow-time
Inspection capacity
Inspection rate
Wafer fabrication
Yield loss

ABSTRACT

Production management aims to maximize profit by increasing salable output while reducing the cost related with inspection, where inspection is defined as the measurement and quality assessment of items produced. This study is based on a semiconductor production line with consecutive deteriorating machines. Each machine is inspected via the items it produces and an inspection result triggers a machine's repair, if needed. Inspection related cost includes fixed and variable cost of inspection capacity, Yield Loss Cost generated due to unsalable throughput, and delivery delay cost caused by inspection flow-time. The effects of inspection capacity and inspection rate on cost are investigated using analytical and simulation models. Under a given inspection capacity, Yield Loss Cost decreases with growing inspection rate until a minimum is reached, and then starts to increase with further growing rate. This increase is explained by the impact of higher load on the inspection facility, which prolongs the inspection response time. Thus, an optimal inspection rate can be derived for a given inspection capacity. It will be shown that the higher the capacity, the higher the optimal rate, and the lower the yield loss. Determination of optimal inspection capacity considers the capacity cost against the other costs and minimizes the total expected inspection related costs.

1. Introduction

1.1. Background

Production management strives to maximize profit by increasing the revenue, gained by the production throughput, while simultaneously reducing the overall cost of production. Some of the production cost is generated by applying quality improvement activities through the production line, which are intended to drive higher throughput and in turn increase the revenue. Since revenue is a function of the average sale price, which rather depends on the market and not on production management, it is disregarded in this study. Rather, only the cost of goods sold is considered which corresponds to the overall cost of production. Therefore, it is assumed that minimizing the overall cost will consequently and equivalently maximize the profit.

This work originates in semiconductor wafer fabrication, where dies are produced on silicon wafers that stream through the production line, via process and inspection steps. It studies the cost related to quality improvement applied by inspection of the items produced. Distinction is made between end-of-line (EOL) inspection performed on the final product, and in-line (IL) inspection performed on partially processed items throughout the production line. This study investigates the scenario of applying IL inspection.

1.2. Investigated scenario

Mittal and McNally (1998) discuss the motivation to "monitor defects for maximizing good die output, through die yield improvement in a cost efficient manner", in a wafer fabrication line which heavily relies on IL inspection. This study considers a general production line with hundreds of consecutive steps which consist of process steps operated with deteriorating machines, and inspection steps that make up to 50% of the production line. Each process machine is inspected via items it produces. The goal of inspection is twofold, it can be used to improve the yield performance of the machines, and improve the quality of the process technology. In this work, the focus is on improving the machines performance rather than the process technology in order to minimize the overall production cost. Each machine quality state is determined by inspecting the items it recently processed. If defects or flaws are detected, then a repair action is applied to the respective machine.

1.3. Preliminaries

The cost structure suggested here relies on the cost of ownership (COO) and activity based costing (ABC) methods. Both are

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http://dx.doi.org/10.1016/j.ijpe.2013.05.012

applied in wafer fabrication practice and literature. Following are the major wafer fabrication cost components defined for the investigation:

- Processing Cost—fixed and variable cost of wafers processing capacity (e.g. machines), materials, maintenance and operation; processing is defined as the procedures of changing the physical characteristics of wafers, and which add value to the items produced.
- Inspection Cost—fixed and variable costs of IL inspection capacity (e.g. machine), materials, maintenance and operation; inspection is defined as the measurement and quality assessment of wafers, which are usually considered as non-value-added (NVA) activities (Block and Carr, 1999).
- Yield loss Cost—cost of unsalable dies at EOL caused by defects and flaws generated via machines' processing in the production line; loss of whole wafers in the line is not considered, since in practice it is negligible (less than 1%).

Since processing capacity, cost and operational policies are not studied here, they are all considered given. The work investigates the impact of wafers inspection capacity and operational policies on Inspection Cost and Yield Loss Cost. In order to avoid dealing with absolute financial figures, the cost-effectiveness of Inspection Cost and Yield Loss Cost is measured in proportion to the assumed given Processing Cost.

The Inspection Cost elements are classified into fixed cost and variable cost. Fixed cost mostly includes building, machine, and overhead costs. Variable cost includes expenses such as materials (e.g. chemicals), facilities (e.g. electricity) and labor. The Yield Loss Cost is affected by the inspection rate (IR) and the response time to repair. The cost impact of longer Flow-Time (FT) on delivery is also taken into account. Different intensities of IR are investigated under various levels of inspection capacity.

