Comparing Transport Policies in a Full-scale 300mm Wafer Manufacturing Facility

J. E. Kiba
Ecole des Mines de Saint-Etienne

S. Dauzère-Pérès
Ecole des Mines de Saint-Etienne

C. Yugma
Ecole des Mines de Saint-Etienne

G. Lamiable
STMicroelectronics

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J.-E. Kiba, S. Dauzère-Pérès, C. Yugma
Ecole des Mines de Saint-Etienne, Centre Microélectronique de Provence, Site Georges Charpak
880 avenue de Mimet, F-13541 Gardanne, France
(kiba@emse.fr, dauzere-peres@emse.fr, yugma@emse.fr)

G. Lamiable
STMicroelectronics
850 Rue Jean Monnet, 38920 Crolles, France
(gilles.lamiable@st.com)

Abstract
Research in semiconductor manufacturing ideally wants to determine the “best” transport policy to ensure continuous production. Determining such a policy is difficult because it depends on many factors such as the layout, the product types, the equipment, etc. Most of the transport policies found in the literature combine dispatching policies (scheduling of transport requests) and routing policies (selection of the path to move from one point to another). This paper investigates a policy called "minimum service" which consists in keeping a minimum number of available vehicles in bays, so that they can quickly answer transport requests and empty travel times can be minimized. This paper aims at comparing, through experimental tests on actual instances of a real semiconductor manufacturing facility, two types of transport policies in terms of cycle time, throughput and Carrier Exchange Time. Moreover, the behavior of the “minimum service” policy is studied when the number of vehicles and the number of starting lots are varied. The results show that the “minimum service” policy is in general more effective than a classical policy, but that its key parameters must carefully be determined.

1 Context

Semiconductor manufacturing processes are among the most complex existing processes. They include a very large number of operations (up to 700), routes, product types and machines. Wafers are grouped in lots of at most 25 wafers, and are transported by automated vehicles in most 300mm wafer manufacturing facilities (called fabs). Transportation being a service for production, it is important to determine transport policies that efficiently meet the transport requests of production lots, i.e. the right lot is brought at the right place and at the right time. It is mentioned in [2] that no transport policy overcomes the others. However, we will show that this is not the case in a unified transportation system, where the bays are linked and the vehicles can travel everywhere in the fab.

In this paper, based on a full-scale fab simulation model, we compare two types of transport policies in a unified fab: (1) a “classical” policy which consists in dispatching the vehicles throughout the whole facility and choosing the most adapted vehicle to answer any transport request, and (2) a “minimum service” policy, where the objective is to ensure that, in each bay, there are at least a specified number of vehicles and at most another specified number of vehicles.

2 Transport policies

Transport policies can be decomposed into dispatching policies and routing policies.

- *Dispatching policies* aim at scheduling the transport requests. The objective is to select a transport request among all the lots waiting for a transfer, and to assign this request to one of the available vehicles. Dispatching policies are studied in [3]. Note that a minimal assignment time is very hard to guarantee in a transport system, since it depends on the work in progress and the positioning of the vehicles.
- *Routing polices* aim at finding the shortest route, in distance or time, that leads the vehicle from its current location to the pickup point, and then to the delivery point. Routing policies are studied in [4], [1] and [5]. Sometimes a shortest route in distance takes more time than a longer one, for example because of traffic jam. This increases the complexity of finding an “optimal” vehicle routing policy.

In this paper, we want to compare two transport policies, in which the same shortest distance routing policy is used. Moreover, the same basic dispatching rules are applied. Hence, the difference lies in how these dispatching rules are applied.

Remark. There are actually two dispatching rules required for a dispatching policy in order to tackle two opposite cases. In the first case, there is one transport request and multiple vehicles are available. Several rules can be used such as “Nearest Vehicle”, “Longest Idle Vehicle”, “Least Utilized Vehicle”, etc. In the second case, there is one vehicle and multiple transports requests must be answered. Existing rules for this case are “Shortest Travel Distance”, “First Come First Serve”, “Unit Load Shop Arrival Time”, etc.

