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EVALUATIONS ON SCHEDULING IN SEMICONDUCTOR MANUFACTURING BY BACKWARD SIMULATION

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ABSTRACT

Manufacturing is today often characterized by a growing number of customer-specific products that have to be manufactured and delivered in given lead times, according to concrete delivery dates. Thus, highly relevant questions like "When to start a production order at latest, in order to stay within my lead time?" are answered by more or less primitive, backward-oriented planning approaches and without taking into consideration uncertainty or alternatives. It gets more complex, if different products are to be produced and the more complex the underlying manufacturing system is (e.g. semiconductor with re-entry cycles). These questions could be answered more specifically, more detailed and more robust, if discrete, event-based simulation (DES) would be applied in a backward-oriented manner. This paper describes evaluation results from the semiconductor domain and names restrictions and limits. They also show, that the backward-oriented simulation approach can be applied successfully for the scheduling of customer-specific orders.

1 MOTIVATION

It is well known since a long time that discrete event simulation (DES) is very suitable to model the reality in a manufacturing system exactly. Such models are easy to parameterize and they are able to consider several influences including stochastic behavior (i.e. Law and Kelton 2000). In addition complex interactions between a large number of resources can be modeled as well as special conditions like maintenance activities or several dispatching-, batching- and setup-rules. Usually, only forward simulation is used for solving scheduling problems. This means, starting from a system state at the time t_1 a future state at the time t_2 will be determined, with $t_1 < t_2$.

Undoubtable, backward simulation would have many advantages in comparison to a simple backward timing without consideration of limited resources, as it is usual in critical path method (CPM) or in most of the ERP systems (ERP – enterprise resource planning). However, the application of DES for backward scheduling problems, in the following referred to backward simulation, is rare. Even more a general theory of backward simulation methods is still lacking.

2 STATE-OF-THE-ART

Backward simulation would have many advantages, as shown by Schumacher and Wenzel (2000), but it could not really be established in the scientific and industrial applications until now. First application studies where orders are scheduled backwards in time by backward simulation are available for more than 20 years. Watson et al. (1993, 1997), Ying and Clark (1994) and Jain and Chan (1997) used such methods for calculating release dates of lots or orders. In the backward model the entry point and the exit point for the jobs are reversed compared to the usual forward model. Jobs enter the system at the exit points of the forward model and leave it at the entry point. The completion date of the backward model is the release date of the forward model. While the backward simulation is not a simple reverse function of the forward simulation both types of simulation do not have to have the same system state for the same simulation time (see also Ying and Clark (1994)).

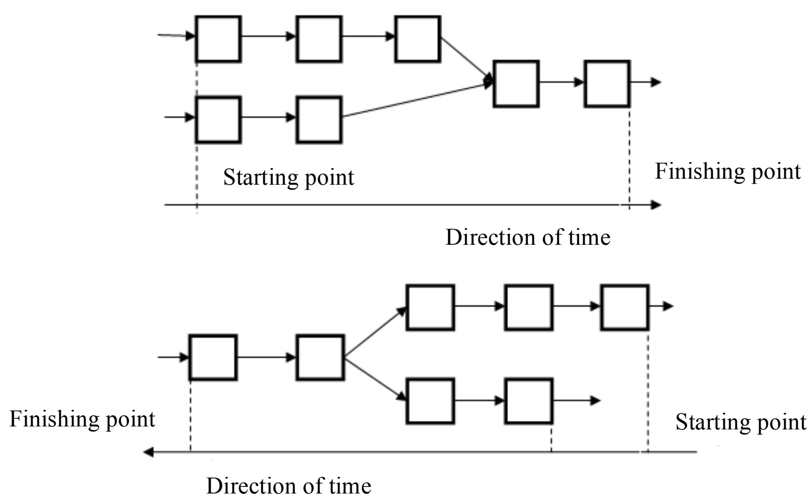

Figure 1: Backward simulation approach.