Section 2 reviews literature on production line modeling, the in-line inspection methods, and production cost structure. Section 3 illustrates the production line model and inspection policies, and Section 4 defines the cost model. Section 5 presents the results, and Section 6 concludes and suggests future research.

2. Literature review

This section reviews relevant literature of wafer fabrication operations and production systems inspection methods, for modeling a production line embedded with inspections. Then, COO and ABC in wafer fabrication are reviewed for modeling the manufacturing cost structure. The rest of the study relies on the concepts and models reviewed here.

2.1. Production line modeling

Studies of wafer fabrication operations frequently apply queueing models (Hopp et al., 2002, Zisgen et al., 2008) in investigating production systems performance measures (e.g. FT, throughput, capacity). Studies that investigate quality performance measures of operations (e.g. yield) are less common. Some rely on the yield-FT premise (Ikeda et al., 2003, Li et al., 2007) that assumes that yield increases with reduced FT and vice-versa. Other studies challenge the premise authenticity (Sakurai et al., 2004, Leachman et al., 2007) yet do not suggest alternate analytical or empirical models.

Deteriorating production systems have been investigated since the early work of Duncan (1956). Some studies focus on cost modeling (Liao, 2007), while more recent ones investigate the deterioration functions (Hu and Zong, 2009). Maintenance of deteriorating systems is surveyed in Wang (2002), including distinction between single-unit and multi-unit systems, and between corrective and preventive maintenance. Further studies of machine maintenance investigate operation-time and repair-time distribution functions. These studies conclude that the exponential distribution is the most adequate (Chandrasekhar and Natarajan, 1997, Schoemig, 1999, Haque and Armstrong, 2007), yet some consider lognormal as well (Chandrasekhar and Natarajan, 1997). A study especially dedicated to wafer fabrication machine maintenance (Jin et al., 2007) also concludes with the exponential distribution. In structuring the production line model applied, this work relies on queuing and deteriorating production system models.

2.2. In-line inspection modeling

Literature of production systems suggests many inspection types. Mandroli et al. (2006) reviews 113 papers, defining inspection strategies and characteristics. It relates to inspection-oriented quality-assurance strategy which drives minimum production cost and deals with in-line inspection (of semi-finished items) of discrete-parts in a serial production system. The scenario presented here is classified in reference to Mandroli et al. (2006), by: simple inspection type (single item, once), error free inspection (assuming no Type I or II errors), defected items are not replaced, repaired or scrapped but continue process (good and bad produce is mixed in the same item), components cost is considered via yield and FT, inspection capacity is limited, parametric strategy (determines the percentage or fraction of items inspected, rather than inspection of all items), fixed inspection locations, and heuristic approach (based on searching for improved solutions vs. optimal ones, due to the scenarios complexity).

Wafer fabrication in-line inspection scenario cannot be fully classified per Mandroli et al. (2006), since: (a) inspection is performed to examine the state of the processing machine and to assess the yield accordingly and (b) inspection is applied (with no errors) and considers work-in-process (WIP) and FT. Thus, following this branch of studies, the work here is unique. Finally, this work relies on a typical production system model established in Tirkel et al. (2009).

2.3. Wafer fabrication cost structure modeling

COO is a method developed in Ellram (1990) and intends to include all quantifiable costs incurred throughout the life cycle of a purchased item from a supplier (Tang 2006). It is one of the preeminent methods for supplier selection techniques (Araz and Ozkarahan 2007). Semiconductors Equipment and Manufacturing International (SEMI) is the global industry association serving the manufacturing supply chain for the micro and nano-electronics industries. SEMI E35 (1995) is the standard metrics for semiconductor manufacturing equipment COO, and a common cost model for wafer fabrication equipment acquisition (Dance et al., 1995, Sohn and Moon 2003, Iwata and Wood, 2000, Iwata and Wood, 2002, Chung et al., 2008). It represents cost per good wafer processed in a machine, and considers: fixed and variable capacity costs, machine utilization and throughput, machine processing quality via yield, and Yield Loss Cost. COO assumes that capital cost of machines constitutes most of the wafer fabrication expenditure, and that all other costs (e.g. materials, labor) can be allocated to these machines. Some literature follow SEMI E35 (1995) to the letter (Dance et al., 1995, Sohn and Moon, 2003, Iwata and Wood, 2002), while other challenge its limitations in allocating cost to machines only, without considering process diversity (Chung et al., 2008) or in excluding the rest of the organization (Miraglia et al., 2002).