The two dispatching rules used in this paper are “Nearest Vehicle” and “Shortest Travel Distance”. The aim is to minimize the empty travel times of the vehicles because, when vehicles travel empty, they decrease the fab transportation capacity.

In the “classical” transport policy, vehicles are dispatched throughout the whole facility using the dispatching rules to answer any transport request. In a large unified system, the problem of such a policy is that it is difficult to guarantee a minimal assignment time. We want to study another type of transport policy, which will be called "minimum service" in the sequel. As the manufacturing process is very complex, planning in advance the vehicle to be selected for a given transport request is difficult. The concept of minimum service aims at trying to ensure that, at all times, a specified number of vehicles are available in each bay. The goals is to always be able to quickly answer a transport request, and thus to reduce the vehicle assignment time.

3 The "minimum service" transport policy

At the 300mm wafer fab of STMicroelectronics in Crolles, the vehicle stream is controlled through the "minimum service" transport policy, which is based on the following two key parameters, defined for each bay: *Low Water Mark* (LWM) and *High Water Mark* (HWM). The first parameter represents the minimum number of non-assigned vehicles that the system wants to permanently keep in the bay, in order to quickly react to transport requests. The LWM can be seen as a minimum service. The HWM corresponds to the maximum number of non-assigned vehicles authorized in a bay. The HWM has two motivations. It may correspond to the maximum number of non-assigned vehicles above which the risk of traffic jam or congestion in the bay becomes large. The HWM can also be set to avoid keeping too many vehicles in a bay that does not require them.

The challenge of this transport policy is to keep at least LWM vehicles in each bay. The system needs to balance the vehicles to meet the LMW of each bay. The balancing mechanism between bays starts when the number of vehicles in a bay is strictly lower than its LWM or strictly larger than its HWM.

> Low Water Mark Case. If the number of non-assigned vehicles in a bay is *strictly lower than* its LWM, the system "calls" the missing vehicles from another bay, which has at least one more vehicle than its LWM.
>
> High Water Mark Case. If the number of vehicles in a bay is *strictly larger than* its HWM value, the system "pushes out" the surplus vehicles toward predefined bays that have not reached their HWMs yet.

Remark. The idea behind the "minimum service" policy is the properties of *repeatability* and *reliability*, that all automated systems should guarantee. Repeatability means the capacity of the vehicles to perform the same task in the same conditions of work in progress. This property ensures, for example, a given number of transports per day for the vehicles. In our case, reliability means the ability of the transport system to guarantee a minimum delivery time.

4 Comparison of two transport policies

We developed a detailed full-scale simulation model integrating transportation, production and storage for the 300mm wafer fab of STMicroelectronics in Crolles (see [6]). Note that we did not find in the literature research integrating in details these three aspects although they are clearly interdependent. This new and original simulation model is used to make a comparative experimental study of two transport policies in an actual unified fab: "classical" and "minimum service". The Carrier Exchange time (CET) is the time between unloading one lot and loading another lot on the same load port in front of a machine. This indicator is used to measure equipment continuous processing. This comparison will not only be based on one transportation indicator, the CET, but also on production indicators: Fab throughput and lot cycle time.

The whole fab is evolving towards a complete AMHS but, at this stage, is partially covered by the AMHS. The fab is divided into zones, corresponding to bays. The simulation time is 180 days with a warm-up time of 180 days. The number of wafers started per week is not given for confidentiality reason. There are 26 vehicles and several hundreds machines in several bays. We compared the "minimum service" transport policy, with different values of the LWM, with the "classical" transport policy. To limit the number of experiments without losing too much information, we focus our study on a bay that concentrates 30% of the total traffic. Let us call this bay the "critical" bay. We varied the LWM in the critical bay from one to four. The impacts of the variation of the HWM will not be analyzed in this paper. The HWM is thus fixed in each bay. In the sequel, we will consider 7 tools inside the critical bay, and 6 outside the critical bay (one in each bay other than the critical bay). For confidentiality reasons, we cannot give the actual cycle time and throughput values. Thus we will compare all values for a given indicator to the largest value that is obtained.