Watson et al. (1993) describe some difficulties when creating backward models. Therefore, for example, assembly stations must be converted into disassembly stations. Unfortunately the queuing discipline is not always intuitive invertible. Most commercial simulation systems are unable to let the time run backwards, so that the time axis must be inverted after the simulation run. Distribution-, setup-, dispatching- and other rules must be modified. In addition, they did not consider work in process exactly.

Quite similar to the backward scheduling in ERP-Systems also the backward simulation is used in combination with forward simulation in order to solve these problems. Jain and Chan (1997) determine at first the bottlenecks of the system by forward simulation. Lots, which are processed on the bottleneck stations, will be grouped to minimize the setup time. After this, the forward model was inverted and the lots will be released on the bottleneck stations at the related completion dates resulting from the previous forward simulation run. Certainly, Jain and Chang used exclusively deterministic models.

Watson et al. (1997) starts with a backward simulation run to schedule new orders. After this, outstanding orders are scheduled by forward simulation. The forward and the backward model differ in degree of detail. The backward model is just a deterministic model. For many variables of the backward model, such as processing times, a slack time is added. Nevertheless, this is in contradiction to the goal, to increase planning accuracy by the backward simulation.

Until now, continuously case studies are published on methods of backward simulation, for example Arakawa et al. (2002), Graupner et al. (2004), Huang and Wang (2009), which report on experiences of single practical cases. Horn et al. (2006) used backward simulation in connection with forward simulation and simulation-based optimization for short-term scheduling in a backend of a semiconductor fab.

3 PRACTICAL IMPACT

Infineon produces customer-specific logic chips in the high-automated Dresden fab. High complexity, caused by the variety of technologies and products with 400 … 800 steps and with many re-entrant process flows, has to be mastered ensuring delivery commitments with short, controllable and predictable cycle times. On the other hand, a semiconductor fab with very expensive machines has to be operated in a high efficient mode. These facts substantiate the need for simulation methods on all levels of the production process. Well established in daily business are applications of common forward simulation approaches, like cycle time and WIP forecast. Important decisions in planning (e.g. start of additional orders) and in operations (e.g. scheduling of machine maintenance activities) are done based on simulation results. One open topic is the optimization of daily delivery from the fab. Due to a lot of stochastic events in a semiconductor manufacturing and the use of dispatching rules for local capacity optimization at high utilized machines (e.g. batching or setup minimization), the products run with a high cycle time spread. On the other hand, on-time delivery is essential for survival of a customer-specific manufacturing. The effect of stochastic events and local dispatching rules on cycle time spread cannot be eliminated completely. Of course, a quantification of these effects is feasible with simulation and the additional needed cycle time buffer can be defined. Nevertheless, this procedure consumes additional capacity on the very expensive machines resulting in increased costs. Furthermore, a customer-specific manufacturing has to be flexible towards sudden change requests, the orders have to start in production at the latest possible date. The challenge to solve this problem is the optimization of the lot release pattern in consideration of the aspired daily delivery plan. Using the common forward simulation, it would be a very extensive process, and if we look into future, it would not be a useful approach for daily business. Therefore, the idea is, run the manufacturing process in simulation in reverse and use the aspired daily delivery plan for input. The output of this reverse or backward simulation is a specific pattern of lots. This is a mirror of the typical characteristics of the process flow, e.g. the sequence of single wafer and batching machines or the used dispatching rules. Assuming in backward simulation the machines show similar behavior to both forward simulation and reality, the result of this approach would be an optimized lot release plan resulting in a real cycle time reduction.

4 APPROACH

In our approach, backward simulation serves as a planning approach for the scheduling of manufacturing orders, which are determined by a given delivery date and a fixed lead-time for production and delivery. By each changing the direction of the simulated time as well as the direction of the underlying material flow, based on a given packet of orders a scheduling plan will be derived (cp. Figure 2). If this can be applied successfully and if the limitations of the approach are wisely elaborated, than this approach can be improved by the introduction of stochastic influences during the simulation-based scheduling process. This shall lead to more robust production plans and reduce the need for re-planning, if disturbing events during the daily production environment happen. Since the theoretical approach seems to be meaningful for us, we started with a practical analysis for its validation.

