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Simulation-based Reduction of Traffic Jam Effects in a Distributed Automated Material Handling System

Simulationsbasierte Reduzierung der Störfallfolgen in einem verteilten Automated Material Handling System

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Abstract: Striving for automation in the semiconductor industry makes automated material handling systems (AMHS) a must in larger fabs. The demand for increasing throughput yields more complex requirements for the transportation system. Especially for transport systems which span several areas connected only by bridges, a system failure at the transportation system can have significant negative effects onto the manufacturing line, too. A new system logic has been developed, which keeps a minimum amount of transportation capacity per area to fulfil transport requirements during failure scenarios. This logic was developed with the help of simulation studies and is based on consideration of transport related restrictions inside the Manufacturing Execution System (MES). Since testing with the real system is not an option simulation is also a suitable method to get first impressions about functionality and performance of new system solutions for AMHS in semiconductor manufacturing facilities.

1 Problem Description

Automation can be found in every area of semiconductor industry. Especially larger semiconductor manufacturing facilities (fabs) cannot fulfil complex transport requirements without using automated material handling systems (AMHS). Mostly Overhead Hoist Transport (OHT) systems are used to save expensive cleanroom space. Modern versions of these systems are not segregated into single bays anymore and allow the travel of vehicles along the whole track network. As long as the system can cover e.g. differences in ceiling height by ramps the Front Opening Unified Pods (FOUPs) only have to be handled at source and destination ports. Transportation in between can be done without any further transitions among dif-

ferent systems. Therefore such unified systems can span several areas and even buildings connected only by bridges. For a part of GLOBALFOUNDRIES' Dresden campus this is depicted in figure 1.

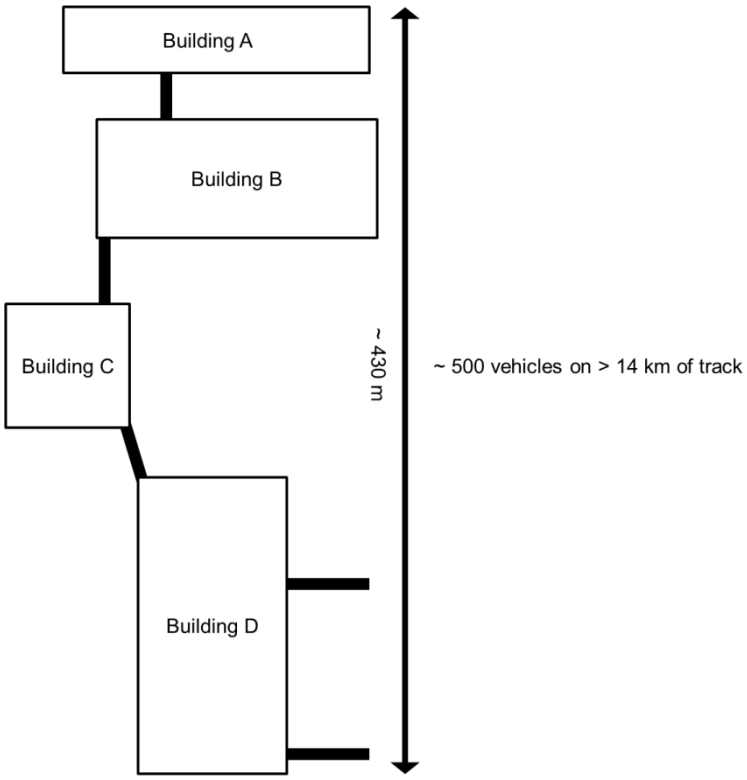

Figure 1: *Schematic of buildings served by connected OHT as AMHS*

The availability of a complex transport network brings specific challenges along, too. The following example gives an impression about how a single traffic jam can affect the whole transport system. In case of a significant traffic jam due to a system failure in a particular production area, many vehicles will pile up quickly because they are supposed to fulfil transport requests in this area. This can lead to other areas running short of vehicles because the affected area still keeps requesting vehicles. As a result, areas even not directly affected do not have enough vehicles to fulfil transport requests any longer. In that case the production of the whole fab can be endangered. To prevent this behaviour the Vehicle Area Balancer (VAB) which is presented in this paper has been developed. This logic ensures an appropriate distribution of the vehicles which represent the restricted resource of the transportation system. The VAB takes the overall situation of the transport system into account and keeps a minimum amount of vehicles in each specified area. This solution goes beyond any known watermark strategies as e.g. can be found in Jimenez et al. (2010). The goal is an at least limited functionality of areas which are not failure affected directly. Simulation studies were used to verify the different