Table 1: Comparing cycle time and throughput between "Minimum service" and "Classical" transport policies

	LWM=1	**LWM=2**	**LWM=3**	**LWM=4**	**Classical**
Cycle time – Mean	0.835	0.835	**0.824**	**0.824**	1.000
Cycle time – Std Dev (%)	15 %	15 %	16 %	16 %	27 %
Throughput (lot)	0.992	0.994	0.988	**1.000**	0.313

Table 2: Comparing Carrier Exchange Time (CET) means, between "Minimum service" and "Classical" transport policies for equipment **inside** the critical bay

	LWM=1	**LWM=2**	**LWM=3**	**LWM=4**	**Classical**
Eqpt 1	0.574	**0.550**	**0.550**	0.558	0.891
Eqpt 2	0.729	**0.705**	**0.705**	0.713	1.000
Eqpt 3	0.682	**0.620**	**0.620**	**0.620**	0.915
Eqpt 4	0.721	**0.659**	**0.659**	**0.659**	0.783
Eqpt 5	0.659	0.597	0.597	**0.581**	0.837
Eqpt 6	0.721	**0.698**	**0.698**	0.705	0.822
Eqpt 7	0.736	**0.721**	**0.721**	0.729	0.860

Table 3: Comparing Carrier Exchange Time (CET) means, between "Minimum service" and "Classical" transport policies for equipment **outside** the critical bay

	LWM=1	LWM=2	LWM=3	LWM=4	Global
Eqpt 8	0.678	0.601	0.607	**0.552**	0.934
Eqpt 9	0.738	**0.705**	**0.705**	0.842	0.934
Eqpt 10	0.743	0.721	**0.710**	0.727	0.967
Eqpt 11	0.732	0.732	0.738	**0.727**	1.000

Eqpt 12	0.738	0.705	**0.694**	0.716	0.923
Eqpt 13	**0.492**	0.497	0.503	0.497	0.503

The results in Tables 1 through 3 show that the “minimum service” policy clearly dominates the “classical” policy. In Table 1, the cycle time is 20% shorter and the throughput is two times smaller with the “minimum service” policy. Tables 2 and 3 show how the Carrier Exchange Time evolves for equipment inside and outside the critical bay. Lots are replaced faster on a load port based on the “minimum service” policy. This is because the assignment time is shortened. Note that the worst case for the “minimum service” policy (LWM = 1) still dominates the “classical” policy.

However, varying LWM in one bay, a key parameter, seems to have no major impact on the efficiency of the manufacturing system. This is why, in the following section, we study how the minimum service policy performs when more activity is given to the transport system, i.e. when the number of vehicle is reduced or when the number of lots is increased.

5 Analysis of the minimum service policy

In this section, we will conduct tests on some critical data to analyze when the transportation system becomes a constraint, and the impact of the Low Water Mark (LWM), a key parameter of the minimum service policy. We conducted two types of tests: On the number of vehicles and on the number of starting lots per week.

5.1 Variation of the number of vehicles

The aim of these tests is to study the impact of the number of vehicles on the manufacturing system. We want to analyze when the transportation system can no longer handle the transport requests from the production system due to a lack of vehicles. To do this, we start with the number of vehicles, i.e. 26, used in the experiments of Section 4, increase this number to 27 and gradually reduce it to 22. The LWM in the critical bay is also varied from 1 to 4.

Table 4: Impact of number of vehicles and LWM on cycle times

		Number of vehicles					
LWM	**Cycle Time**	**22**	**23**	**24**	**25**	**26**	**27**
1	Mean	0.942	**0.935**	0.942	0.942	0.949	0.935
	Std Dev (%)	21%	**21%**	21%	21%	21%	22%
2	Mean	0.942	0.942	**0.935**	0.942	0.942	0.949
	Std Dev (%)	21%	21%	**21%**	22%	21%	22%
3	Mean	**0.935**	0.942	0.942	**0.935**	**0.935**	**0.928**
	Std Dev (%)	20%	21%	22%	21%	21%	21%
4	Mean	**0.935**	0.942	1.000	**0.935**	0.942	0.935
	Std Dev (%)	20%	21%	19%	22%	21%	21%

The impact of the number of vehicles and the LWM on the cycle time can be found in Table 4. It must be noted that the variations are never very large and probably not really relevant. Hence, with the minimum service policy, the transportation can handle the production capacity, even with a reduced number of vehicles. Note that LWM=3 consistently provides good results.