Based on given use-cases, the first idea was to derive the specific success criteria for backward simulation that lead to good and valid results. In the given state-of-the-art, the researched use-cases came to different conclusions and so some more objective criteria for a successful application of backward simulation should be elaborated. In a second step, it should be researched, if the solution quality of backward simulation could be better, than the existing dispatching-rules at the Infineon use-case. Better here means, that an improved quality of delivery rates is achieved, or that a given delivery rate can be achieved with less stock of semi-finished goods. In the last step, the integration of stochastic influences and uncertainty should be integrated in the planning approach. **Figure 2** shows the initial planning approach including backward simulation.

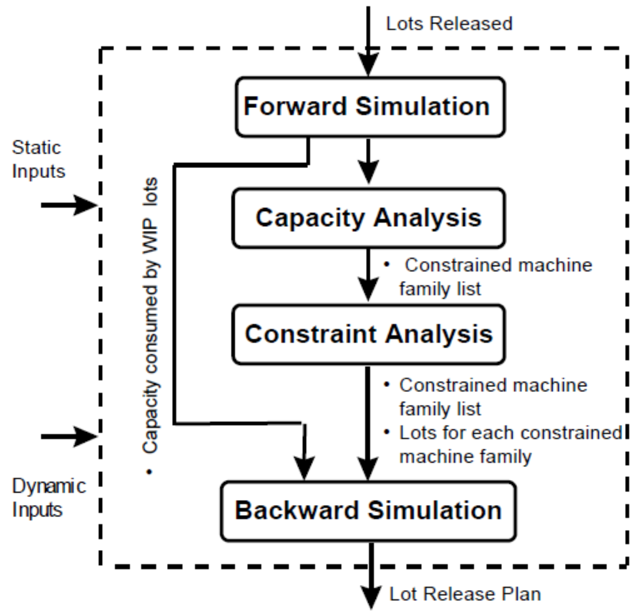

Figure 2: Planning approach for scheduling with backward simulation.

5 FIRST EVALUATIONS

In the given production environment of the semiconductor manufacturer we started with some very simple on stage machine problems and tried to invert the most common dispatch rules, that are currently implemented in the factory. The systems are widely spread over nearly all manufacturing systems and even more complex systems with a single bottleneck can be reduced to this simplified model. According to the backward simulation of such systems, it is necessary to invert the selected dispatch rule, e.g. from LTP (longest processing time first) to SPT (shortest processing time first) and the backward simulation model. Another example: a common dispatch rule like EDD (earliest due date) can be transferred to 'earliest stop date first' in the backward simulation.

Based on the results, some more complex simulation models have been constructed by introducing either the multistate problem or parallel machines. After investigating some very simple job shop problems, the first results show that based on the inverted dispatch rules other machines has been selected for the same jobs, but without losing significant amount of performance. Another very common scheme that can be found in semiconductor manufacturing are batch machines, where multiple jobs are processed at the same time. In order to process these machines in the most cost efficient way, number of lots or jobs, that is processed in parallel, has to be maximized. Here, the simple turnaround of the simulation model into the backward simulation model comes to its limits very soon. Figure 3 describes the behavior of the simple batch machine, where lots can be processed in parallel. The maximum waiting time in order to build a batch from two jobs in the simulation model is half of the processing time. In the original simulation model, EDD is used to determine starting time for job. A simple invertation to a backward simulation model with a corresponding transfer of EDD leads to the production plan; it can be seen in Figure 3 on the right-hand side. As it can be seen, the number of batch processes sinks dramatically. Moreover, it can be seen, that different lots are connected to a batch process, so that a complete different production schedule would be the result.

