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A SIMULATION-BASED APPROACH FOR AN EFFECTIVE AMHS DESIGN IN A LEGACY SEMICONDUCTOR MANUFACTURING FACILITY

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ABSTRACT

This paper addresses the design of an Automated Material Handling System (AMHS) for wafer lots in the photolithography workshop of a 200mm wafer manufacturing facility (fab) that was not initially built to have such a system. Lots transportation has to be performed using an Overhead Hoist Transport (OHT) system that was already chosen to transport reticles in the workshop. The main objective is to propose a decision support tool to characterize the AMHS elements including lot handling, transportation as well as the storage space design. A simulation-based approach is proposed to evaluate different scenarios and propose an effective AMHS design. Experimental results based on real instances confirm the capability of the proposed AMHS design to support the workshop activity.

1 INTRODUCTION

After the migration in the semiconductor manufacturing from High Volume-Low Mix to Low Volume-High Mix, 200mm wafer manufacturing facilities (fabs) have encountered many challenges to remain on the competitive edge. Typical 200mm fabs were built in the last 1990s without incorporating the automated handling tools to transfer the parts through their complex production process. Establishing an automated handling system in such previously-built fabs renders chip producers to various constraints such as space limitation, clean rooms requirements and technology of production tools. Accordingly, the considered 200mm fab operates in a semi-automated mode; meaning that the lot transportation and storage are performed by operators, however, lot loading/unloading and production tool setting are automated. Corresponding decision makers (DMs) start modernizing their 200mm fabs in order to integrate an AMHS into the existing infrastructure to serve the current production system. DMs start this integration from the bottleneck area in 200mm fab, namely photolithography. An operation of a lot in this area requires an auxiliary resource called a reticle for processing.

The remainder of this paper is organized as follows. A literature review is illustrated in Section 2. In Section 3, we present the problem statement. Section 4 is dedicated to the description of the simulation-based approach used to solve the problem. Simulation results and analysis are summarized in Section 5. Section 6 analyzes the interaction between the transport of lots and reticles. Conclusions are given in Section 7.

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2 LITERATURE REVIEW

2.1 Handling Automation in 200mm Fabs

Several papers focused on the problem of AMHS capacity, design and performance improvement in 300mm fabs using the simulation tool (Chang, Huang, and Yang 2014a). However, there are few papers investigating these issues for 200mm fabs that mostly operate in a manual handling mode and need an upgrade by the AMHS integration. Miller, Menser, and Gustafson (2004) described the challenge of AMHS integration in a working IBM 200mm fab. The authors claimed the opportunity to improve the fab performance thanks to the automation. However, the paper does not provide details on AMHS design. A simulation-based cost modeling methodology was developed by Murray et al. (2000) to evaluate the automation benefits of an existing fab. The comparison between manual handling and AMHS clearly favors AMHS by examining the financial issues. Recently, Ben-Salem et al. (2016) discussed the design of AMHS based OHT for reticles in a 200mm fab by developing a simulation model to characterize OHT components and to evaluate the benefits of the automated transportation and storage.

2.2 AMHS Design in Wafer Fabs

The OHT system is characterized by a tracks (rails) network at the ceiling and a fleet of vehicles traveling under tracks to perform material transport. The determination of the fleet size had been widely addressed in the literature. Chang, Huang, and Yang (2014a) proposed a discrete-event simulation tool to find the required number of vehicles. The authors performed several scenarios in order to evaluate the AMHS performance. A combined simulation optimization method was used in Chang, Chang, and Kuo (2014b) to determine the optimal fleet size. They proposed a multi-objective formulation. Ndiaye et al. (2016) discussed the design of an AMHS based Automated Guided Vehicle (AGV). The authors used a simulation-based approach to determine the fleet size and the best layout configuration. They performed several experiments and evaluated the impact of the number of vehicles on the transportation service performance. In this paper, a simulation approach is used to design the AMHS in the photolithography workshop of a 200mm fab as in Ndiaye et al. (2016). Different from the above references, in this paper, we investigate the design of an AMHS for wafer lots using an OHT already proposed for reticles transport. In fact, the interaction between the transport of lots and reticles needs to be characterized to evaluate the impact on the performance of the photolithography workshop.