Table 5: Impact of number of vehicles and LWM on Carrier Exchange Time (CET) mean for equipment **inside** the critical bay

		Number of vehicles					
	LWM	**22**	**23**	**24**	**25**	**26**	**27**
Eqpt 1	1	0.911	0.984	0.932	0.911	0.858	*0.847*
	2	0.937	0.911	0.842	0.853	0.826	*0.805*
	3	0.853	0.842	**0.779**	**0.779**	*0.753*	0.768
	4	**0.816**	**0.811**	0.795	0.795	***0.753***	**0.768**
Eqpt 2	1	0.932	1.000	0.942	0.926	0.884	*0.874*
	2	0.963	0.932	0.863	0.868	0.842	*0.826*
	3	0.879	0.874	**0.805**	**0.805**	*0.779*	0.795
	4	**0.832**	**0.837**	0.821	0.821	***0.779***	**0.795**
Eqpt 3	1	0.689	0.737	0.689	0.674	0.653	*0.637*
	2	0.711	0.684	0.637	0.632	0.616	*0.600*
	3	0.647	0.632	0.595	0.589	*0.579*	0.589
	4	**0.621**	**0.605**	**0.589**	**0.589**	***0.574***	**0.579**
Eqpt 4	1	0.895	0.953	0.884	0.868	0.837	*0.821*
	2	0.905	0.874	0.816	0.811	0.784	*0.768*
	3	0.821	0.805	0.768	0.758	*0.742*	0.753
	4	**0.805**	**0.784**	**0.763**	**0.747**	***0.737***	**0.742**
Eqpt 5	1	0.911	0.968	0.895	0.879	0.832	*0.811*
	2	0.889	0.853	0.784	0.784	0.753	*0.726*
	3	**0.774**	0.763	0.726	0.726	*0.695*	0.705
	4	0.779	**0.753**	**0.721**	**0.684**	***0.663***	**0.679**
Eqpt 6	1	0.905	0.905	0.879	0.858	0.858	*0.853*
	2	0.837	0.837	0.805	0.800	*0.779*	*0.779*
	3	***0.747***	**0.768**	0.789	0.789	0.779	0.763
	4	0.816	0.821	**0.768**	***0.716***	***0.716***	***0.716***
Eqpt 7	1	0.863	0.853	0.826	0.816	*0.795*	*0.795*
	2	0.779	0.768	0.747	0.737	0.732	*0.711*
	3	***0.684***	**0.716**	0.732	0.726	0.721	0.700
	4	0.779	0.758	**0.711**	***0.647***	***0.647***	**0.653**

Table 6: Impact of number of vehicles and LWM on Carrier Exchange Time (CET) standard deviation for equipment **inside** the critical bay