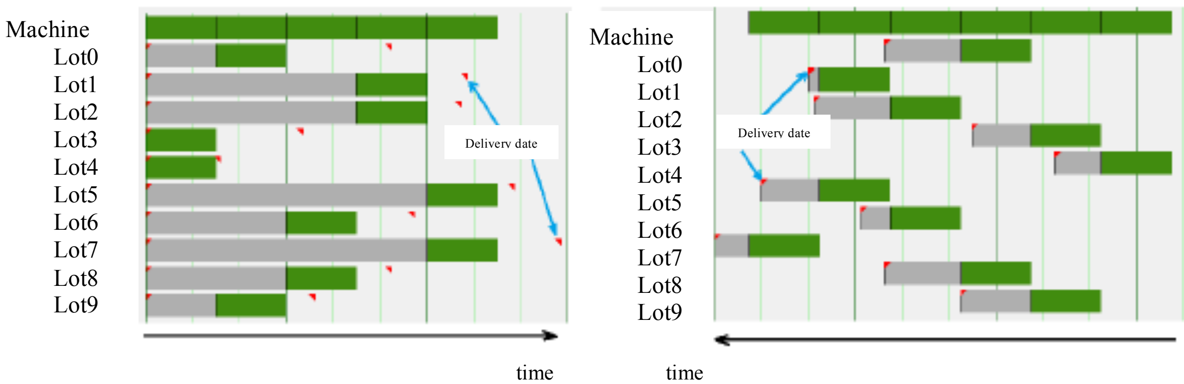

Figure 3: First use-cases of a batch-process with a simplified model.

Further experiments with job shop and flow shop problems also show the potential benefits of the intended backward simulation methodology. Whereas in a common flow shop model with existing dispatch rules some jobs are delivered beyond that due date, the resulting schedule from the backward simulation approach leads to the production plan, when all orders are delivered in time.

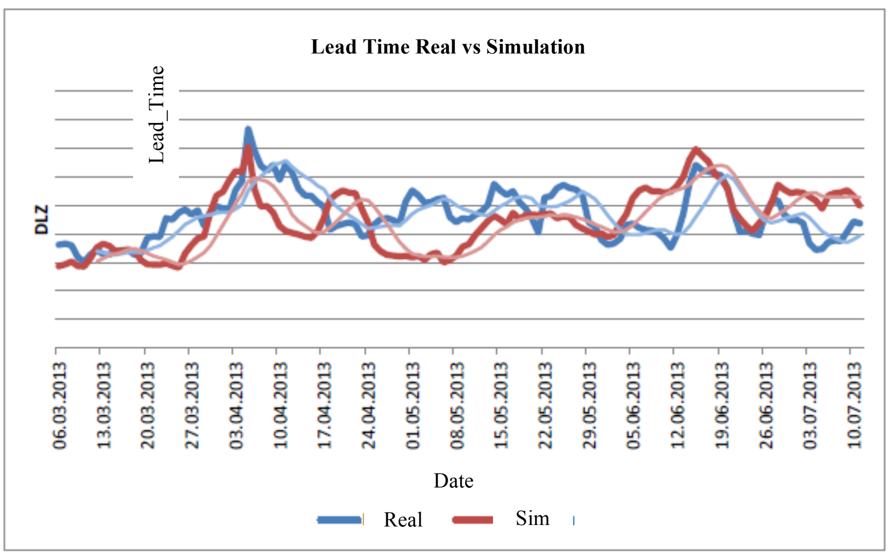

Figure 4: Results of a first real-world use-case 'Wafertest'.

However, the gained results have been limited in another aspect: the investigated systems have only manufactured jobs based on one single product. In order to gain some further results of higher complexity, a use case from semiconductor manufacturing has been chosen with a more or less XXX characteristics, but taking into consideration different product types with different processing times and routes through the process. Here the so-called wafer test was selected. Placed in the front end of the manufacturing process, the wafer test section covers functionality tests, optical controls, the cutting of the wafers and some further processes till the delivery of the manufactured chips. In order to reduce complexity, only a section of the complete wafer test was selected, where the bottleneck of the overall process was identified. Based on a first data analysis, this construction of a reduced simulation model seems reasonable, since lead time for production in this section has a high deviation.