necessary vehicle amounts. Since there is a need to check incoming transport requests for feasibility also further boundary conditions of fab automation have to be considered besides OHT regards: dependencies as well as interdependencies with the dispatching system in terms of transport request generation (Nishi and Tanaka 2012). Through integration of a replication of the developed solution into an existing simulation model it was possible to test different failure scenarios in advance and investigate functionality and benefit of the VAB.

The remainder of this paper is organised as follows: In section 2 analyses of layout, transport flow and vehicle quantities are presented, followed by section 3 where a detailed description of the VAB is provided. In section 4 details of the simulation model and the simulation experiments are presented accompanied by results. The paper ends with a summary in section 5.

2 Pre-Consideration

2.1 Layout and Transport Analysis

The bigger the connected transport system, the more tools and storages are available as possible destinations for a lot which has just finished a process step and has to be picked up to clear the load port of the tool. But if the OHT connects different buildings within one AMHS these connections can lead to increased traffic jam risks, too. In some cases it only needs one vehicle in error mode causing a traffic jam just in front of an entrance or exit of a building and the whole exchange of carriers and vehicles between the buildings will be disrupted. These transport and vehicle exchange dynamics are crucial for a semiconductor facility with different buildings because the throughput goals can only be achieved by interaction of different buildings and production areas. To get a better understanding of the correlation between MES-triggered inter-building transports on the one hand and bottlenecks of the transport system on the other hand layout and transport analyses have been carried out.

The main focus during transport pattern analysis was put on the relation between intra- and inter-building transports. Results have shown that transports changing a building (inter-building) exceeded those with source and destination within the same building (intra-building). For the transport system this ends in highly utilised connections (thick, black coloured) links between the different buildings as shown in the track utilisation chart in figure 2.

The next step was to calculate the betweenness centrality which gives information about how often a link is part of a shortest path (Anthonisse, 1971). When analysing links within the transport system by calculating the betweenness centrality with the Floyd-Warshall-Algorithm (Floyd 1962 and Warshall 1962) the resulting picture was pretty much the same: In a comparison of all connections of possible sources and destinations in the transport system, the links connecting different buildings are used most. This is depicted in figure 2 where again black coloured links show high utilised areas and grey coloured links show low utilised ones.

Figure 2: *Comparison of Betweenness Centrality (left) and Track Utilization Chart (right) showing utilisation differences from low (grey, small) to high (black, thick) utilisation*

In summary system failures affecting the dynamic exchange of carriers and vehicles between the different buildings will have significant impact onto the whole transport system. Area connections are the most important parts of the OHT from both points of view: manufacturing side (transport job generation) and transport system side (shortest paths). Nevertheless there will be intra-building transports which can be carried out even during failure scenarios. For this reason transport capacity has to be kept within the buildings to be able to clear tool load ports and fulfil transport requirements.

2.2 Vehicle Quantities

Goal of the VAB was to prevent certain areas from running out of vehicles to ensure a minimum functionality of areas not directly affected during traffic jams. A measure for the minimum amount of necessary vehicles per area to fulfil limited transport requirements had to be found. To find a measure for the minimum necessary amount of vehicles different aspects as transport patterns, delivery times and vehicle utilisation have been included (Mackulak and Savory 2001). Based on this, different simulation studies have been executed to find most important parameters to be included in this measure. This leads to the following formula to calculate minimum amounts of vehicles VAB ($B_{i,j}$) for the different transport relations as input parameters for the VAB in general:

$$VAB(B_{i,j}) = \frac{tph(B_{i,j}) \cdot t(B_{i,j})}{U} \quad (1)$$

Let:

i Source area index i = 1, 2, …, I (I as amount of different source areas)

j Destination area index j = 1, 2, …, J (J as amount of different destination areas)

$B_{i,j}$ Transport relation from source area i to destination area j

$tph(B_{i,j})$ Average transports per hour for transport relation from source area i to destination area j

$t(B_{i,j})$ Average delivery time for transport relation from source area i to destination area j

U Vehicle Utilization as rate of vehicle usage time with $0 \leq U \leq 1$

For i=j the critical value for each defined area can be calculated. Again simulation was used to validate these values regarding their target achievement of fulfilling transport requirements for each area.