		Number of vehicles					
	LWM	**22**	**23**	**24**	**25**	**26**	**27**
Eqpt 1	1	36%	42%	37%	34%	*29%*	*29%*
	2	40%	36%	29%	31%	27%	*25%*
	3	32%	31%	**24%**	**23%**	***20%***	22%
	4	**28%**	**27%**	25%	25%	*21%*	**22%**
Eqpt 2	1	35%	42%	36%	34%	31%	*29%*
	2	40%	37%	29%	30%	27%	*25%*
	3	33%	31%	**24%**	**24%**	*21%*	**22%**
	4	**27%**	**27%**	26%	25%	***21%***	23%
Eqpt 3	1	29%	35%	28%	27%	24%	*22%*
	2	36%	32%	25%	24%	22%	*19%*
	3	28%	26%	**19%**	**17%**	***16%***	**18%**
	4	**23%**	**21%**	20%	20%	*17%*	19%
Eqpt 4	1	36%	42%	35%	33%	30%	*27%*
	2	41%	36%	29%	29%	26%	*24%*
	3	33%	30%	**23%**	**22%**	***20%***	**21%**
	4	**28%**	**25%**	25%	23%	*21%*	22%
Eqpt 5	1	46%	51%	43%	42%	37%	*36%*
	2	45%	42%	34%	33%	30%	*27%*
	3	35%	33%	**27%**	27%	*23%*	24%
	4	**34%**	**31%**	28%	**24%**	***21%***	**23%**
Eqpt 6	1	35%	38%	33%	*29%*	30%	*29%*
	2	32%	30%	25%	26%	*22%*	*22%*
	3	**21%**	**22%**	22%	22%	21%	*19%*
	4	26%	28%	**21%**	**16%**	***14%***	***14%***
Eqpt 7	1	38%	36%	33%	32%	*29%*	*29%*
	2	31%	28%	26%	25%	23%	*20%*
	3	**19%**	**23%**	24%	22%	22%	*18%*
	4	29%	26%	**22%**	**15%**	***14%***	***14%***

Tables 5 through 8 show that, in most cases, the mean and standard deviation of Carrier Exchange Times (CET) decrease when the number of vehicles increases. This decrease is drastic in some cases. Moreover, as observed in Tables 5 and 6, the value of LWM in the critical bay has a clear impact on the CET of equipment inside and outside the critical bay.

Setting LWM to 4 seems to be preferable in the critical bay. This can be explained by the fact that, in this case, more vehicles are available in the bay, and thus ready to pick lots from load ports but also to bring lots to load ports. The latter is true because there are a rather larger number of internal transports in the critical bay, i.e. transports that start and end in the same bay.

Table 7: Impact of number of vehicles and LWM on Carrier Exchange Time (CET) mean for equipment **outside** the critical bay

		Number of vehicles					
	LWM	**22**	**23**	**24**	**25**	**26**	**27**
Eqpt 8	1	0.832	0.948	0.718	0.653	0.680	*0.570*
	2	0.959	0.876	0.821	0.698	0.619	*0.574*
	3	0.821	0.790	**0.540**	**0.515**	***0.478***	**0.546**
	4	**0.763**	***0.608***	0.619	0.615	0.667	0.622
Eqpt 9	1	0.955	0.935	0.753	0.715	0.715	*0.595*
	2	1.000	0.979	0.856	0.766	0.653	*0.608*
	3	0.849	0.784	***0.495***	**0.536**	**0.502**	**0.564**
	4	**0.804**	***0.615***	0.643	0.639	0.646	0.708
Eqpt 10	1	0.447	0.447	0.436	0.436	0.436	*0.433*
	2	0.450	0.447	***0.433***	0.436	*0.433*	*0.433*
	3	**0.430**	**0.436**	**0.433**	0.433	0.433	*0.426*
	4	0.440	0.440	0.440	**0.426**	***0.423***	***0.423***
Eqpt 11	1	**0.526**	**0.498**	**0.488**	**0.488**	**0.485**	***0.481***
	2	**0.526**	0.512	0.495	0.495	0.488	*0.485*
	3	0.533	0.515	0.502	0.502	0.498	***0.481***
	4	0.533	0.526	0.505	0.502	0.491	***0.481***
Eqpt 12	1	0.381	0.385	0.375	0.375	*0.368*	0.371
	2	0.388	0.385	0.375	0.375	*0.371*	0.375
	3	**0.357**	0.381	**0.371**	0.371	0.368	***0.354***
	4	0.375	**0.378**	0.378	**0.357**	***0.354***	0.357
Eqpt 13	1	0.364	**0.340**	0.323	0.326	**0.320**	*0.316*
	2	0.357	0.344	0.333	0.326	0.326	*0.323*
	3	**0.337**	0.347	**0.326**	0.323	0.326	***0.309***
	4	0.340	**0.340**	0.337	**0.320**	**0.320**	*0.316*

