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ANALYZING THE IMPACT OF KEY PARAMETERS OF VEHICLE MANAGEMENT POLICIES IN A UNIFIED AMHS

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ABSTRACT

This paper deals with the management of vehicles in the Automated Material Handling System of a semiconductor wafer fabrication facility. Vehicle management policies (allocation of vehicles to transport requests, positioning of idle vehicles,...) strongly impact critical performance indicators, among them the allocation time (delivery time) and the lot cycle time. In the literature, most studies on the impact of vehicle policies on delivery times focused on segregated layouts and generally do not consider minimum service transport policies. We investigate a minimum service policy which consists in keeping a minimum number of available vehicles in bays to quickly answer transport requests. After describing the transport policy, we investigate how to define its key parameters. Using a detailed discrete event simulation model of a real semiconductor manufacturing facility, various simulation studies are performed to analyze the impact of these parameters.

1 INTRODUCTION

In a semiconductor wafer fabrication facility (fab), hundreds of machines are available in a large area. Moreover, wafers require several hundreds of steps to be completed, and are coming back many times (up to 40) to the same work area. Hence, wafers travel a long distance during their manufacturing process. Moving wafers between machines is thus very frequent and has been automated when the wafer diameter moved from 200mm to 300mm. Wafers are grouped to be produced and transported in lots of at most 25 wafers. Multiple reasons motivated the idea of automated transportation to replace human operators.

- Physical constraints: Carrying lots that are relatively heavy, is tricky. It is a delicate task that affects the physical capacity of operators and may lead to accidents (damaging wafers during a fall).
- Economic constraints: For a 300mm diameter, a wafer costs between 3,000 and 4,500 dollars. This high cost requires to have a reliable system that ensures priority, integrity and wafer protection. Adding to relatively expensive labor costs, semiconductor companies struggle to make products that can compete in terms of price. Thus, the need to automate the production was a necessity in order to reduce payroll and ensure competitiveness.

In addition, a semiconductor manufacturing facility is very expensive (average cost of 3 billion dollars for a 300mm fab). This is why it is a priority to optimize the return on investment. It is also important that the automated transportation system guarantees reliable and repeatable service. Repeatability means the capacity of the vehicles to perform the same task in the same conditions. Reliability means the ability of the transport system to guarantee a given delivery time.

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A lot of wafers undergoes three types of actions: Processing, transportation and storage. Hence, the AMHS is required to move, store and help in the processing of a lot. The performance of the fab is linked to the architecture of the AMHS (number of vehicles, ...), the layout of the fab and the rules implemented in the transport management system. As already written, when managing a fleet of transport vehicles in a manufacturing facility, the goal is to guarantee reliable and fast transport times. To reach these objectives, we focus on the management of vehicles (vehicle policies). More precisely, based on a full-scale fab simulation model, we study the impact on the delivery time of key parameters of a ”minimum service” transport policy. The objective of a ”minimum service” policy is to ensure that, in each area, there is at least a specified number of vehicles and there is at most another specified number of vehicles to avoid idle vehicles and balance vehicles between areas.

The remainder of this paper is organized as follows. Section 2 gives a brief overview of the literature on AMHS and vehicle management. Section 3 describes the features of the ”minimum service” transport policy. Sections 4 and 5 focus on the study of the impact of key parameters of this transport policy on the delivery time. Section 6 concludes the paper.

2 LITERATURE REVIEW

In the literature, most studies on the impact of vehicle policies on delivery times focused on segregated layouts and generally do not consider minimum service transport policies. In fabs with segregated layouts, moving lots from a source to a destination requires three independent transport commands: One to leave the source area, one to travel along the central loop and, finally, one to move in the destination bay. Unified AMHS layouts are relatively recent, and less studied in the literature. Because vehicles are allowed to move everywhere in the fab, defining appropriate vehicle policies, such as the minimum service policy is important since, for example, all vehicles could be in the same area and not be able to quickly answer transport requests, see (Kiba et al. 2009).