After the deeper analysis of the data quality, we finally came to a simulation model, which corresponds to some real-world measurements in a quite sufficient way (cp. Figure 6 as an example for lead time). Based on this simulation model, the construction of the backward simulation model was derived according to the principles described above. However, some specific dispatch rules could be identified during this process, where the corresponding rule for the backward simulation model could not be constructed in a simple way. One example is given in Figure 5: in the forward simulation model, the machine setup is changed to another product, if the waiting time after the finished job exceeds four hours. This rule takes into consideration some 'historic' measurements that cannot be applied in a corresponding way and the backward simulation model. Here, the simulation expert has to find corresponding rules during the construction of the backward simulation model.

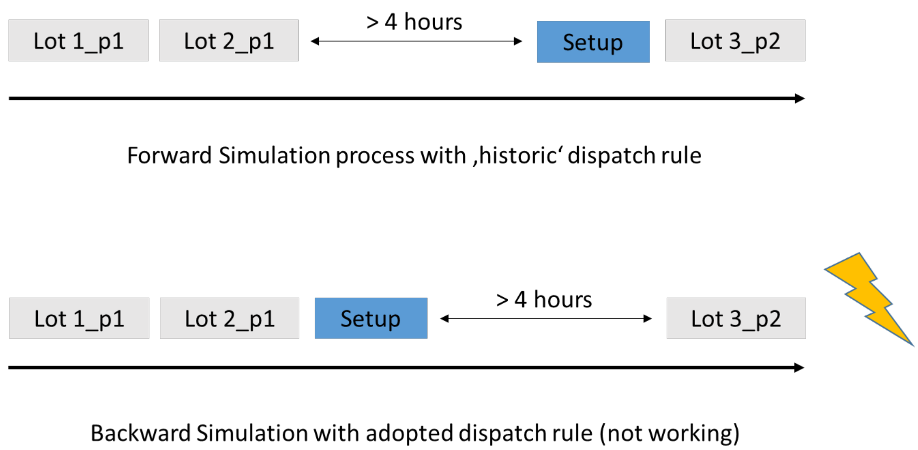

Figure 5: Identified limitations of the backward simulation approach: 'historic' rules.

By doing so, the backward simulation model can be used for scheduling of determined jobs even in the more complex manufacturing environment. Figure 6 shows some early results of the mentioned wafer test use case, where the red line shows the result of the forward simulation model based on the real data. The corresponding green line shows again the result of the forward simulation, but here the schedule generated by the backward simulation model is taken as an input data. It can clearly be seen, that by a backward oriented scheduling the cycle time can be reduced in a significant way.

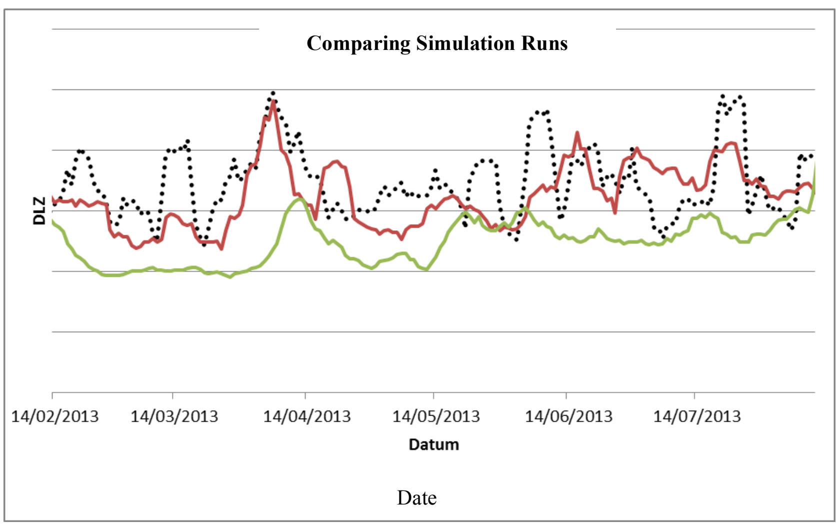

Figure 6: Evaluating a schedule generated by backward simulation.