2.3 Storage Management in Wafer Fabs

Research papers mainly focus on the inter-bay storage using central big stockers with a high capacity. In this context, many problems linked to the characteristics of big stockers were investigated using simulation based approaches: determination of the stocker dimensions (Cardarelli and Pelagagge 1995) and the configuration of the central stockers (Miller et al. 2011). Despite same advantages of centralized big storage (e.g. large capacity), such a system is a potential bottleneck because of the handling time under a stocker. Today, in modern fabs, unitary stockers (or Overhead Hoist Buffer (OHB)) are used. Given that OHBs are placed at rails and directly accessible by vehicles. Thus, an efficient management of such a system leads to a reduction of the access time compared to big stockers. In the literature, this issue is not widely investigated. Dauzère-Pérès et al. (2012) focused on the definition of OHB sets assigned to production tools sets in a unified 300mm fab. A Mixed Integer Linear Programming (MILP) model was proposed to optimize the OHBs allocation to production tools. However, the proposed MILP is limited and cannot be used for real instances since the computing time is huge. A new layout of rails called “Dual Unified OHT (DUO)” was proposed by Han et al. (2006) to enhance the delivery time and reduce traffic problems.

3 PROBLEM STATEMENT

In the considered photolithography area lots and reticles are manually handled. There are more than 4000 reticles, and when they are not used, pods (multi-reticles containers) are stored in specific locations. Lots are transported by operators and stored at shelves. Given this high number, handling tasks are tedious and challenging. In fact, lots and reticles management requires physical efforts and continuous concentration of operators to verify that the right reticle or lot is properly delivered to the right tool at the right time. To handle this problem, the integration of AMHS based OHT system was already decided to automate the transportation of reticles (Ben-Salem et al. 2016). In this paper, we focus on the lot transportation problem using the same OHT system.

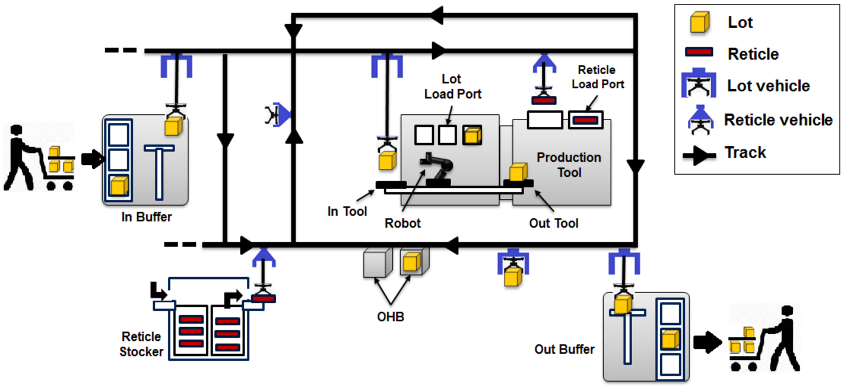

Figure 1: AMHS in the photolithography workshop.

Figure 1 represents the schematic of AMHS in the photolithography workshop. To enter lots to the workshop, an “In-Buffer” system (with a limited capacity of X lots, X is integer between 10 and 12) is used to receive the arriving lots from other workshops and brings them one by one from the buffer to a single position (high position) directly accessible by vehicles. Then, a vehicle that can transport a single lot is assigned to take the lot from the In-Buffer system to Overhead Hoist Buffer (OHB). The lot remains in OHB until its release date for processing. At this moment, the lot is transported from OHB to the production tool. Due to technical constraints linked to the production tools technology, vehicles transporting a lot cannot directly access the load port. To handle this issue, a robot system, called “Side Loader”, will be implemented for each tool to transport the lot from an “In Tool” position to the load port. When a reticle is required, a vehicle picks-up this reticle from the reticles stocker and transports it to the production tool. Then, the reticle is directly dropped-off on the load port. When the reticle is no longer needed, it has to be transported from the production tool to the stocker. At the end of the photolithography operation, the Side Loader transports the lot from the load port to an “Out Tool” position. After that, a vehicle has to transport the lot to an “Out-Buffer” system that allows receiving the lot from the vehicle at the high position and put it in a buffer. Finally, the operator has to pick-up lots from the buffer in order to free up the place for other incoming lots.