In the following the resulting values for the different transport relations are used as the critical values within VAB as explained in the next section.

3 Vehicle Area Balancer

Although minimum functionality of an area is ensured by defined vehicle amounts the realisation cannot be done without an according adjustment of dispatching rules and the transport jobs generated by the manufacturing execution system (MES). Even during failure scenarios transport requests for local to-tool transports have to be generated while inter-area transports through effected areas have to be rejected. If the transport controller recognises a critical value for the vehicle quantity within a certain area communication of this exception has to reach the MES. MES then has to identify the transport related situation and to draw the right conclusion. In the following, non-affected areas will be considered as local. That means they don't have any available transport relations which are using jammed areas. An overview about the ways of communication between the different parts of the system architecture can be seen in figure 3.

Bay Control Units (BCUs) calculate amounts of vehicles within each BCU in a periodic process. This information about BCU borders and vehicle quantities leads to the possibility to define specified areas and their critical values. Critical values have to be monitored by a sub program of the Overhead Hoist Transport Controller (OHTC). If one of the critical values is reached there has to be a defined warning message arriving at the Material Control System (MCS). This message finally has to be transmitted to the MES to be recognised by the Real Time Dispatcher (RTD). This trigger for the critical area has to be communicated and interpreted in the right way to identify the transport system state and to adjust the transports in the appropriate way.

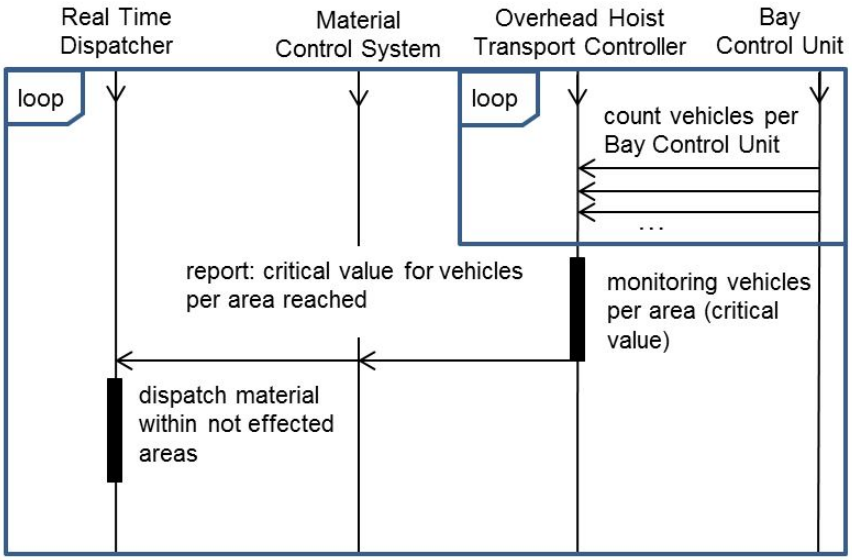

Figure 3: *VAB communication sequence diagram*

The innovation of the VAB is the consideration of transport related issues within the RTD decision level. RTD describes a software solution within the MES environment which dispatches available production material by considering the current fab situation (e.g. including tool utilisation and cycle time). Based on this, scheduling lists of production material are generated and finally certain material is assigned to a certain tool. To ensure an at least limited functionality of non-affected areas during traffic jams, consideration of this decision level is essential.

The described new system logic intervenes significantly into transport job generation and subsequently the control of the whole fab. Transport jobs are rejected or adjusted by taking into account not only parameters of the manufacturing line but also transport related issues. Rejecting transport requests due to AMHS problems is not state of the art. Since it could help to increase transport capacity and reduce the time until the traffic jam is cleared, negative consequences of system failures can be reduced. However, testing the new logic by implementing it into the real system is impossible for a bunch of reasons. Simulation is a suitable method to get a first idea about functionality and benefit of the VAB, if it is worth initiating further development steps and for optimisation of parameters.