Table 8: Impact of number of vehicles and LWM on Carrier Exchange Time (CET) standard deviation for equipment **outside** the critical bay

		Number of vehicles					
	LWM	**22**	**23**	**24**	**25**	**26**	**27**
Eqpt 8	1	80%	71%	47%	35%	49%	*29%*
	2	69%	69%	71%	40%	32%	***25%***
	3	**56%**	50%	**27%**	**22%**	***19%***	30%
	4	66%	**34%**	34%	*31%*	41%	35%
Eqpt 9	1	91%	74%	54%	42%	48%	***27%***
	2	78%	76%	65%	52%	37%	*30%*
	3	**60%**	56%	**28%**	**23%**	***22%***	28%
	4	71%	**34%**	38%	*32%*	37%	47%
Eqpt 10	1	12%	12%	10%	10%	*9%*	*9%*
	2	14%	12%	10%	10%	*9%*	*9%*
	3	**10%**	11%	**9%**	9%	8%	*7%*
	4	11%	**11%**	10%	**8%**	***7%***	***7%***
Eqpt 11	1	**14%**	**12%**	**10%**	**10%**	10%	***9%***
	2	17%	14%	11%	11%	***10%***	*10%*
	3	19%	14%	12%	12%	11%	*10%*
	4	17%	16%	13%	13%	11%	*10%*
Eqpt 12	1	12%	12%	10%	10%	*9%*	*9%*
	2	13%	12%	10%	10%	*9%*	*9%*
	3	**9%**	11%	**9%**	9%	8%	*7%*
	4	11%	**11%**	10%	**8%**	***7%***	***7%***
Eqpt 13	1	13%	11%	9%	9%	*8%*	*8%*
	2	14%	12%	11%	*9%*	*9%*	*9%*
	3	12%	12%	**9%**	9%	9%	***7%***
	4	**11%**	**11%**	12%	***8%***	***8%***	*8%*

Tables 7 and 8 show that the impact of the LWM can be very different for equipment outside the critical bay. Selecting LWM smaller than 4 might be preferable. This can be explained by the fact, when LWM is equal to 4, too many vehicles may stay in the critical bay and are thus not available for other bays.

Reducing the CET mean implies that machines have less chance to become idle because no lots are available on one of its load ports, thus improving the quality of the transportation service. Reducing the CET standard deviation ensures that the service is more reliable.

5.2 Variation of the number of starting lots

The goal of these tests is to study the behavior of the minimum transport policy when the number of lots in the system is increased. The number of starting lots used in our previous experiments is increased by 11%, 17% and 28%, respectively. We want to show that choosing an adequate value for LWM in bottleneck bays is critical for the transportation system to be more efficient.

Table 9: Impact of number of starting lots on throughput

	Number of starting lots			
LWM	**X**	**X + 11%**	**X + 17%**	**X + 28%**
1	0.949	0.868	0.778	0.705
2	**1.000**	0.858	0.800	**0.731**
3	0.947	**0.933**	**0.914**	0.718
4	0.949	0.871	0.794	0.725

Table 9 illustrates that, when the number of starting lots is small enough and the number of vehicles large enough, the impact of LWM is not as critical as when the number of starting lots increases. When the number of starting lots is equal to X+11% and X+17%, choosing LWM=3 helps to maintain an effective throughput, whereas the transportation system becomes bottleneck for other values of LWM. When the number of starting lots is equal to X+28%, the production system becomes bottleneck, and the impact of LWM is no longer significant.

