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Estimating job cycle time in a wafer fabrication factory: A novel and effective approach based on post-classification

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ABSTRACT

Estimating job cycle time is an important task for a semiconductor manufacturer as it helps to strengthen relationships with customers and is also conducive to the sustainable development of the manufacturer. The research trend in this field has moved toward the development of hybrid methods, especially those that are classification-based. Most existing methods use pre-classification; however, such methods have several drawbacks, such as incompatibility with the estimation method and unequal sizes of different job groups. In contrast, a post-classification approach has great potential, and therefore is used as a basis for the new approach in this study. In the proposed methodology, a systematic procedure is established to divide jobs into several groups according to their estimation errors. In this way, the classification and estimation stages can be combined seamlessly because they optimize the same objectives. A real case is used to evaluate the effectiveness of the proposed methodology and the experimental results support its superiority over several existing methods. The shortcomings of the existing methods based on pre-classification are also clearly illustrated.

1. Introduction

As semiconductor manufacturing becomes increasingly competitive, it is more and more difficult to survive in the industry and pursue sustainable development. To tackle these difficulties, semiconductor manufacturers have taken various actions to meet customer requirements. In the past, some of the dynamic random access memory (DRAM) manufacturers shifted to original engineering manufacturing (OEM) because the global DRAM demand was shrinking. While some foundry factories continued to invest in next-generation wafer technologies, others persisted in their low-end foundry operations using 8-inch wafers, as there was still demand for such products.

This study investigates the estimation of job cycle time, which is considered to be one of the most important tasks to meet customer requirements, as

(1) Every deal starts from the quotation of a due date that is usually based on the internal estimates of the cycle time and completion time of the possible order.
(2) Available-to-promise (ATP) is an important business function for a semiconductor manufacturer that provides a response to customer order enquiries based on resource availability. It generates available quantities of the requested product and deliverable due dates. Since the job cycle time estimation is important to internal due date assignment, it is also crucial for the determination of ATP.
(3) In the production process, customers will want to know the progress of their orders and when they can be completed, both of which depend on an accurate estimate of the remaining cycle time.
(4) In manufacturing, a downstream partner can always be regarded as a customer. Estimating the cycle time of a job in a wafer fabrication factory is important to downstream operations, such as wafer sorting, final testing, and packaging, because the estimated completion time of fabrication determines the earliest possible start time of their operations.

These issues are distributed throughout different stages to meet customer needs, as shown in Fig. 1. Through the mechanism in Fig. 1, the effectiveness of the job cycle time estimation supports the sustainable development of a semiconductor manufacturer.

Relevant literature on the job cycle time estimation in a wafer fabrication factory is briefly reviewed below. If jobs are released periodically into the factory and the factory capacity remains fixed during fabrication, then the job cycle times can be considered to be a time series. However, if any one of the assumptions is violated,

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1568-4946/

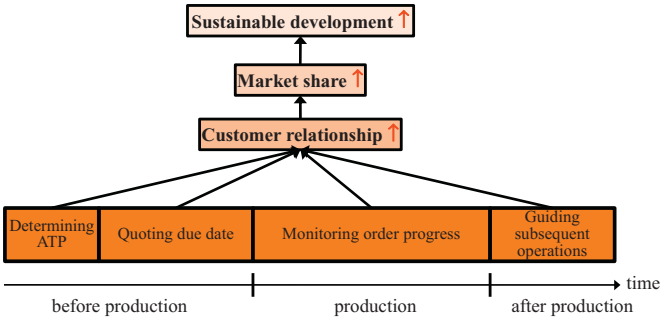

Fig. 1. The importance of the job cycle time estimation at different stages.

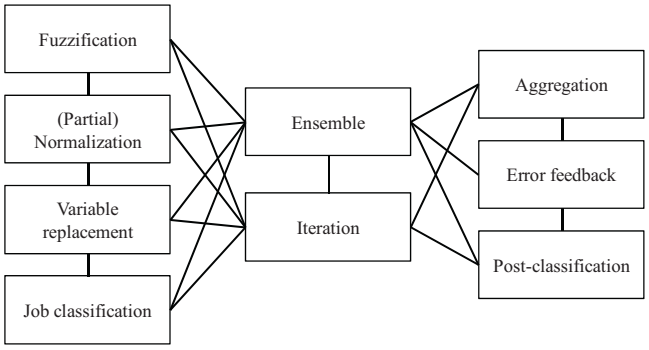

Fig. 2. The research issues in the development of hybrid approaches.

