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Applying Aggregated Line Modeling Techniques to Optimize Real World Manufacturing Systems

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Abstract

The application of discrete event simulation methodology in the analysis of higher level manufacturing systems has been limited due to model complexity and the lack of aggregation techniques for manufacturing lines. Recent research has introduced new aggregation methods preparing for new approaches in the analysis of higher level manufacturing systems or networks. In this paper one of the new aggregated line modeling techniques is successfully applied on a real world manufacturing system, solving a real-world problem. The results demonstrate that the aggregation technique is adequate to be applied in plant wide models. Furthermore, in this particular case, there is a potential to reduce storage levels by over 25 %, through leveling the production flow, without compromising deliveries to customers.

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Keywords: Discrete event simulation, Aggregated line modeling, Multi-objective optimization, Manufacturing systems

1. Introduction

Manufacturing companies, and automotive companies in particular, are facing new challenges with regards to the needs of mass customization, environmental focus, rapidly changing markets, and continuously shorter product life cycles [1]. Automotive companies are also in a high degree effected by the transformation to electric propulsion. To address these problems, companies need to accurately predict the consequences of these changes and the effects they will exhibit on their manufacturing systems.

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A common method to model, evaluate, and predict manufacturing system performance in the development of manufacturing operations is through the use of discrete event simulation (DES) according to Jahangirian et al. [2]. Generally, the use of DES is focused on the complex modeling of production lines and not on the complete manufacturing system [3]. Interesting answers can be found by optimizing, with the help of simulation-based optimization (SBO), on the factory level instead of the line level.

Until recently, analysis of the higher levels of manufacturing systems, through the application of DES, has been limited due to model complexity and lack of aggregation techniques. While mathematical models and system dynamic models could be used on higher level manufacturing systems, they tend to be somewhat limited for modeling of complex manufacturing systems with stochastic variation [4]. Recent research, by Pehrsson et al. [5,6], has introduced new aggregation methods for DES which holds potential to simplify the creation of simulation models for entire factories, but has not until now been officially tested on real world applications. This paper aims to test the aggregation technique on a real-world industrial problem to identify bottlenecks and constraining issues on manufacturing plant level and thereby give additional decision support.

This paper will be structured as follows: In section two, a brief literature review of aggregation techniques and DES will be presented concluding with a motivation for selecting the aggregation technique for the case study. The studied industrial system and how it operates will be analyzed and explained in section three. Continuing with a case study of the aggregation technique on a real-world manufacturing system in section four where some additions and changes to the technique will be proposed. The paper will be concluded by a section detailing the results and suggestions for future work.

2. Literature review for manufacturing simulation on site level

Simulating and modeling complete manufacturing plants containing several production systems and logistical processes is not a trivial task but have enormous potential to increase efficiency in a company [7]. To gain this efficiency, companies need to react faster to changes and make the most optimal decisions with knowledge about the state of the current system, but also with knowledge about the future with consideration to new products and volumes. Simulation is a means to bridge the gap between what is currently known and the state to reach in order to deliver on future promises and targets.

Detailed simulation models are often the best way to represent manufacturing lines, and to answer specific and detailed questions about changes to the lines. However, running detailed simulation models is time consuming and require a large amount of data [8]. When several of these detailed simulation models for manufacturing lines are combined and material transports between the lines are added, further complexities arise in regards to data needed and simulation running time. The further into the future we are trying to analyze, the more the number of possible scenarios will increase due to market uncertainties and customer trends. Furthermore, detailed data could also be difficult to specify in a scenario only a few years into the future or for new lines. These issues calls for a decrease in the complexity of the models to be able to run them faster, and modify them more easily in the face of increasing change [9–12].

Several methods for aggregation of detailed manufacturing models have been studied by other researchers. Using effective process time (EPT) by Hopp and Spearman [13], has been analyzed and applied by several authors [14,15]. Another technique is the use of clearing functions to represent system behavior, mostly related to supply chain problems [16,17]. Hybrid modelling in the form of combining DES and System Dynamics are also used to gain insights into systems [18,19]. Being able to model industrial systems on a higher level, with fast computing time, correct variability of outputs, and with few inputs using DES is a good option if detailed DES models are already created to draw data from.