In this paper, the challenge is to develop a relevant AMHS design that can meet the large need for transportation in the photolithography workshop. In fact, we have to ensure that such system can perform the same activity volume. In fact, the solution for automated transport has to support at least more 65 lots to process per tool per day performed by the current manual handling system (operator). For this, we have to characterize the AMHS elements. Moreover, the interaction between the transport of lots and reticles has to be also addressed to evaluate the transportation efficiency and to avoid productivity decrease which has never been discussed in the literature.

4 SIMULATION-BASED APPROACH

Discrete Event (DE) may seem an appropriate method for modeling the described OHT transport problem. But since DE is based on predetermined static information, it is generally expensive and time-consuming to develop large scale systems. Agent-Based (AB) approach seems more flexible, looks to be a suitable method for modeling large scale manufacturing systems. But the concept of queue which is the most important part of manufacturing systems is not defined in an AB method. Accordingly, a simulation method which is flexible such as AB and covers queueing concepts such as a DE method is developed for modeling the problem. Combining AB and DE simulations can be done two ways as presented in Figure 2: (a) Process inside agents can be designed using event simulation; (b) In some systems modeled by DE, entities have different plans and strategies in using the system, thus they can be defined as agents which are active entities (Sadeghi, Dauzère-Pérès, and Yugma 2016). In this study, a simulation model, that combine DE-AB approaches by integrating both ways, was developed using Anylogic software. The model is alimented by real instances of the Work-In-Process (WIP) that provide process and scheduling parameters (the triple (lot ID, reticle ID, Tool ID), processing time…).

(a) (b)

Figure 2: Two ways to combine AB and DE simulation methods.

4.1 Simulation Model Structure

For confidential reasons, we cannot show the workshop configuration. Figure 3 presents the simulation model structure.

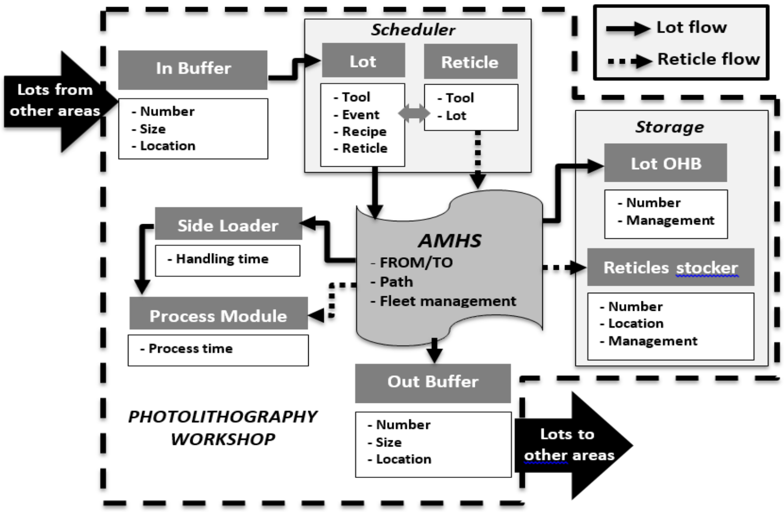

Figure 3: The structure of the simulation model.

The AMHS at the center of the model structure performs transportation requests for scheduled lots and reticles. The from/to matrix provides the couple (origin/destination) for each transport request. In addition, we modeled the storage process for both lots (OHB) and reticles (stockers). Production tools (tracks and scanners) are modeled by including the processing time for lots without considering operation details (handling operations) inside the machines. Experiments are performed by considering one factor each time (fleet size, "In-Buffer" number, etc.). Developing a model that includes the production and storage as well as AMHS issue is a challenging task. We address the global problem including transport and storage to evaluate their impact on the workshop productivity.