4 Simulation

4.1 Simulation Model

The simulation model was developed in AutoMod. It combines four different buildings as depicted is figure 1. The simulation model uses the same layout as the real fab and includes the following system attributes:

- 825 process tools, direct accessible by AMHS
- about 20.000 storage locations in total

- more than 14 km of track
- more than 500 vehicles

The model logic also uses the same vehicle control strategies as the real system. Empty vehicle balancing dispatches empty vehicles according to common watermark strategies. Secondary the vehicle routing is based on optimised cost settings instead of travel length or time only. Thus, not only shortest paths are taken into account but also system depending parameters (Hammel et al., 2012). This leads to beneficial paths for transporting vehicles in order to avoid bottlenecks whenever possible. Furthermore, the real system vehicle speed characteristics are implemented in the simulation model. Vehicle speed is set depending on whether the vehicle is using or approaching a curve, merge, diverge or a straight piece of track. By using even more details and logic of the real system than the described features the simulation model reaches a mean deviation in performance measures compared to the real system of less than 5%. This measured deviation makes it suitable to gather reliable results and conclusions from this reproduction of the real system.

The above mentioned features are essential for reflecting failure free simulation scenarios. Additionally, there are other features which make simulation the most suitable approach to get a first idea regarding VAB logic functionality. It is possible to stop vehicles within the simulation model at a certain place for a certain amount of time and therefore to reproduce system failures. Besides deadlock escape settings there are different vehicle amount restrictions, too. These are very important to reflect real system traffic jam behaviour which would be the use case for the VAB. For example there are parameters which define maximum vehicle quantities for each BCU or even ceiling load restrictions which have to be considered by the ceiling mounted OHT. Finally, there is the possibility to use and manipulate real fab transportation data as input for the simulation model. The VAB rejects and adjusts transport jobs depending on where the system failure takes place and which area is endangered to lose minimum transport capacity. Therefore the adjustment of the transport data sets is essential to be able to test VAB logic by using the simulation approach.

4.2 Simulation Experiment Description

To get a large set of information about VAB functionality and system performance effects different scenarios for simulation runs have been developed.

As already mentioned in section 2.1 the main bottlenecks regarding the transport system have been found along the connections between different buildings. According to these results the top 3 bottlenecks have been chosen for the simulation studies.

The impact of traffic jams for the transport system not only depends on the place but also on the duration. If a vehicle stops due to a failure and it can be released within a few minutes it will not have fab-wide impact. The longer it blocks a route the more vehicles will pile up within the traffic jam. This leads to higher transportation times, waiting times and lower throughput as well. To see the influence of the newly developed VAB logic as a function of the failure duration, three different intervals (described as short, medium, long) have been considered for the simulation scenarios.

Additionally, three different sets of transport data generated by the fab have been used to cover a higher variety of different system states. Therefore, a methodology to implement real fab data into the simulation model had to be developed. Combination of different denotations between real system and simulation model could be achieved by using a self-developed data base approach. Subsequently another step where the data sets can be adjusted according to the VAB logic has been implemented into synchronisation: depending on which bottleneck was blocked in each scenario transport jobs have been adjusted or rejected according to source and destination type.

An example of transport job adjustment can be found in Table 1. It refers to one of the scenarios where the entrance of area A (fig. 1) is blocked and other areas are not affected. After a certain period of time the pre-defined critical value for the minimum vehicle quantity of area A is reached and the VAB logic starts working. Hence all outgoing inter-building transports will be adjusted while ingoing inter-building as well as intra-building transports will not be affected. The way of adjustment depends on the source and destination type. The simplified logic is as follows:

- If source type is tool, the load port has to be cleared and the FOUP will be transported into a storage next to the tool
- If source type is storage, the FOUP stays at the port and the transport job is rejected

Table 1: *Transport Adjustment according to VAB rules (Src = Source, Dst = Destination)*

SrcType	SrcArea	DstType	DstArea	Adjusted DstType	Adjusted DstArea
Tool	A	Tool	Other	Storage	A
Tool	A	Storage	Other	Storage	A
Storage	A	Tool	Other	Rejected	Rejected
Storage	A	Storage	Other	Rejected	Rejected

Furthermore, each simulation run has been subdivided into a warm-up, failure and relaxation period to cover all different system states (normal, traffic jam with VAB logic and return into normal state).