Using only a few inputs ad work in process (WIP) control based on Little's law [20] in combination with stochastic variation, a technique described in Pehrsson et al. [5], was chosen to be implemented in an application study. In comparison to the previous aggregation techniques, EPT and clearing functions, the technique is developed to be applied in a DES software, using common objects, to enable visualization. The technique uses four objects, *LineInput*, *LineWIP*, *LineOutput* and *WIPControl* to represent a complete manufacturing line with variations and delays. The available WIP in the system is controlled and is released back with stochasticity from *WIPControl* to vary the return to the *LineInput*. The technique is well suited for general applicability, as shown in the original paper [5].

3. Industrial problem

In this section of the paper, the structure of the industrial system to be studied will be explained followed by an overview of the planning systems and procedures. The first part will also contain a section explaining the difficulties facing the system and how those complexities arose. The last part explains why the use of simulation, and especially aggregation techniques, are important for answering specific questions about this industrial system.

3.1. Industrial setup

The industrial setup consists of several raw material storages, each connected to one or more highly automated machining lines (ML) producing one of four different main components, A-D. Some components have multiple machining lines, and are named iteratively 1..N, as can be seen in Figure 1. The figure represents a high-level description of the industrial system and the model. Input and output data from the model have been masked to protect the company's internal information and are in some cases also generalized due to the need for brevity. However, all relations in the data has been preserved.

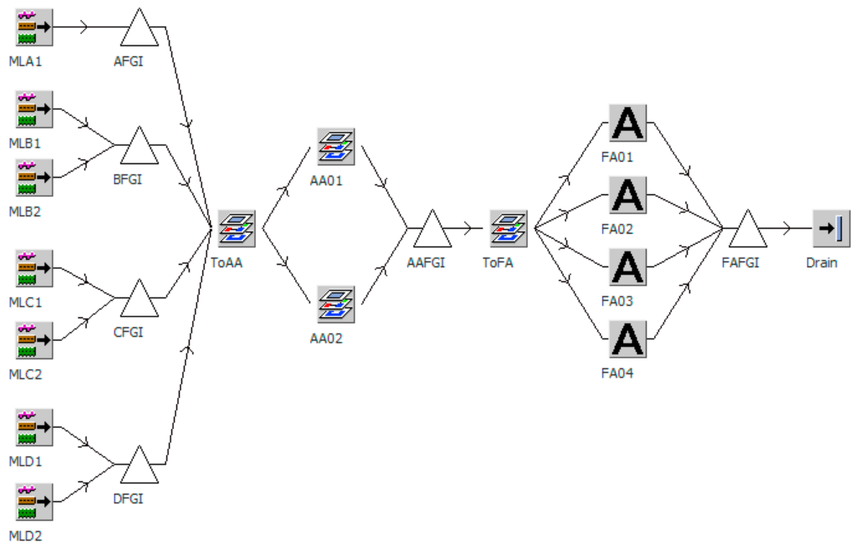

Figure 1. Industrial setup represented in the model

The products can be divided into two families, each with several variants. Each type of component is machined in multiple steps and then placed into a finished goods inventory (FGI), which holds the parts until the next step in the process. The components are transported via automated systems to be assembled in a semi-automated line, referred to here as automated assembly (AA), and after assembly, placed in another FGI for intermediate parts. AA lines are not fully flexible, meaning they are setup to only produce variants from one of the families of products each. Finishing the process are multiple parallel manual assembly flows, from here on referred to as final assembly (FA), and finally stored in the dispatch area.

3.2. Industrial system planning and operation

For production scheduling, planning, and process control, several systems are used. Automatic planning systems takes customer orders and schedules them for completion against FA. FA systems can be planned as a one-piece flow, and are setup to be very flexible, though most often they are operated with small batches to facilitate production in AA. These orders are mirrored to the AA, taking into consideration the variant and family restrictions.

The goal of the production planning is to utilize a fixed plan from AA until the completed products are placed in the dispatch area to be delivered to the customer. This is not always possible due to unforeseen circumstances downstream in the production flow such as receiving faulty material from suppliers or changing demands from the customers. This leads to planning changes and causes a Bullwhip/Forrester effect [21], due to larger batch sizes in the machining lines.