4.2 Simulation Model Validation

AMHS has to perform the transportation of lots and reticles instead of operators. Thus, we have to ensure that the model control (reticle location, destination, lots scheduling, etc.) is logically respected. Even though any AMHS cannot be separated from the production system, control interface of delivery mission can be dissociated from the production controller. For reticles delivery, we validated the simulation model by comparing the real matrix of from/to reticle movement with the simulation outcomes as presented in Table 1 (with X and Y are integer numbers). Moreover, lots and reticles scheduling on production tools (the triple (lot, reticle, tool)) enabled us to verify that the production planning was respected in the model compared to the real planning in the workshop. Also, the real performance indicators of the photolithography tools are compared with the model statistics as shown in Table 2. Based on several similar illustrations, we can validate the simulation model.

Table 1: The from–to distance (upper position, meters) and arrival rate (lower position, total reticle moves) between tools and storage area.

		From				
		T01	***T02***	***T03***	**…**	***Stocker 1***
To	***T01***	-	5.78X -	2.2X Y	…	66.98X 1181Y
	T02	5.78X -	-	5.65X 17Y	…	61.36X 1253Y
	…	…	…	…	…	…

Table 2: A comparison between real tools performance and model statistics.

Indicator		**Tool** ***T09***	 ***T17***	 **…**	**Total throughput** **Average utilization**	**Error (%)**
Throughput (lots)	Model	295	438	…	5976	1.02
	Reality	298	442	…	6038	
Average utilization (%)	Model	83.8	84.88	…	89.91	1.04
	Reality	83.92	84.94	…	90.86	

4.3 Simulation Parameters and Performance Indicators

The simulation horizon is set to 28 days and the simulation duration is around 10 minutes that was enough to reach the steady state. For each simulation run, three independent replications are performed. Table 3 summarizes the basic system parameters for simulation experiments. The AMHS parameters are mainly derived from the characteristics of the real system. Regarding the production tools, the real parameters (the throughput, the number of load port, etc.) of the existing tools in the fab are considered. A set of key indicators related to both delivery missions and area performances are selected in order to evaluate the AMHS design: (1) the delivery mission parameters: three types of delivery requests are considered (D1): from In-Buffer to OHB, (D2): from OHB to Production Tool and (D3): from Production Tool to Out-Buffer. Each request type can be divided into three delivery steps: the assignment time required to find an idle vehicle to execute the delivery (AT), the movement time of a vehicle to pick-up the lot (MT) and the travel time of the vehicle with the lot (TT), (2) the mean utilization rate of vehicles and (3) the photolithography area throughput (number of processed lots).

Table 3: Basic system parameters.

AMHS component	**Parameter**	**Value**
Vehicle	Number of vehicles (for lots, for reticles)	(14, 8)
	Max speed (meter/second)	3.33
	Loading time (seconds)	5
	Unloading time (seconds)	5.2
	Hoist time (seconds)	8.6
In-Buffer	Number	3
	Handling time (seconds)	10
Out-Buffer	Number	2
	Handling time (seconds)	60
OHB	Number	1000
Reticle stockers	Number	3
	Handling time (seconds)	Between 10 to 100
Side Loader	Handling time (seconds)	20

5 RESULTS AND ANALYSIS

5.1 Fleet Size and Management

The selected supplier for OHT system proposes only one dispatching policy for vehicles. This policy mainly consists of assigning the same vehicles to a specific tools bay (zone). Thus, only vehicles assigned to this bay can perform the transport requests under the considered bay. Two mains scenarios are evaluated: the case of 2 zones (or bays) and the case of 3 zones. Simulation results are presented in Figure 4. It is clear, from Figure 4, that vehicles assignment to 3 zones reduces the delivery time compared to the case of 2 zones whenever the number of vehicles changes. Moreover, more appropriate vehicles utilization is observed while considering 3 zones instead of 2 zones. As a matter of fact, in the case of 3 zones, vehicles have to travel a lower distance to perform a delivery mission compared to the case of 2 zones. In fact, the assignment and the travel time of vehicles are reduced in the case of 3 zones compared to only 2 zones.