Moreover, Figure 7 shows, that nearly all jobs can be scheduled in such a way, that most of the jobs are delivered on time and closer to the desired delivery date. Embedded in the practical application, this would lead to reduction of work in progress as well as buffers between the production steps. Figure 8 underlines these results in showing that nearly all scheduled jobs are delivered until one day after the desired delivery dat ˉn a practical application, one could use these theoretical findings by considering additional ‘planning ˈfer’ of one day in order to improve the schedule quality.

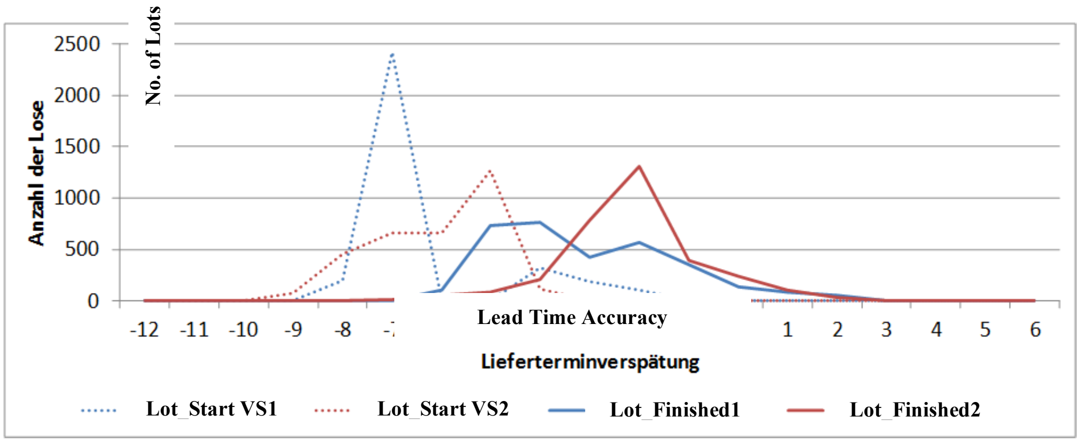

Figure 7: Gained advantage - batches are finished closer to delivery date.

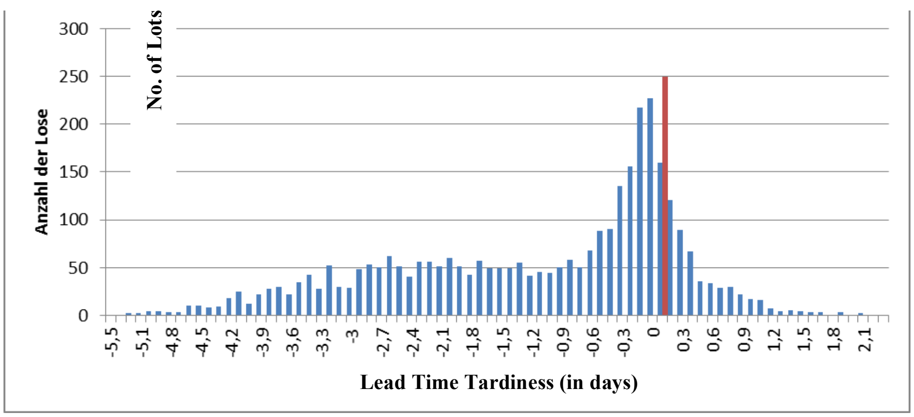

Figure 8: Resulting schedule has high quality.

Based on these results, another part of the manufacturing system was taken into consideration for deeper analysis. To gain knowledge the first application is now applied in a more complex model with even more product types, which have to be scheduled over large set of machines. Again, the simple inversion of the forward simulation model brings up poor results and manually some additions to the corresponding backward simulation models have to be done. Several key performance indicators (KPIs) were used in order to evaluate the quality of the backward simulation model: WIP, lead-time and utilization of the machines. Especially the batching process becomes more and more important role, since nearly all measured deviations are caused by the creation of different batches in comparison to the real data from the manufacturing system. By adjusting these rules and especially the waiting times for the batching process for the different machine groups, the quality of the schedule, generated by the backward simulation, can be further improved, so that again the jobs are manufactured very close to their desired delivery date.