Customer orders are available for approximately one year in advance, but orders are only partially fixed for the next 10 upcoming days. Products are ordered from the machining FGI to AA by the same production plan. Planning, ordering of raw materials, and scheduling for the machining lines are done manually by production planning personnel. They plan the production based on daily production targets matched against current FGI levels and forecasts of customer demands.

The studied plant has some inherent issues with flow balance due to numerous updates and changes implemented over time. Machining lines are complex with heavy machinery and automated material handling and therefore more expensive to buy than AA and many times more expensive than FA. Different machining lines have been bought with different capacities regarding JPH and different prerequisites when it comes to flexibility in setup to produce different variants. The machining lines are also more prone to longer breakdowns compared to the assembly systems.

All the machining lines are operated on additional shifts, in combination with increased batch sizes to offset setup requirements and maintain an overall high overall equipment effectiveness (OEE) value to meet an increasing customer demand. Since the machining lines do not have a customer on the weekends, and are being outpaced on the weekdays, large FGI's are needed between machining and base assembly to offset this misalignment. Analyzing the behavior of the factory and the effect of proposed changes, either product or process related, has become increasingly difficult without the use of simulation. Static analysis tools like value stream mapping is not sufficient to capture the dynamic and stochastic behavior of the real-world system [22]. The next section will go into further detail about the model built to analyze the industrial case.

4. Methodology

Modeling large and complex production systems using DES is a difficult task. Selecting the correct level of detail will have a large impact on the results and execution time. This first section explains how the DES model has been built using the aggregation technique selected in Section 2 and details some modifications to the technique. The last part will detail the issues of the industrial system to be analyzed by the model and potential solutions to the issues.

4.1. Model setup for the case study using aggregation on factory level

The model is built in the DES software Siemens Tecnomatix Plant Simulation 14.0.2 and represents different time periods for the industrial system in order to evaluate the effects from an increasing number of variants, customers and suppliers. Each manufacturing line, machining or assembly, is modelled by using the aforementioned aggregation technique [5]. By supplying processing time (PT), maximum WIP, average WIP, minimum lead time (LT), availability, and mean time to repair (MTTR) the lines can be modelled with only a few objects while retaining the dynamic input and output of the lines.

Planning and scheduling input to the model is either the one-year forecast program exported from the planning system or a scenario-based forecast, primarily on the strategic level [23]. These scenario-based orders are then divided in the same way the automatic planning system would have divided them amongst the FA orders. In addition to the variants and volumes, input such as the number of shifts, paces, and working times also needs to be added. In place of the manual planning done for the machining lines, an implementation of safety stock and reorder points have been implemented. The levels for both safety stock and reorder point are calculated with fixed lead times due to simplicity [24].

Some additions have been made to the aggregation technique during the application study. The main change has been related to the introduction of a matrix of setup times for each variant in the input and output object. This is of critical importance for certain lines where setups can be over an hour between each type of product. Setup can be captured in the previous aggregation technique but will have to be estimated as part of the availability and MTTR value, which is not trivial to accomplish. Additional control has also been implemented to facilitate changing the target processing time depending on planning requirements for each shift.

4.2. Issues to solve in the industrial system

The current industrial setup has an unbalanced takt, is not fully optimized from a flow perspective, the FGI levels are too large in the machining area due to the unbalanced takt, and the setup is rigid in relation to volume fluctuations between variants. If these issues were to be remedied the whole flow will benefit [25]. In order to solve these issues, the proposition was to limit the rate of the different sub systems to produce during the same number of hours, for each product type.

Based on the current setup of paces and production time, three different production scenarios were developed. By levelling the number of hours of operation, and thus limiting the production rate for the affected lines, the industrial system can achieve a better synchronization between the sub-sites and a more levelled flow. That is, moving the operational principles from resource optimization towards the optimization of the production flow [26]. Notable here is that some of the production lines will be performing well below their respective capacities but that is an acceptable consequence in the short term.

The three scenarios are then tested in the simulation model and the improvements are measured against the KPIs in Table 1. In the next part of the paper, a design of experiments of the case study will be presented and the results will be shown and analyzed using graphs of the storage levels.