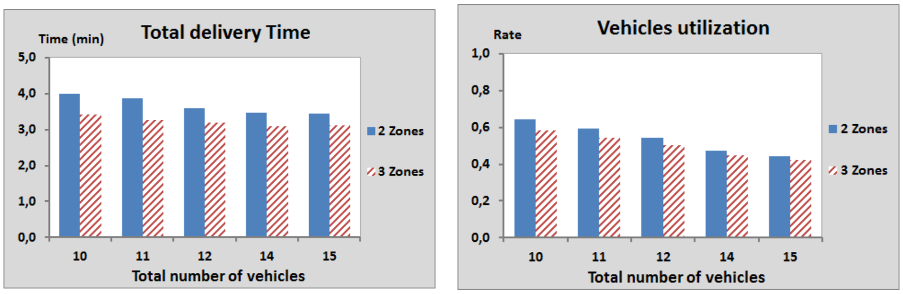

Figure 4: The total delivery time and vehicles utilization for different vehicles number: case of 2, 3 zones.

With regard to the fleet size, initially, the formula (1) is proposed as in Ndiaye et al. (2016) to determine the minimum number of vehicles needed to meet the transport demand.

$$NV_{\min} = \frac{\sum_{ij} d_{ij} \cdot \bar{t}_{ij}}{T} \tag{1}$$

Where T: represents the considered period, i, j ($i \neq j$) are locations (stockers or machines) considered as origins and destinations for vehicles, dij represents the total number of movement (loading/unloading) from i to j in the period T and tij : accounts for the loaded travel between i and j, unload and load times.

The calculation shows that, at least, 10 vehicles are required to satisfy the transport need without decreasing the productivity. Simulation results from Table 4 indicate that the variability of the assignment time is reduced when the number of vehicles increases. Figure 5 depicts the delivery time for all types of transport request for different numbers of vehicles. Generally, we note that increasing the number of vehicles leads to a reduction in the delivery time. Figure 5 shows that from 14 vehicles adding vehicles has no significant reduction in the delivery time.

Table 4: The mean and standard deviation of the assignment time.

Number of vehicles	**AT(1) (minute)**		**AT(2) (minute)**		**AT(3) (minute)**	
	Mean	***Sta. Dev.***	***Mean***	***Sta. Dev.***	***Mean***	***Sta. Dev.***
10	0.232	0.429	0.187	0.427	0.218	0.456
11	0.183	0.409	0.147	0.397	0.104	0.439
12	0.095	0.247	0.068	0.218	0.075	0.237
13	0.051	0.186	0.36	0.142	0.034	0.233
14	0.039	0.147	0.027	0.126	0.028	0.23
15	0.038	0.126	0.026	0.109	0.028	0.2

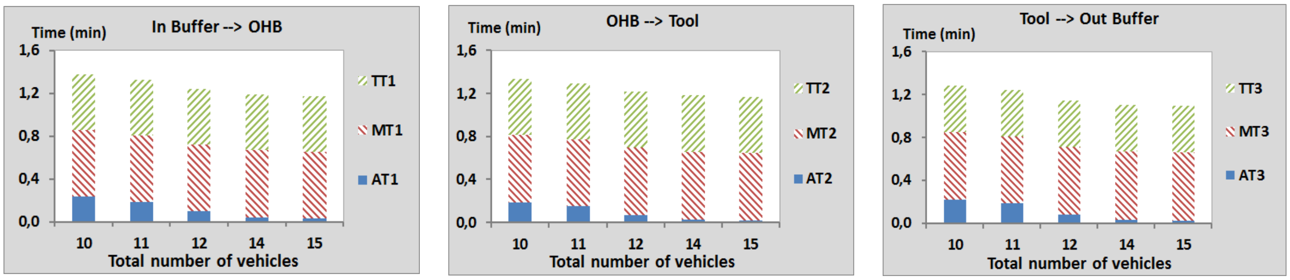

Figure 5: The delivery time for different number of vehicles and different types of transport request.

With respect to other AMHS elements, simulation outcomes, presented in Table 5, illustrate the variation of the entering time of lots in the three "In-Buffers" for a different number of vehicles.