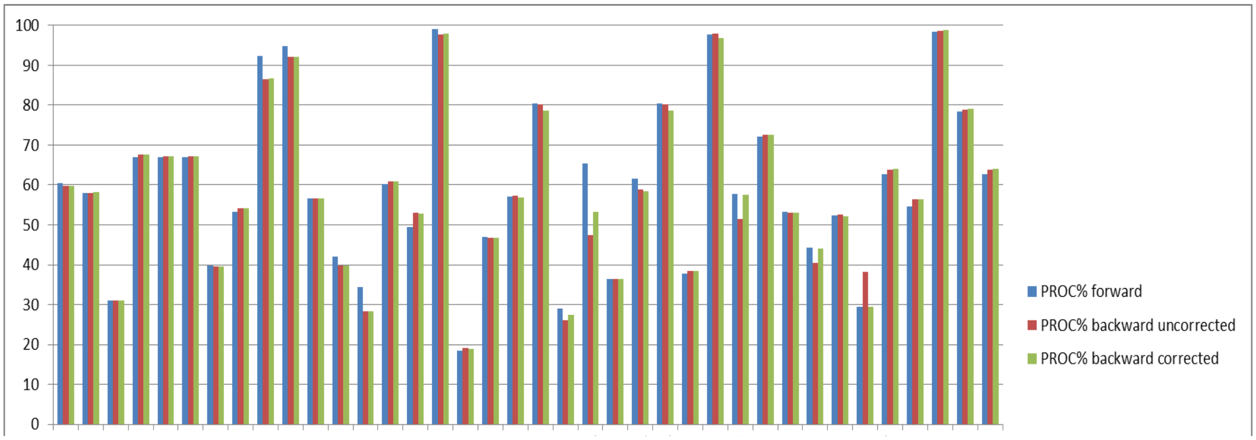

Figure 9: Machine utilization for the second use-case.

Figure 9 shows one of the gained results, where several lots are started each day in such a way, that the mean utilization of 60% for the overall production process is achieved. Each group of the blue, red and green bar stands for a specific machine group. Some of the considered machine groups are already at their maximum throughput. The blue bars show the desired machine utilization based on the forward simulation of the real data. The red bar shows the results of the forward simulation at the validation step for the simple backward simulation model. The green bar shows the results for the forward simulation at the validation step for the improved backward simulation model. Although the difference seems to be very low on the first view, the corresponding results show a much better quality of the generated job schedule.

6 CONCLUSION AND OUTLOOK

Manufacturing is today often characterized by a growing number of customer-specific products that have to be manufactured and delivered in given lead times, according to concrete delivery dates. Corresponding scheduling questions can be answered more specific, if discrete, event-based simulation (DES) is applied in a backward-oriented manner (backward simulation). This paper describes first evaluation results from the semiconductor domain and names identified restrictions and limits. The results generally show that with the backward-oriented simulation approach production schedules can successfully be generated for customer-specific orders in the semiconductor domain. However, the modeling of a backward simulation model corresponding to an existing simulation model of the manufacturing system is neither simple nor can be done automatically today. Especially, existing priority rules based on historical data of the manufacturing system and batching processes lead to problems during the inversion of the simulation mode. Here, specific domain knowledge is needed, in order to build customized rules for the backward simulation model.

Further evaluations are to be done in the future in order to elaborate additional limits and possible workarounds for the inversion of simulation models in order to apply them for a backward oriented scheduling. Most of the mentioned test cases in this paper are moreover based on deterministic simulation models. Thus, a major advantage of the mentioned approach is the application of stochastic influences, where needed, in the scheduling process. This is also to be researched and refined in future work.

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