Table 1. Outputs from the model

Variable	Abbreviation	Measured in
Products out from system per hour	JPH	Products/hour
Lead time through system per component	$LT_{1..n}$	Hours
Current storage level per FGI	$WIP_{1..n}$	Number of products

5. Results

Configuring the model with the parameters shown in Table 2, enables an improved synchronization of the industrial system. Only the assembly systems are considered here, because they are operating at an overcapacity in comparison to the machining lines. The machining lines will need to utilize all available hours to reach the production volumes. Limiting the production rate of the assembly and compensating with more time will enable the plant to reduce LT and WIP in all the FGIs for machining. Product routing is also a limitation, AA01 produces for FA01-02, while AA02 produces for FA03-04, leading to the production setups seen in Table 2. All other simulation settings are unchanged when running these scenarios. Simulated horizon is four weeks with one week warm-up time for the model.

Table 2. Paces for each shift per experiment compared to base

	Baseline				Experiment 1				Experiment 2				Experiment 3			
Line	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AA01	37	37	15		30	30	30		30	30	30		27	27	27	27
AA02	41	41	34		33	33	33	33	33	33	33	33	33	33	33	33
FA01	20	20							10	10	10					
FA02	17	17	15		30	30	30		20	20	20		27	27	27	27
FA03	21	21	21		21	21	21	21	21	21	21	21	21	21	21	21
FA04	20	20	13		12	12	12	12	12	12	12	12	12	12	12	12

The experiments for the storage levels, in Figure 2, show that synchronizing the factory can yield possibilities for the reduction of FGI storage levels for every product. For the baseline, the unlevelled flow can be seen for A-DFGI, due to not having a customer on the weekends. The machining lines are being constantly outpaced on the weekdays but gaining significantly on the weekends. This problem will still be an issue due to low performance of the machining lines, although the problem is lessened in the later experiments.

Figure 2. Storage levels for the experiments 1-3, compared to the baseline

Reducing the FGI storage levels will reduce the cost of tied capital in the factory and give more focus to improving the lines themselves instead of relying on the FGI. This reduction is possible without any late deliveries to the customers, internal or external. The figure also shows that the variability of the storage levels decreases. Decreasing the variability would also improve the situation for production planning in the factory, especially for the manual planning being done in the machining lines.

Comparing the largest storages in machining, found in Table 3, between the baseline and experiment three, overall reductions in 26% of total volume, 32% in maximum values, and 56% in standard deviation. Increases can be found in AAFGI for Experiment 3, and FAFGI for all experiments. These increases will be handled by a different strategy for unloading to the customer on weekends.

Table 3. Change in storage levels compared to baseline in percent. SD stands for standard deviation.

	Experiment 1				Experiment 2				Experiment 3			
Storage	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
AFGI	-26	-57	4	-31	-27	-57	5	-32	-38	-66	-27	-41
BFGI	-11	-43	14	-9	-11	-42	14	-8	-18	-66	10	-18
CFGI	-2	-23	-5	-7	-5	-21	-17	-8	-29	-43	-23	-36
DFGI	-16	-30	-1	-25	-16	-30	-1	-25	-21	-53	-4	-31
AAFGI	-2	-13		-16	-23	-24		-24	139	21		41
FAFGI	-42	237	-83	-6	-41	226	-82	-7	-39	216	-80	-12

6. Conclusions and future work

A case study has been performed by building an aggregated model of a complete industrial system and utilizing the model to generate decision support. The simulation model, using the studied aggregation technique, enabled answers to be given to complex questions without the need of detailed data. The results from the simulation study are first a possible manufacturing setup with substantially reduced (>25 %) storage levels and second, a significantly improved flow on plant level. Some additions to the aggregation technique has also been identified and proposed to further improve the application of the technique. In summary, the first conclusion is that the aggregation technique is well suited for aggregation and modeling of real world manufacturing lines into higher level models on plant level. The second conclusion is that the simulation with such models can provide valuable decision-support for the development of higher level manufacturing systems.

In terms of further work, other forms of aggregation might be of interest for further study. Additionally, the current technique could be tested on problems related to supply chain optimization and include customers as well as suppliers in the higher level industrial system. Further work should also consider exploring the potential to improve the aggregation method in terms of computational effectiveness, especially if optimization should be applied in analysis of larger scale problems. In terms of industrial problem solving the model used in this paper has the potential to enable analysis and optimization of long term manufacturing system development and evaluate the consequences from future actions and trade-offs to support strategic decision-making.

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