Most authors in the literature consider ”classical” transport policies where vehicles are dispatched through the whole facility using dispatching rules to answer transport requests (Nazzal and McGinnis 2005). The drawback of these policies is that they cannot guarantee a minimal assignment time by allocating available vehicles ahead of time, because predicting the transport requests of each area is complicated. As semiconductor manufacturing processes are complex, planning the vehicle to select for a given transport request is difficult. The idea of minimum service is to try to ensure that, at all times, there are enough available vehicles in each area to quickly answer a transport request and to reduce vehicle assignment times, and thus lot delivery times. (Nazzal and McGinnis 2005), (Nazzal and McGinnis 2006), (Kahraman, Gosavi, and Oty 2008) and (Nazzal and McGinnis 2007) try to estimate allocation times using Markov chains. Conventional analytical models are considered to be unable to integrate the vehicle traffic density. (Hammel, Schmidt, and Schops 2012) provide a static model of a transport system using graph theory to track the system weakness and improve global performance indicators. The advantage of this method is the rapidity to get results from aggregated data, but the main drawback is the total absence of dynamics such as traffic jam and vehicle positions.

The research that addressed the management of vehicles is primarily based on mathematical models and simulation approaches with empirical estimates of the input data. At this stage, these studies are not applicable on an industrial case. (Wertz et al. 2008) and (Kiba et al. 2009) briefly explain the policy of balancing vehicles. This policy, based on the definition of a minimum and maximum number of available vehicles by area, manages the available transport resources. To ensure this, various criteria are mentioned such as the need for parking spaces to avoid cluttering the area. The advanced study by (Wertz et al. 2008) presents simulation results without specifying how to define the parameters of the vehicle policy (the number of vehicles by area, number of parking spaces, ...). (Kiba et al. 2009) study this policy through a partial modeling which guarantees the dynamic aspects of the transport system. The major drawback of this work is that the minimum service policy is partially modeled since vehicles are not allocated per area but for the whole fab, i.e. a vehicle can answer a transport request anywhere in the fab. This is different from the actual minimum service policy where vehicles can only serve the area in which they are located. In addition, a list of parking spaces is used where vehicles can go to be available to serve the corresponding area. This scenario is opportunistic and does not conform to the actual policy.

We want to show that optimizing the key parameters of the minimum service policy is very important to reduce the allocation time of vehicles. Establishing the relation between the allocation time and the number of transport requests is difficult. This is why we use discrete event simulation to model the dynamics of the system. In this paper, we model in details the minimum service policy in a detailed simulation model of a real 300mm semiconductor manufacturing facility that includes production, transportation and storage of lots.

3 THE MINIMUM SERVICE POLICY

The minimum service policy aims at logically managing transport resources to satisfy transport requests in each area of a unified fab.

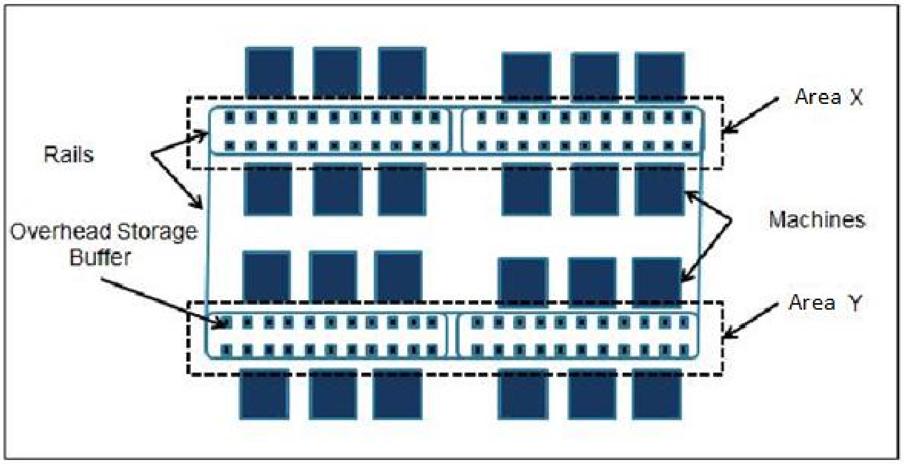

Figure 1: Examples of two areas in a semiconductor manufacturing facility.

Two areas X and Y are considered in Figure 1. Available vehicles in each area are managed using two key parameters:

- LWM (Low Water Mark): Minimum number of available vehicles that should be available in the area.
- HWM (High Water Mark): Maximum number of vehicle that should be available in the area.

