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A simulation-based optimization approach for a semiconductor photobay with automated material handling system

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ABSTRACT

This study addressed the issue of automated material handling systems (AMHS) in the photolithography zone of a 300 mm (12-in.) wafer fab facility. The lithography process accounts for 40–50% of the time required to produce wafers. Therefore, managing the AMHS in the photolithography zone is a challenging task. This paper examines the dispatching rule and the number of vehicles in variable wafer input cases. With a stochastic and complex manufacturing process, a photobay simulation may lead to excessive iterations and wasted computation time. The most frequently used approach for process management in the literature is performance analysis with a model that simulates each alternative for *N* times. However, this approach becomes time consuming as the number of variables and iterations increases. To address this issue, we use Optimal Computing Budget Allocation (OCBA) and extend OCBA by adding particle swarm optimization (PSO). With this combined approached, the number of iterations of each alternative is determined by OCBA, and the optimal solution in the domain of feasible solutions is identified through PSO. This research provides a useful reference to optimally allocate lithographical resources and the number of iterations with random parameters for both scholars and practitioners. Results demonstrate the superiority of PSO_{OCBA} in terms of searching quality and robustness.

1. Introduction

With the rapid development of the semiconductor industry, wafer manufacturing has moved from the 200 mm (8-in.) and 300 mm (12-in.) standards to the 400 mm (16-in.) standard. Currently, most wafer fab facilities manufacture 300 mm wafers [44]. The semiconductor industry involves wafer integrated circuit (IC) design, mask production, wafer fab, packaging, and wafer probing. The most complicated of these processes is wafer fab, as it typically requires 200–300 entries, with a wafer being moved frequently between machines. Thus, wafer handling plays a crucial role in wafer fab. In addition, the front opening unified pod (FOUP) weighs about 9.1 kg, making it difficult to handle. Entries and re-entries make wafer fab extremely complicated, and the laborious handling inevitably leads to error. Mönch et al. [29] concluded that in the future various specific properties of modern AMHS have to be taken into consideration more precisely so that more precise planning solutions can be found. In pursuit of greater handling efficiency, developing an effective automated material handling system (AMHS) is an issue worthy of discussion. (Jimenez et al. [12] and Montoya-Torres [31] for more details on AMHS

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in semiconductor manufacturing) In general, 40–50% of wafer fab processing time is spent on photolithography [26]. The AMHS process within the photobay is very important. Photolithography is a highly reentrant process, creating an imbalance in handling requirements. Increasing handling requirements in the photobay, such as for semiconductor fab, leads to the increased need for AMHS and control. This research, which is focused on the AMHS, is conducted by carrying out a simulation analysis and a performance analysis, including the analysis of management issues such as dispatching rules for vehicle and machine control. An effective approach is to create a simulation-based optimization model for an AMHS and to compare results under different conditions.

In practical settings, vehicle allocation in the AMHS is a difficult task because of the complexity, uncertainty, randomness, and unpredictability of production. Although too few vehicles cannot meet the material handling requirement, too many vehicles increase traffic intensity, resulting in blockage or even in deadlock; thus, more energy is consumed. A non-trivial trade-off exists. Thus, when facing a large number of vehicles, the manufacturing execution system (MES) and material control system (MCS) should be designed with a control mechanism to prevent problems such as collision or deadlock [14,15,22,25]. Lin et al. [21] categorized four handling behaviors of cassettes in interbay and intrabay systems, forming the four concepts associated with various vehicle category combinations. Lin et al. [22] expanded their previous research (2003) by calculating the number of vehicles required for each category. In terms of the demand for empty vehicles, the minimal distance for empty vehicle procession was introduced by Maxwell and Muckstadt [27], enabling the calculation of the number of vehicles. Hsieh et al. [10] proposed a segmented dual-track bidirectional loop (SDTBL) design for an AMHS. The examined segmentation strategies result in reduced cycle times and increased stocker utilization while the throughput remains the same. Huang et al. [11] specified the vehicle allocation problem in a typical 300 mm wafer fab as a simulation optimization problem. In particular, they found that the number of vehicles in AMHS can significantly affect the overall performance. Furthermore, the optimum design alternative of vehicle numbers in the interbay and intrabay systems can be obtained through simulation optimization methods. Therefore, the vehicle number allocation is an important component of the AMHS in wafer fab facilities.

Dispatching rule, traffic management, empty trip, and congestion are also factors affecting AMHS performance. Previous research on vehicle dispatching problems has been conducted through simulation analysis to improve system performance [17,23,44,26]. Automatic guided vehicle dispatching is widely addressed in the literature on the AMHS of job shop manufacturing. Egbelu and Tanchoco [8] divided the vehicle dispatching decisions into two categories: work center-initiated task assignment and vehicle-initiated task assignment. They showed that in a busy shop, the vehicle-initiated rule has a more significant effect on system performance than the work center-initiated rule. Egbelu [7] further compared the performance of a demand-driven rule and several source-driven rules in a batch manufacturing system. The demand-driven rule is comparable with source-driven rules. Lin et al. [23] presented a performance evaluation of a double-loop interbay AMHS in a wafer fab, considering the effects of the dispatching rules. The combination of the shortest distance (SD) with the nearest vehicle (NV) and the first-encounter-first-serve (FEFS) rule outperformed the other rules. Therefore, an optimal AMHS system design with efficient control strategies will enhance production performance as well as the movement performance of lot and vehicle.

In the existing literature, AMHS performance is assessed based on either an analytical model (e.g., [35,34] or a simulation model (e.g., [41,20]. Ting and Tanchoco [42] used an analytical approach to develop optimal single-spine and double-spine overhead track layouts and to minimize travel distance. They also indicated that the simplicity, track length, and flow distances of the spine layout made it suitable for a 300 mm fab. The analytical models, either deterministic optimization models or queuing models, are developed based on certain assumptions [35], such as the response time that is independent of the move's original location. Hence, such models may not be applicable to problems wherein these assumptions do not hold (or at least are not verifiable). Montoya-Torres and Gonzales [33] proposed an integer linear program to determine the location (or positioning) of vehicles that minimizes the maximum time needed to serve a transport request. By contrast, discrete event simulation has been known as a powerful tool in analyzing manufacturing system performance. Through simulation, Pierce and Stafford [36] studied three types of interbay layout: spine, perimeter, and custom track systems. The custom layout had a 16% more efficient delivery time than the spine layout, and the perimeter layout had the worst performance in terms of delivery time, vehicle utilization, and track length requirement. Wang and Lin [43] presented the behavior of inter-arrival time for all stockers from a real data set to verify the assumption of the simulation model. They found that for most stockers, inter-arrival times belong to the exponential or Weibull distribution. In addition, their simulation results show that the number of vehicles significantly affects the average delivery time and the average throughput. Scholl et al. [37] ignored transports and their durations are simply modeled as distribution functions in fab simulations. Miller et al. [28] developed the simulation models to discuss the design and test of conveyor-based AMHS configurations with emphasis on comparing centralized versus distributed storage systems, which include turntables and storage areas near the processing equipment. The advantage of the simulation approach is that it can consider all important details of the manufacturing process and yield better estimates for the performance measure of interest. Numerous issues related to simulation-based AMHS studies have been raised, including high variability and randomness. Few researchers have addressed the simulation optimization issue, such as determining the optimal design alternative that includes the relationship among wafer inputs, dispatching rules, and vehicle numbers. For complex problems, simulation may be time consuming because of the numerous iterations and possible design alternatives. Therefore, determining the optimal design alternative while maintaining efficiency is a crucial issue in AMHS applications.