Table 5: The entering time for lots in "In-Buffers" for different number of vehicles.

Number of vehicles	**Time to enter a lot (minute) (In-Buffer 1; In-Buffer 2; In-Buffer 3)**	
	Mean	***Sta. Dev.***
10	(1.56; 2.1; 2.02)	(1.35; 1.55; 1.5)
11	(1.47; 2.03; 1.96)	(1.3; 1.49; 1.44)
12	(1.38; 1.91; 1.82)	(1.12; 1.35; 1.28)
13	(1.34; 1.89; 1.81)	(1.09; 1.32; 1.26)
14	(1.3; 1.86; 1.77)	(1.03; 1.27; 1.21)
15	(1.29; 1.86; 1.77)	(1.02; 1.26; 1.2)

We remark that the required time to enter a lot from "In-Buffer" is reduced when adding more vehicles, in addition to the variability reduction. That is because more idle vehicles are available to pick-up the lot from "In-Buffer". With 14 vehicles, there is no signification gain on time to enter a lot is observed. Based on the above results and analysis, a decision to consider only 14 vehicles was taken instead of 20 vehicles that was decided before this simulation study.

5.2 Number of In and Out-Buffer Systems

Let us start with “In-Buffers”. Table 6 shows the results obtained for different handling times in the case of 2 and 3 “In-Buffers” with the same total capacity of buffers. Note that the time to enter a lot represents the difference between the date when the lot is put in the buffer and the date when a lot is transported to the high position. A general observation, from Table 6, is that increasing the handling time of the “In-Buffer” system by 10 seconds leads to an increase of 25 seconds (an increase of 150%) in the average time to enter a lot. In fact, lots have to wait a longer time at the In-Buffer when increasing handling time. Moreover, workload (lots entering) is better split in the case of 3 In-Buffers compared to only 2 In-Buffer, which leads to a slight reduction in the time to enter a lot. This means that lots entering process is faster and more fluid, which requires a faster assignment of vehicles to pick-up lots from the high position. Furthermore, the vehicles assignment time has been doubled when adding a third In-Buffer system as shown in Figure 6. From the above analysis, a decision to implement 3 “In-Buffers” was taken while setting a handling time target of lower than 20 seconds.

Table 6: The average time to enter a lot for 2 and 3 “In-Buffer” for the basic system parameters.

Handling Time (second)	**Average time to enter a lot (minute)**	
	2 In-Buffers	**3 In-Buffers**
10	1.69	1.64
20	2.13	2
30	2.6	2.5

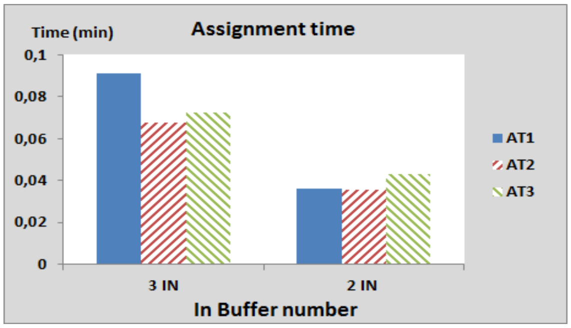

Figure 6: The assignment time for 2 and 3 In-Buffer.

With respect to “Out-Buffers”, as for “In-Buffers”, the number and the handling time have a significant impact on the time to exit a lot as shown in Table 7. Based on these results, three “Out-Buffer” systems will be implemented in the photolithography workshop to reduce the time to exit a lot. Note that no significant effect on the assignment time of vehicles was observed for 2 or 3 “Out-Buffers”.

Table 7: The time to exit a lot for 2 and 3 In-Buffer.

Handling Time (seconds)	**Average time to exit a lot (minutes)**	
	2 In-Buffers	**3 In-Buffers**
60	1.25	1.2
120	2.32	2.2
240	4.42	4.2

5.3 Storage Strategy

The goal of this section is to define the way that lots have to be assigned to OHBs which may impact the delivery time. Two assignment heuristics have been proposed.