The policy works as follows. When a transport demand is triggered in area X, the first step is to find an available vehicle in the same area to minimize the allocation time. Otherwise, the demand will wait in a queue until one vehicle in area X becomes free or a free vehicle comes from area Y. The Low Water Mark allows to keep available vehicles in the area to satisfy future demands. When the number of available vehicles in the area is strictly smaller than LWM, the system tries to invite empty vehicles from other areas to reach the LWM. On the contrary, when the number of vehicle in the area is strictly larger than the High Water Mark, the system tries to send the additional vehicles to other areas. This policy aims at reducing the delivery times of lots and at balancing transport resources in the fab. To reach this objective, it is necessary to define the right values of LWM and HWM per area and to decide where to look for empty vehicles and to where extra vehicles should be sent. Figure 2 shows that the delivery time is composed of numerous steps which starts by looking for an available transport resource (allocation time) and ends by unloading the lot at the destination. Going to source time, loading time, transport time and unloading time are parameters that are usually well established. However, because of its variability, the allocation time is the parameter that impacts the most the delivery time.

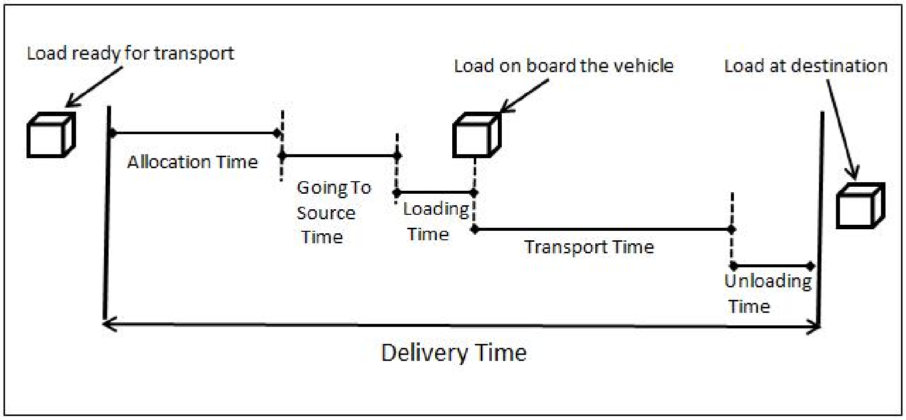

Figure 2: Allocation time as a main component of delivery time.

To estimate the delivery time, two scenarios must be considered. In the first scenario, an available vehicle is in the area and immediately reserved for the transport request and the allocation time is null. In the second scenario, there is no available vehicle in the area and the lots waits for the balancing system to send an available vehicle to the area. The resulting allocation time depends on:

- Where is the idle vehicle looked for (distance between areas)?
- Blocking events in the route to the area (traffic jam or stopped vehicle)?
- The impact in the area where the vehicle is taken (the number of transport requests in each area)?

The allocation time is function of the distance between the source area and the destination area, the probability of blocking events during the trip and the number of transport requests in the destination area. It is very difficult to define this function, but we can study the impact of varying the parameters on allocation times using discrete event simulation. To do this, we modeled the real 300mm fab of STMicroelectronics in Crolles. We want to study the impact of key parameters (LWM and HWM) of the minimum service policy on the allocation times of vehicles. The right definition of HWM and LWM allows vehicles to travel shorter distances to satisfy transport requests and potentially avoid transport requests.

4 STUDY OF THE LOW WATER MARK

In this section, we analyze the interaction between the values of LWM and the number of transport requests in each area. It is important to differentiate between the transport requests that remain in the area, and thus for which the vehicles stay in the area, and the transport requests that leave the area, for which the vehicles are lost for the area.

4.1 INTERACTIONS BETWEEN LWM AND THE DEGREE OF FREEDOM OF THE AMHS

Normally, each area requires an available vehicle to satisfy a transport request. Through simulation, we study the impact of the flow variation of each area on its LWM. Typically, an area with a large number of transport requests would need more vehicles than an area with less transport requests. Let us denote by $NbTrans_j$ the daily number of transport requests in area j, and by NT the total number of vehicles. Also, let us define L as the “degree of freedom”. This parameter helps to specify how many vehicles are available to ensure balancing between areas. More precisely, $L = 20\%$ means that 80% of the vehicles are used to satisfy the LWMs. We propose to define the LWM of area j as:

$$LWM_j = \frac{NbTrans_j}{\sum_{i=1}^{n}(NbTrans_i)} \times NT \times (1-L). \tag{1}$$

Table 1 details the characteristics of the four scenarios that were simulated with different values of the degree of freedom L.