4.3 Results

The evaluation of the simulation experiments was carried out with statistical analysis regarding transports per hour (TPH), vehicle utilisation, mean and 95%-quantile of delivery time. The results depicted in figure 4 reveal a significant reduction of delivery time measures for each simulated failure duration interval. Referring to the close approximation of simulation to real system the results show that the VAB improves the performance of the transport system during failure scenarios. For the short and medium failure durations the expected reduction in TPH due to transport job adjustment can be recognised. Although the VAB logic rejects a certain amount of transports, the TPH for the long failure durations with using the VAB logic is

even higher than in the original state where a certain amount of requests cannot be transported. By adjusting and rejecting transports according to the new logic, this transportation capacity can be increasing compared to the original state. This effect is even more obvious when looking at intra-building transports only because these should be the most affected ones. As depicted in figure 4 the increase of transport capacity is even reached at medium failure duration.

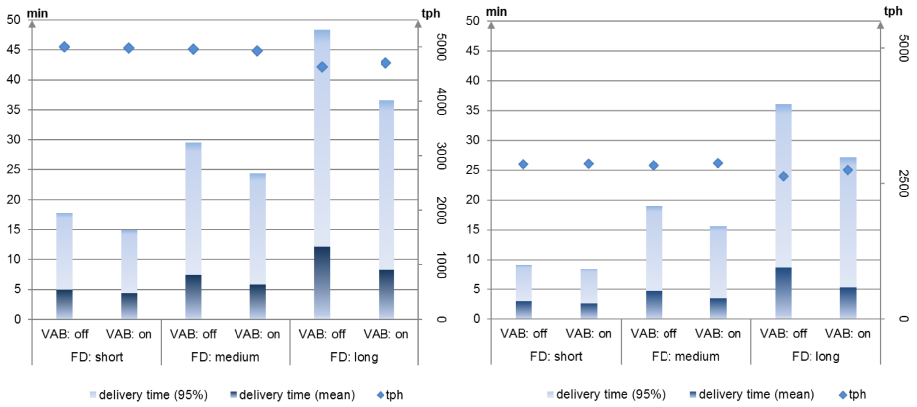

Figure 4: *Summary of simulation experiments for all transports (left) and for intra-building transports only (right)*

With this result in mind, simulation delivered the assumption that the VAB not only improves system performance. The developed solution also effectively increases transport capacity during failure scenarios to support production as good as possible.

By using simulation as a validation tool of the developed logic, first positive results regarding functionality and operational readiness have been achieved. Especially, in semiconductor industry simulation is a strong analysis tool which is indispensable because of the system complexity. Testing transport related changes within the real system would always involve high risks. The failure of the new method very easily could cause a loss for production in the amount of several millions of Euros.

5 Conclusion

Even in fully automated semiconductor manufacturing facilities the MES dispatches production material according to tool utilisation and shortest cycle times. Transport related restrictions have not been involved into these decisions upon today. The VAB is an innovative system solution which combines these issues. It was developed to reduce negative effects of failure scenarios in a distributed AMHS.

The presented approach goes beyond common techniques but the transport system as well as the manufacturing line will profit from this innovation. It offers new opportunities to reduce transport related risks for production especially for persons responsible for the transport system. Simulation is a suitable tool to bring this kind of innovative approaches forward and emphasise their usability.

Simulation was used during different parts of the VAB development: Evaluation of important parameters for the calculation of the critical values for each area, validation of these values and finally to test the VAB logic for the first time. Especially the possibility to manipulate real fab data regarding different dispatching rules and testing these rules with the simulation model in advance is beneficial. Simulation studies showed the expected behaviour and that the VAB is a possible tool to improve system performance and increase transport capacity during failure scenarios by keeping a minimum amount of vehicles in each predefined area.

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