Table 10: Impact of number of starting lots on Carrier Exchange Time (CET) mean for equipment **inside** the critical bay

		Number of starting lots			
	LWM	**X**	**X + 11%**	**X + 17%**	**X + 28%**
Eqpt 1	1	*0.943*	0.966	*0.943*	0.977
	2	*0.891*	0.897	0.909	*0.891*
	3	***0.869***	0.886	**0.874**	0.886
	4	***0.869***	**0.874**	0.880	**0.880**
Eqpt 2	1	0.971	0.989	*0.960*	1.000
	2	0.920	*0.914*	0.931	*0.914*
	3	*0.903*	***0.903***	**0.909**	0.920
	4	***0.897***	**0.903**	**0.909**	**0.909**
Eqpt 3	1	*0.709*	0.714	0.714	0.726
	2	*0.663*	*0.663*	0.669	0.674
	3	***0.646***	0.651	**0.651**	0.657
	4	***0.646***	***0.646***	**0.651**	**0.651**

Eqpt 4	1	*0.914*	0.926	0.920	0.931
	2	0.857	*0.851*	0.863	0.869
	3	*0.829*	0.840	**0.834**	0.840
	4	***0.823***	***0.823***	**0.834**	**0.829**
Eqpt 5	1	*0.909*	0.937	0.931	0.943
	2	0.817	*0.811*	0.823	0.834
	3	*0.766*	0.789	0.777	0.789
	4	***0.749***	***0.749***	**0.771**	**0.760**
Eqpt 6	1	*0.920*	0.954	0.966	0.954
	2	*0.857*	0.863	0.869	0.886
	3	*0.823*	0.834	0.840	0.851
	4	***0.800***	**0.811**	**0.823**	**0.823**
Eqpt 7	1	*0.857*	0.891	0.886	0.903
	2	*0.794*	0.800	0.823	0.817
	3	*0.743*	0.766	0.760	0.771
	4	***0.726***	**0.731**	**0.754**	**0.749**

Table 11: Impact of number of starting lots on Carrier Exchange Time (CET) standard deviation for equipment **inside** the critical bay

		Number of starting lots			
	LWM	**X**	**X + 11%**	**X + 17%**	**X + 28%**
Eqpt 1	1	*36%*	*36%*	*36%*	37%
	2	*33%*	*33%*	35%	*33%*
	3	***31%***	33%	33%	**32%**
	4	32%	***31%***	**32%**	**32%**
Eqpt 2	1	*35%*	36%	*35%*	37%
	2	32%	32%	33%	*31%*
	3	***30%***	32%	**31%**	32%
	4	*31%*	***31%***	***31%***	***31%***
Eqpt 3	1	*37%*	38%	38%	39%
	2	***34%***	***34%***	35%	**36%**
	3	***34%***	35%	***34%***	**36%**
	4	*35%*	*35%*	36%	**36%**
Eqpt 4	1	*36%*	37%	37%	37%
	2	33%	*32%*	***32%***	34%
	3	***31%***	33%	**32%**	33%
	4	*32%*	***32%***	***32%***	***32%***

Eqpt 5	1	*45%*	48%	47%	47%
	2	*39%*	*39%*	40%	41%
	3	***37%***	39%	**38%**	38%
	4	***37%***	***37%***	**38%**	***37%***
Eqpt 6	1	*34%*	38%	37%	36%
	2	*28%*	29%	29%	30%
	3	*26%*	27%	27%	28%
	4	***24%***	**25%**	**26%**	***24%***
Eqpt 7	1	*36%*	40%	39%	38%
	2	32%	*31%*	32%	32%
	3	*28%*	31%	**30%**	30%
	4	***26%***	**27%**	**30%**	**27%**

As expected, in Tables 10 through 13, the Carrier Exchange Time (CET) usually increases with the number of lots in the fab. As when the number of vehicles is varied, Tables 10 and 11 show that the CET mean and standard deviation for equipment inside the critical bay are generally improved when LWM is increased.