Table 1: Four scenarios with different LWMs

		LWM			
Area	Nb of transport requests	Scenario 1 ($L = -100\%$)	Scenario 2 ($L = 0\%$)	Scenario 3 ($L = 20\%$)	Scenario 4 ($L = 40\%$)
1	702	3	2	1	1
2	**1345**	**6**	**3**	**2**	**2**
3	434	2	1	1	1
4	957	4	2	2	1
5	**1903**	**8**	**4**	**3**	**2**
6	**1749**	**7**	**4**	**3**	**2**
7	1553	6	3	3	2
8	430	2	1	1	1
9	**2605**	**11**	**6**	**5**	**3**
10	401	2	1	1	1

- In the first scenario, $L = -100\%$, i.e. the total number of vehicles is not sufficient to satisfy the balancing system for all the areas ($\sum_{i=1}^{n} LWM = 2 \times NT$).
- In the second scenario, $L = 0\%$, i.e. a total allocation of the transport resources ($\sum_{i=1}^{n} LWM = NT$). All the vehicles in the system are balanced between areas.
- In the third scenario, $L = 20\%$, i.e. $\sum_{i=1}^{n} LWM = 0.8 \times NT$.
- In the fourth scenario, $L = 40\%$, i.e. $\sum_{i=1}^{n} LWM = 0.6 \times NT$.

The ten areas studied in this paper includes four specific areas: Areas 2, 5 and 9 characterized by high throughputs and Area 6 where machines operate by batches of six lots. Given their characteristics, these areas will be more sensitive to the variation of their LWM. The number of transport requests considered in the scenarios matches the number of lots shipped during one day in each area. The duration of the simulation is three days. In the section below, we analyze the impact of varying the degree of freedom (L) on delivery times.

4.2 ANALYZING THE IMPACT OF THE DEGREE OF FREEDOM

In the first scenario, the sum of the LWMs is larger than the number of vehicles available in the fab ($\sum_{i=1}^{n} LWM = 2 \times NT$). This setting has a major drawback since the system is unstable for all areas. The mean and standard deviation of the delivery time for Areas 1, 3, 4, 7, 8 and 10 are relatively large compared to the other scenarios (min = 389 seconds, max = 511 seconds for the mean and min = 2.85%, max = 4.61% for the standard deviation). It means that, because of the overestimation of the LWMs, many transport requests are waiting for a long time because areas are unable to get vehicles. Area 6, composed of furnaces which operate by batches of six lots, has the higher standard deviation (6.29%). Once the processes are completed on a furnace, six vehicles are required to unload the machine and six vehicles to load the machine which explain the high variability. However, the standard deviations for Areas 2, 5 and

Table 2: Means and standard deviations of delivery times for different values of L

	Delivery Time							
	Scenario 1 ($L=-1$)		Scenario 2 ($L=0$)		Scenario 3 ($L=0.2$)		Scenario 4 ($L=0.4$)	
Area	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
1	389	4.36%	354	2.61%	257	1.62%	299	2.88%
2	**287**	**1.71%**	**330**	**1.84%**	**203**	**0.94%**	**301**	**2.13%**
3	447	4.61%	432	2.86%	301	1.43%	378	3.03%
4	511	3.37%	445	2.70%	354	0.98%	479	2.12%
5	**349**	**2.77%**	**281**	**2.67%**	**141**	**1.39%**	**188**	**2.01%**
6	**357**	**6.29%**	**307**	**1.93%**	**181**	**1.62%**	**450**	**3.95%**
7	390	4.38%	245	3.03%	180	2.63%	267	2.48%
8	510	3.35%	489	2.07%	354	1.65%	345	2.77%
9	**576**	**1.73%**	**511**	**1.84%**	**127**	**1.58%**	**271**	**1.86%**
10	403	2.85%	412	1.77%	397	1.02%	354	3.16%

9 are lower than for other areas (min = 1.71%, max = 2.77%). These areas are specific since their high throughputs (processing times between 2 and 15 minutes) lead to a large number of transport requests and allow them to have relatively high LWMs to keep many vehicles at the expenses of other areas. The mean delivery time of Area 9 is relatively long (576 seconds) despite its high LWM (15 vehicles). Some analysis shows that this is because the high LWM leads to an accumulation of extra vehicles which causes a traffic jam.

In the second scenario, the degree of freedom (L) is null, allowing more vehicles to be available to perform transport requests. Both means and standard deviations improved although the LWMs of areas with high throughputs have decreased (from 6 to 3 for area 2, from 8 to 4 for Area 5, from 7 to 4 for Area 6 and from 11 to 6 for Area 9). These changes allow other areas to keep vehicles and answer transport requests. However, this improvement is still insufficient because the variability is relatively high (min = 1.77%, max = 3.03%).