5.3.1 Random Assignment Heuristic

A lot is randomly assigned to an OHB whenever in the workshop and no particular rules are implemented. Figure 7 is a screenshot from the model that represents the evolution of the number of occupied OHBs over time. For the considered WIP instances, the required number of OHBs can be directly determined from the graph peak (red circle). From Figure 7, the storage capacity should be around 760 OHBs.

Figure 7: The number of occupied OHB over time.

5.3.2 Nearest Assignment Heuristic

Now, using the same setting as for random assignment (i.e. number of OHBs), the key idea consists of assigning a set of OHBs to a set of production tools (Fischmann et al. 2008). The assignment rules of OHB sets to the production tool sets were based on many criteria such as OHBs location. To explain, when a tool is qualified to process a lot, this lot is automatically transported to one of OHB set assigned to this tool. If there is no idle position in the OHB set assigned to this tool, the lot will be transported to a backup OHB set. Simulation results presented in Figure 8 show that the nearest assignment heuristic reduces the delivery time.

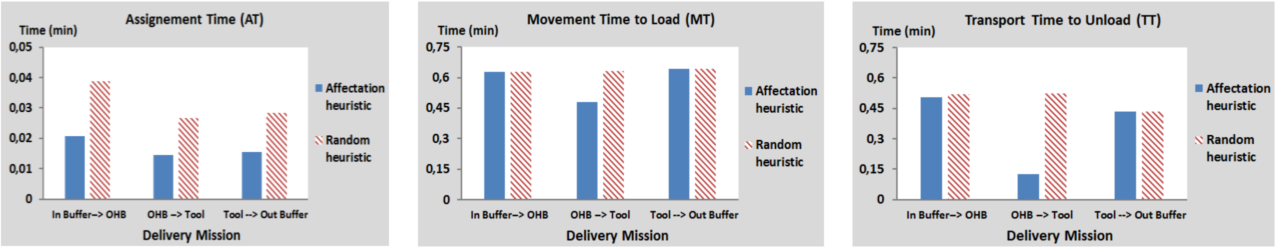

Figure 8: The delivery time for different type of transport: case of random and nearest assignment policy.

From Figure 8, we observe a gain up to 50% of the assignment time (AT) obtained with the nearest assignment heuristic compared to the random heuristic. Moreover, Figure 8 confirms that vehicles spend less time to transport a lot from OHB to the production tool in the case of nearest assignment heuristic compared to the random one. This is due to the locations of assigned OHB sets that are closed enough to tool sets. In another side, for both type of transport (In-Buffer → OHB and Tool → Out-Buffer), the average values of (MT) and (TT) have not significantly changed in the case of nearest assignment and random heuristics. In fact, the locations of In-Buffer, Out-Buffer, OHBs and tools have not changed.

Now, we aim to limit the storage cost by reducing the number of OHBs to increase Return-On-Investment (ROI). In any case, this must not degrade the workshop Key Performance Indicators (KPI): the delivery times and the number of completed wafers. Table 8 summarizes the results obtained when limiting the number of OHBs. From Table 8, the main conclusion is that when the number of OHBs is limited to 400, the productivity performance (number of processed lots (activity volume) and average utilization rate of tools) is degraded compared to the productivity using manual handling system (operators). Moreover, in Table 8, we illustrate the average number of lots that were blocked in the queue at the workshop entrance (before In-Buffer system). Results affirm that limiting the number of OHBs may lead to a high increase in the number of lots to store at the upstream workshops. This phenomenon needs to be noticed carefully to avoid storage capacity problems.

Table 8: The effect of OHBs number.

Case	**Number of OHBs**	**% of activity volume performed**	**Average utilization rate of tools**	**Average number of lots in the queue**
Basic	1000	100%	89.91%	0
2	600	100%	89.91%	56.77
3	500	100%	89.91%	541.99
4	400	82%	72.45%	3493.88

6 INTERACTION BETWEEN LOTS AND RETICLES TRANSPORT

To transport lots and reticles, two different fleets of vehicles have to travel around the same tracks network. This can lead to a reduction in the investment cost. However, the interaction between the transport of lots and reticles should be addressed. Table 9 shows the different traffic parameters chosen to evaluate the vehicles traffic. Note that, for reticles, the location of stockers had a significant impact on the vehicle traffic. In Table 9, the results obtained for the best scenario of stockers' locations are presented. Given the traffic targets fixed by consulting another company fab and supplier recommendations, we confirm the effectiveness of the proposed OHT design under these traffic conditions.

