Production Logistics Design and Development Support: A Simulation-Based Optimization Case Study (WIP)

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ABSTRACT

Manufacturing sectors in Sweden have a long history that leads to common non-optimized flows on the shop floor. Especially when having a really high product mix and a low-volume of customized products, a great deal of effort with respect to flow optimization is needed to stay present and compete in the globalized market. The goal of this project is to support the design and development of the implementation of new production systems and logistics flows considering the shop floor plant layout of a Swedish middle-size water pumps factory. In this paper, with the help of different types of simulation models and optimization, some results of a new technologically adapted production line are analyzed and relevant information and potential improvements in the production are found. The further development of optimization studies using the exiting simulation models is stated as ongoing and future work. The obtained and potential results can serve for decision makers and stakeholders to apply changes and adaptations in the system considering the mid and long term goals of the company.

Author Keywords

Simulation-based optimization; mix-model assembly line; production; logistics; layout.

ACM Classification Keywords

I.6.1 SIMULATION AND MODELING.

INTRODUCTION

Manufacturing sectors in Sweden have a long history and tradition and support a significant part of the national gross domestic product with its export-oriented economy. Most of the Swedish manufacturing companies have taken part in a modernization and adaptation process to be able to compete and to be present in a global industrialized world. However, mainly due to the requirements of short-term goals, shop floors have usually been adapted at different stages along decades without an overall thinking and design. This fact limits considerably the capacity of the production and growth of the industrial production.

In order to support this effort of modernization and adaptation, different tools and approaches are utilized in the industry within the production and logistic flows of major manufacturing companies. A common approach is Discrete-Event Simulation (DES), one of the most reported approaches in the literature. A powerful characteristic of this type of approach is the possibility of working with different existing and hypothetical scenarios. However, individual what-if scenarios can become a really tedious and time-consuming task when many possible solutions are considered. In order to be able to analyze all these possible combinations in a feasible manner, Simulation-based multi-objective Optimization (SBO) is one of the most suitable approaches for this kind of systems [1]. Combining DES and SBO it is possible to solve complex production problems of high product mix with low-volume customized products as well as to help to find optimal solutions for the definitive production and logistics methods considering the layout.

Going through this paper with a case study of the production line 220 of the Xylem Water Solutions, it is demonstrated that this methodology combining DES and SBO together can be a really useful and necessary method to be implemented as a decision support system in big and middle size manufacturing companies. Furthermore, the ongoing work in progress of this project is focused on a new layout configuration of this ABX shop floor, considering the optimization of different alternatives for the line feeding problem and different possible configurations of the production lines. This method can contribute significantly to increase the productivity and efficiency of the Swedish manufacturing industry to stay present and compete in an international and globalized industrial framework.

The structure of this paper is organized as follows: in Section 2, the existing literature review of related papers in DES, SBO and manufacturing systems with high product mix and low volume production is presented. Section 3, introduces this case study and explains the system and the followed methodology. In Section 4, the validation results and an introduction to what-if scenarios are presented. Finally Section 5, presents the main conclusions and ongoing and future work of this project.

LITERATURE REVIEW

Simulation and optimization

Simulation is an analytical tool to create, maintain, evaluate or improve a system or process. Simulation is the imitation

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of the operation of a real-world process or system over time and it presents a huge potential for manufacturing process development and improvement [2, 3].

It has been demonstrated that simulation techniques are the most suitable approach for process improvement of complex systems with high variability. The variability and difficulty of the processes within complex systems demand the analytic power of Discrete-Event Simulation (DES). One of the more highlighted characteristics of DES studies is the possibility to apply "what-if" questions or scenarios to the existing systems without disturbing them. Within these scenarios new alternatives, ideas, systems and work proceedings can be tried out without disturbing the real system, or be developed even before a system is constructed [4].

Traditionally, simulation and optimization have been considered as different approaches in the operational research domain, but they have developed together and finally the idea is to use the great detail of simulation in combination with the ability of optimization to give optimal solutions [4]. It has been demonstrated that the combination of optimization and simulation tools allows decision makers to quickly determine optimal system configurations, even for complex integrated facilities [5]. When multiple objectives are considered at the same time, Simulation-based Multi-objective Optimization (SBO) is the correct approach to be applied. SBO facilitates the search for trade-offs between several conflicting objectives [6].

Different authors have described how simulation and optimization techniques applied together have improved production or material handling systems. Nevertheless, there are not many cases in the literature where DES and SBO applied together to support the design or development of production and logistics systems of high product mix and low volume production.

High product mix and low-volume production manufacturing systems

Low-volume assembly lines with a high amount of product variants are characterized by a large amount of manual processes, buffer space constrains, specialized resources and external suppliers [7]. As stated by Ziarnetzky, low-volume serial production is usually characterized by a small number of typically large-sized objects with a big number of necessary processing steps. The characteristics of the products usually need a high level of customization, often including a complex bill of materials, multiple routes and a high degree of parallelism. The processing times usually rely on the amount and skills of the necessary workers; the degree of automation is often low mainly due to many labor-intensive processes. The major sources of complexity of this kind of production are the high customization, the high amount of involved suppliers, the necessary highly skilled workforce, the learning curve of the staff and the spatial constrains for systems objects. The resources are usually mobile and workers and auxiliary resources are important. Finally buffers are also a major constrain due to the size of the system objects. Golz [8] states that the main problems related to production systems with a high product mix in the automotive sector are: to determine a proper configuration of the production lines regarding the equipment and processes of the different stations, to have the production lines balanced according to the expected production and the master production schedule for individual models over a short-term planning. Also the production sequencing and resequencing in case of disruption and the material flow control.