In the third scenario, the degree of freedom (L) is equal to 20%, i.e. only 80% of the transport fleet is used to ensure the stability of the system. The means and standard deviations of the delivery time are considerably improved (min = 127 seconds, max = 397 seconds for the mean and min = 0.98%, max = 2.63% for the standard deviation). This is due to the fact that vehicles do less balancing missions and transport resources are better allocated to satisfy transport requests.

In the last scenario, the degree of freedom (L) is equal to 40%. i.e. only 60% of the transport fleet is used to ensure the stability of the system. The results show a degradation in Area 2 (from 203 to 301 seconds for the mean and from 0.94% to 2.13% for the standard deviation), Area 5 (from 141 to 188 seconds for the mean and from 1.39% to 2.01% for the standard deviation), Area 9 (from 127 to 271 seconds for the mean and from 1.58% to 1.86% for the standard deviation) and Area 6 (from 181 to 450 seconds for the mean and from 1.62% to 3.95% for the standard deviation).

To conclude, selecting the right LMWs and an appropriate degree of freedom is critical for the performance of the Automated Material Handling System. Both the mean and the variability of the delivery times are influenced. In the next section, we study the impact of the different types of flows on the calculation of LWM.

4.3 RELATIONSHIP BETWEEN LWM AND TRANSPORT TYPES

In the previous section, scenarios do not take into account the interactions between areas. However, there are two types of transport requests: Some transport requests start and end in the same area, thus keeping the assigned vehicles available in the area, and the other transport requests start in one area and end in another area, thus reducing the number of vehicles in the origin area and increasing the number of vehicles in the destination area. Vehicles assigned to outside transport requests are lost for the origin area. The daily number of transport requests $NbTrans_j$ in area j can be written:

$$NbTrans_j = FI_j + FS_j$$

where FI_j, respectively FS_i, is the number of transport requests staying in, respectively leaving, Area j. Moreover, let FE_j be the number of transport requests from other areas entering Area j. The LWM should be impacted by FS_j and FE_j since, if there are more entering than leaving transport requests, i.e. $FS_j < FE_j$, than the reactivity of area j to satisfy transport requests should be improved. On the opposite, i.e. $FS_j > FE_j$, than the reactivity of area j to satisfy transport requests should be degraded. We take into account the different types of transport flows by changing (1) to:

$$LWM_j = \frac{FI_j + (FS_j - FE_j)}{\sum_{i=1}^{n}(FI_i + (FS_i - FE_i))} \times NT \times (1 - L) \tag{2}$$

It seems relevant to consider the dynamics of the system when calculating the LWMs to take the variability of transport requests into account. Hence, we also study the case where the LWMs are adjusted in real time in the simulation, depending on the current values of FI_j, FS_j and FE_j.

Three scenarios are proposed which are detailed in Table 3:

- The first scenario is the third scenario of Section 4.2,
- The second scenario consists of calculating the LWMs using (2) only once,
- In the third scenario, LWMs are regularly adapted using (2) every 30 seconds.

Table 3: Three scenarios with different types of flows

	Flows			LWM		
Area	FS	FI	FE	Scenario 1	Scenario 2	Scenario 3
1	602	100	187	1	1	$LWM_1(t)$
2	**846**	**499**	**840**	**2**	**1**	$LWM_2(t)$
3	201	233	604	1	0	$LWM_3(t)$
4	800	157	1255	2	1	$LWM_4(t)$
5	**1499**	**404**	**897**	**3**	**2**	$LWM_5(t)$
6	**1332**	**417**	**752**	**3**	**1**	$LWM_6(t)$
7	929	624	1099	3	2	$LWM_7(t)$
8	133	297	352	1	1	$LWM_8(t)$
9	**1000**	**1605**	**1003**	**5**	**3**	$LWM_9(t)$
10	101	300	716	1	0	$LWM_10(t)$

The number of transport requests matches the number of lot shipped per day in each area. The duration of the simulation is three days. Only the results of Areas 2, 5, 6 and 9 (data in bold in Table 3), characterized either by high throughput or the nature of the equipment(batch machines in Area 6), are presented in Table 4

Comparing the first two scenarios, note that the delivery time has not increased. In Areas 2 and 9, the number of transport requests leaving the area is nearly equal to the number of transport requests entering the area. Hence, even though the LWM is decreased (from 2 to 1 for Area 2, from 3 to 2 for Area 5, from 3 to 1 for Area 6 and from 5 to 3 for Area 9), the delivery time is not impacted. In the third scenario, the mean of the delivery time has considerably improved (minimum of 89 seconds and maximum of 151 seconds) with a reduced variability (minimum of 5.31% and maximum of 7.74%). This illustrates that taking the dynamics of the system into account when calculating the LWMs is relevant.