Table 9: Simulation results for different configurations of storage location.

Lots traffic (vehicle/track/minute)		**Reticles traffic (vehicle/track/minute)**		**% Network used by vehicles**
Max traffic rate	***Mean traffic rate***	***Max traffic rate***	***Mean traffic rate***	
1.523	0.48	0.892	0.557	82.73%

Congestion problems in addition to other phenomena may impact delivery time for reticles and lots. For the production process in the photolithography workshop, a time windows is defined to perform two transport requests (1) Picking-up the processed lot from the load port of the production tool and carrying it to the next destination, (2) Picking-up the new lot to be processed from its origin location and carrying it to the load port of the production tool. Similarly, for reticles, the nature of the photolithography operation (see Section 1) involves a time windows to change a reticle. For confidential reasons, the values of the time windows for reticles and lots cannot be mentioned.

From the histograms of lots and reticle delivery times illustrated in Figure 9, we notice that for both lots and reticles, about 80% of the delivery mission are performed in only 120 seconds. Furthermore, the maximum delivery time is around 240 seconds and 300 seconds for lots and reticles, respectively. Let us start with lots delivery, by considering the diagram of delivery time, the proposed AMHS design was able to perform transport service without loss of productivity. In fact, the number of processed lots was not degraded when considering the AMHS compared to operators. Regarding reticules, as already explained in Section 1, when a lot is starting the first process step at the production tool, the required reticle has around 5 minutes to be transported in order to start the second process step. Considering this time windows imposed by the process nature, we can confirm that the delivery process of reticles will not also degrade the workshop productivity.

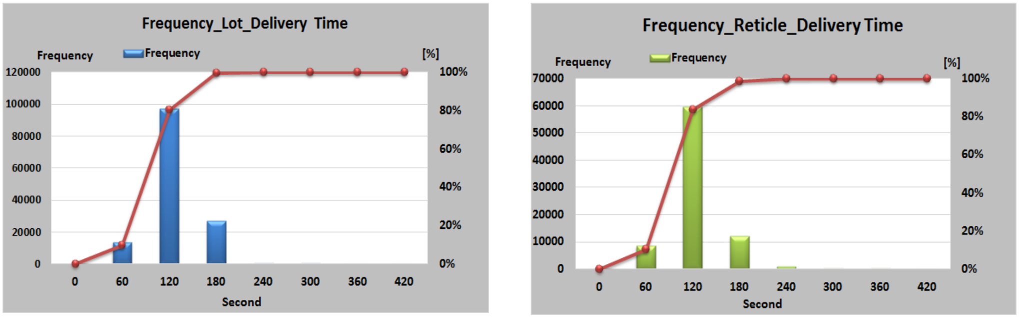

Figure 9: Histograms of the delivery time for lots and reticules.

7 CONCLUSION

In this paper, the main challenge was to develop an effective AMHS design for wafer lots in the photolithography workshop of a 200mm wafer fab that was not initially built to have such a system. A simulation combining Discrete Event and Agent-Based approach is proposed to solve the problem. This approach allowed proposing a relevant design by the evaluation of several scenarios, and to anticipate problems (e.g. the effect of the limitation of the storage capacity) before the real implementation of the AMHS. Moreover, a significant reduction in the investment cost was provided.

The AMHS components such as the fleet of vehicles and storage spaces were characterized based on in-depth analysis of simulation results. With regard to the storage process, results obtained demonstrated the importance of way that lots are assigned to the storage space and the impact of the storage capacity on the workshop performance. Thanks to our simulation approach, an in-depth analysis was performed to measure the interaction between the transport of lots and reticles since they share the same rail network.

We are currently looking for proposing an efficient heuristic for reducing the high quantity of lots in the queue at the entrance of the workshop when considering a limit storage capacity.

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