Table 12: Impact of number of starting lots on Carrier Exchange Time (CET) mean for equipment **outside** the critical bay

		Number of starting lots			
	LWM	**X**	**X + 11%**	**X + 17%**	**X + 28%**
Eqpt 8	1	0.815	0.823	0.914	***0.806***
	2	0.802	**0.806**	***0.797***	0.909
	3	***0.776***	0.823	0.802	0.832
	4	0.819	0.828	0.836	*0.815*
Eqpt 9	1	***0.810***	0.862	1.000	**0.845**
	2	0.836	***0.832***	0.871	0.966
	3	*0.823*	0.849	**0.849**	0.888
	4	*0.853*	0.866	0.884	0.879
Eqpt 10	1	*0.547*	0.552	**0.552**	0.556
	2	***0.543***	**0.547**	**0.552**	**0.552**
	3	***0.543***	**0.547**	**0.552**	**0.552**
	4	***0.543***	**0.547**	**0.552**	**0.552**
Eqpt 11	1	***0.608***	***0.608***	**0.616**	0.621
	2	*0.612*	0.616	0.621	0.621
	3	*0.616*	*0.616*	0.625	0.629
	4	*0.621*	0.625	0.629	0.629

Eqpt 12	1	***0.466***	0.474	**0.474**	**0.483**
	2	***0.466***	**0.470**	0.478	**0.483**
	3	*0.470*	0.474	**0.474**	**0.483**
	4	*0.470*	0.474	0.483	**0.483**
Eqpt 13	1	***0.401***	***0.401***	***0.401***	***0.401***
	2	0.409	0.405	***0.401***	***0.401***
	3	0.414	0.418	*0.405*	0.409
	4	0.422	0.418	0.414	*0.409*

Table 13: Impact of number of starting lots on Carrier Exchange Time (CET) standard deviation for equipment **outside** the critical bay

		Number of starting lots			
	LWM	**X**	**X + 11%**	**X + 17%**	**X + 28%**
Eqpt 8	1	*51%*	55%	79%	56%
	2	54%	**52%**	***51%***	71%
	3	***49%***	53%	52%	**56%**
	4	*52%*	54%	54%	60%
Eqpt 9	1	*54%*	61%	75%	60%
	2	59%	***57%***	**59%**	74%
	3	***54%***	59%	**59%**	60%
	4	58%	58%	60%	***56%***
Eqpt 10	1	***20%***	**22%**	**22%**	**22%**
	2	*21%*	**22%**	**22%**	23%
	3	*21%*	**22%**	23%	23%
	4	*21%*	**22%**	23%	23%
Eqpt 11	1	27%	***21%***	***21%***	***21%***
	2	***21%***	***21%***	22%	***21%***
	3	*22%*	*22%*	*22%*	23%
	4	24%	*23%*	24%	25%
Eqpt 12	1	***24%***	**25%**	**26%**	27%
	2	*25%*	26%	27%	**26%**
	3	*27%*	*27%*	*27%*	28%
	4	*27%*	29%	28%	29%
Eqpt 13	1	***26%***	**28%**	**27%**	**28%**
	2	*27%*	29%	28%	30%
	3	*29%*	31%	30%	31%
	4	32%	33%	*31%*	32%

As illustrated in Tables 12 and 13, the CET of equipment outside the critical bay may increase when LWM is too large, i.e. the CET is usually better when the critical bay does not keep too many vehicles. Hence, there is a trade-off between selecting LWM large enough to ensure the right service for a bay, i.e. that the corresponding CET is small enough, and selecting LWM small enough to avoid penalizing the service in other bays. This is particularly true for critical bays with many transport requests that receive many vehicles.

6 Conclusion

In this paper, we compared through simulation tests on actual instances of a real semiconductor manufacturing facility two transport policies: A classical policy that assigns the nearest vehicle to a transport request, and a “minimum service” policy. The concept of “minimum service” is to assign a given minimum number (called Low Water Mark) of available vehicles to bays in order to quickly react to a transport request.

The tests showed that it is important not to let vehicles wander freely in the facility, otherwise indicators such as throughput and Carrier Exchange Time (CET) worsen. The “minimum service” policy is more effective. However, this policy requires determining the right values of key parameters such as Low Water Marks (LWM) for each bay. One of the difficulties is that the best LMW value for one bay may negatively impact the performances of other bays. Our current research aims at proposing approaches to determine the Low Water Marks that globally optimize the performances of the transport system.

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