Table 4: Simulation results for scenarios with different transport types

	Delivery Time					
	Scenario 1		Scenario 2		Scenario 3	
Area	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
2	203	6.59%	182	6.27%	121	5.31%
5	141	9.72%	136	10.68%	111	7.74%
6	181	11.32%	184	8.57%	151	7.16%
9	127	11.06%	113	8.12%	89	7.48%

5 IMPACT OF THE HIGH WATER MARK

The High Water Mark (HWM) is defined as the maximum number of available vehicles that can be in the area. This parameter is important to satisfy the transport requests in the area but also to satisfy transport requests in other areas. Moreover, the HWM helps to avoid area to be saturated with vehicles. The right values of the HWMs depend on the variability of the transport requests of the area. The HWM can be seen as a function of the LWM, the number of transport requests and the variability of the transport requests in each area. If $HWM_i > LWM_i$, then extra available vehicles are wanted in Area *i*. Thus, the setting of this parameter is important to cope with instant variability. We analyze two scenarios:

- The first scenario considers the impact of HWM_i on the performance of Area *i*,
- The second scenario considers the impact of HWM_i on the performance of its neighborhood.

The simulation is used to analyze the impact of the HWM on the delivery time. The reporting will be done for four specific areas: Areas 2, 5, 6 and 9. The number of replications is equal to 3. The duration of the simulation is one day.

Table 5: Simulation results for analyzing the HWM impact

	HWM(t)							
	LWM(t)+1		LWM(t)+2		LWM(t)+3		LWM(t)+4	
	Delivery Time		Delivery Time		Delivery Time		Delivery Time	
Area	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
2	118	8.29%	107	4.27%	106	4.35%	108	4.76%
5	105	9.44%	108	6.32%	112	5.01%	101	5.25%
6	138	8.70%	130	6.98%	121	8.13%	111	6.81%
9	84	8.46%	87	6.24%	81	3.37%	79	3.61%

From the results of Table 5, we note the improvement of the delivery time when the gap between HWM and LWM increases. It shows that the adjustment of the gap is very important to consider the variability of transport requests. In addition, note also that, when $HWM > LWM + 3$, the delivery time starts to stagnate. When the HWM is larger than a given value, there is a risk of having too many vehicles without improving the delivery time.

Then, we study the impact of the HWM of a given area on its neighbor areas. The study is focused on Area 2, which is characterized by a large variability. In each simulation, we modify the HWMs of the three closest areas (Areas 3, 6 and 1). We consider the scenarios of Table 6. Table 7 shows the changes on the delivery times of Area 2. In the first scenario, the mean delivery time is 148 seconds, which decreases (121 seconds) when the HWM of Area 3 is increased in Scenario 2. The decrease of the mean delivery time (134 seconds) is not as large when the HWM of Area 6 is increased in Scenario 2, although Areas 3 and 6 are as close from Area 2. It can be explained by the fact that Area 3 has less transport requests than Area 6 and thus can provide more vehicles than Area 6. Area 1 being relatively far from Area 2, the mean delivery time in Area 2 does not really improve in Scenario 4 (144 seconds).

Table 6: Impact of varying HWM on its neighbor areas

Scenario 1	Scenario 2	Scenario 3	Scenario 4
$HWM_i(t) = LWM_i(t)$, $i = (3,6,1)$	$HWM_3(t) = LWM_3(t) + 3$	$HWM_6(t) = LWM_6(t) + 3$	$HWM_1(t) = LWM_1(t) + 3$

Table 7: Scenarios to study the impact of HWM on its neighbor areas

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Delivery Time		Delivery Time		Delivery Time		Delivery Time	
Area	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
2	148	27.98%	121	20.22%	134	21.61%	144	30.19%

6 CONCLUSION

Using discrete event simulation, we showed the importance of carefully setting the key parameters of a minimum service transport policy in a unified AMHS of large semiconductor manufacturing facility. Both the average values and the variability of delivery times are strongly influenced. Formulas were proposed to calculate these parameters. More research is required to evaluate the relevance of these formulas. Future studies will also focus on formalizing the approach to provide a decision support tool that determines in real time when the parameters should be updated.

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