then the cycle time of a job can only be estimated from its decisive factors. Existing methods can be divided into the followings categories: statistical analyses, simulation, soft computing, and hybrid approaches [1]. Some examples in these categories are summarized in Table 1. A survey of methods in these categories is provided in [2]. Several recent advancements are reviewed as follows. Chen [3] proposed a fuzzy collaborative forecasting method for estimating the cycle time of a job in a wafer fabrication factory, in which each expert used a fuzzy back propagation network (FBPN) that effectively set the lower and upper bounds on a cycle time estimate, improving the estimation precision. Through the collaboration of multiple experts, such an improvement resulted in a higher estimation accuracy. Hsieh et al. [4] incorporated a response surface methodology (RSM) with simulation and proposed the progressive simulation metamodeling (PSM) method for analyzing the relationship between the average cycle time of normal lots and the percentage of hot lots in a wafer fabrication factory. Chen and Wu [5] estimated the range of a cycle time by using a back propagation network (BPN). The cycle time range was asymmetric to support various managerial applications.

The research trend in this field has moved toward the development of hybrid approaches, in which the following issues have attracted the attention of researchers (see Fig. 2):

(1) Pre-processing (*i.e.* processing before estimating the job cycle times)—In the literature, there are at least four pre-processing techniques: fuzzification, (partial) normalization, variable replacement, and job classification. Fuzzification maps the inputs to a number of pre-defined linguistics variables. (Partial) normalization converts data of different ranges to the same range to facilitate the subsequent computation. Variable replacement replaces the original interdependent variables with a set of new independent variables so that their relationship with the job cycle time can be better studied. Job classification classifies a job by considering the job attributes and factory conditions.

Table 1
A categorized summary of the existing job cycle time estimation methods.

Category	Method
Statistical analyses	Gamma distribution fitting [6], Decision trees [7], Petri nets [8], Regression [9], Weibull distribution fitting [10], CART [11]
Simulation	[12–14]
Soft computing	CBR [15], BPN [1,7,16]
Hybrid approaches	FBPN [1], EFR [17], SOM-BPN [18], SOM-WM [19], SOM-FBPN [20], kM-FBPN [21], NLP-BPN [22]

BPN: back propagation network; CART: classification and regression tree; EFR: evolving fuzzy rules; FBPN: fuzzy back propagation network; kM: k-means; NLP: nonlinear programming; SOM: self-organization map; WM: Wang and Mendel's method.

(2) Processing (*i.e.* estimating the job cycle times)—Some treatments, including ensemble and iteration, have been developed to further improve the estimation accuracy of methods in the field. Ensemble means that multiple experts, networks, or systems collaborate to estimate the cycle time of a job. Iteration is a technique that develops the job cycle time estimate by repeatedly applying the same method where the results of a previous iteration are used as basis for the results of the following new iterations.

(3) Post-processing (*i.e.* processing after estimating the job cycle times)—After estimating the job cycle time, the estimate is post-processed through aggregation, error feedback, and post-classification. First, in an ensemble-based method, aggregation is necessary to combine the estimates from the components into a single representative value. Second, in error feedback, the estimation error is used to fine-tune the cycle time estimation result. Third, in a method based on post-classification, jobs are post-classified in consideration of the estimation error, rather than pre-classified according to the job attributes.

Various studies on these issues have been summarized in Table 2. As can be seen from the statistics in Fig. 3, there are issues or combinations that have not been fully discussed. Of these, post-classification (with only 2 instances) attracted the attention of this study's researchers, and thus, this paper proposes a new approach based on post-classification to further improve the accuracy of job cycle time estimation.

Chen et al. [25] proposed an approach based on post-classification in which a back propagation network (BPN) was applied to estimate the cycle time of a job, after which jobs were sorted according to their estimation errors. The first half of the

Table 2
A summary of studies using job classification.

Reference	Issues
Chen [1], Chang et al. [17]	Fuzzification
SOM-BPN [18], SOM-FBPN [20], kM-FBPN [21]	Normalization + Job classification
Chen [23]	Partial normalization + Job classification + Error feedback
Chen [24]	Ensemble + Aggregation
Chen et al. [25]	Normalization + Post-classification
Chen [26]	Normalization + Job classification + Post-classification
Chien et al. [22]	Iteration + Error feedback
Chen and Wang [27]	Partial normalization + Job classification + Iteration + Error feedback
Chen [28]	Partial normalization + Ensemble + Aggregation + Iteration
Chen and Romanowski [29]	Variable replacement + Partial normalization + Job classification