The related literature to this kind of high product mix and low-volume production systems regarding the layout, production lines and logistics has been deeply studied. In most of analyzed papers some of the problems mentioned above are addressed specifically, sometimes analyzed from an overall perspective but few of them including the layout, logistics and production lines of these high product low-volume production systems. Most of the relevant papers analyzed are related to the automotive sector. Several authors focus mainly on the balancing problem of the different process involved in the production lines and many others mainly focus of the production sequencing [9-13]. Another main focus of papers analysed in this field of high product mix and low-volume production systems is the line feeding problem. The literature review is addressed in the following sub-chapter. Due to the specific case study of this paper, it is not easy to find related papers on similar production systems, hence, the ones found related to the automotive sector have been utilized as a guide due to the similarities in high product mix and low-volume production.

Line feeding problem

Part logistics in the automotive industry has been deeply studied and analysed by Boysen [9]. In his paper an extensive literature review and description of the different logistics types [7] analyses an aircraft production case study using DES. This paper is more focus on the modelling aspects, different modelling blocks and the analysis of the inventory and buffer levels. An heuristic solution procedure is developed by Golz [8] to minimize the required number of drivers for in-house shuttle tours between part storage and delivery areas in the automotive sector. Emde [14] develops an exact solution for the optimal scheduling and routing problems of the transportation method with tow-trains between a central supermarket storage and the assembly lines in the automotive industry. Many authors have analysed the in-house transportation methods from the parts storage area to the production lines [15, 16]. However the topic considering the part feeding problem has been widely rejected [8]. Golz divides this problem into the planning of the transportation orders and the assignment of those orders to the shuttle system considering the transportation capacity restrictions. They mention that the main objective in feeding the parts to the production line is to ensure the efficiency of the logistics processes; stating that one of the key problems according to the just-in-time principle is to retrieve the parts in their respective unit loads from a central storage system until they are assigned to the designated assembly locations, with the proper transportation tour. They state that the exact timing in the material supply is of utmost important to avoid interruptions in the production line. One of the closest articles involving these three mentioned principles is [16], which defines an integrated approach for parts and components management to optimize the centralization degree of warehouses in order to minimize storage costs and to choose the right feeding policies. However, their approach is strictly related to Assembly to Order/Manufacturing to Order and there is not much emphasis or description of the simulation and optimization parts. Another complete article but more focused in tow-trains sizing, [17], presents the line feeding problem and models the logistics between a central supermarket area and the production lines of an italian automotive company.

Summarizing, even though there is an extensive literature in production (especially in the automotive sector), in the field of the line feeding problem including different types of in-house transportation methods and routing, as well as considering different types of production lines (with different automation levels) and the layout, not much literature has been found beside the analysed here.

XYLEM WATER SOLUTIONS CASE STUDY

The goal in this project is to support the development and optimization of the production logistics, including modifications of production flow and shop floor layout of the factory in Emmaboda, Sweden. This project is part of a study started at the end of 2015. The facilities of the factory have been adapted along decades to meet the requirements and demand of the company, resulting in several shop floor buildings mainly due to continuous expansion of the production of water pumps. In order to be able to support decision makers to increase the production and efficiency of this factory through simulation, virtual models of the different parts of the real system have to be designed and built according to the improvement requirements. These requirements are for example the lack of enough free space on the shop floor, the excessive amount of traffic inside the factory and the extensive amount of manpower needed to produce the different models of pumps. The main improvement approaches in which this project is based are DES and SBO. The area is very interesting for the Swedish industry due to many plants in the country have a long history and usually they are not flow-optimized.

Methodology

In this section the steps used to develop this SBO project are described; this includes steps such as the process mapping, modelling, what-if scenarios and optimization in order to support the design and development of the production system and logistics of the Swedish factory. The methodology followed in this project is based on the generic simulation project steps from Banks [18] with the additions of the optimization procedures described by Deb [6] and applied to the different fields mentioned in this paper: layout and logistics and production line systems with low-volume and high product mix. A case study of the production line 220 of the ABX shop floor at the factory of Emmaboda is analyzed.

The first step in this project is the definition of the objectives. They have been defined based on the requested goals and tasks of the project according to the necessities of the company and the research requirements. An important issue is to consider what processes, resources and staff are strictly necessary to take into account in the simulation model and which of them can be omitted because they are unnecessary for the improvement methodology. The next step is the construction of the process flow diagrams; it requires an important consideration in order to try to avoid possible changes in the simulation model afterwards.

In order to build the simulation models, DES is necessary due to the high complexity and variability of manufacturing processes. These models have to be verified and validated. Verification and validation are necessary to ensure that the model properly represents the real system as it is. The next step is to perform a system analysis.

The model has to be analyzed in order to find all the possible weaknesses of the real system. It is done by checking the simulation, analyzing the results and trying to find bottlenecks and shifting bottlenecks of the processes [19]. These bottlenecks are the limitations of the system that constrain the performance, impeding in most of the cases a greater or improved outcome and revenue. In this part of the project what-if scenarios are defined to check possible improvements in the existing configuration of the systems, for example different configurations of the production lines. Finally, with all the knowledge obtained from the real system, the simulation models and the what-if scenarios, the optimization engine can be designed in order to find the best possible set of suitable solutions for the different scenarios and combinations of the system.

Data collection

One of the most important tasks in the field of simulation is how to get high quality data to make an accurate model. High quality data is really necessary to perform an accurate representation of a real system. It can be obtained by using historical records, work measurement procedures or estimations from subject matter experts [20]. Standard time data of every single process has to be necessarily known to model the flow , however, in some cases, historical record methods based on the record of similar, previously performed jobs can be applied in order to get an estimation of the needed times [20]. The most difficult aspect of modelling is gathering data of sufficient quality, quantity, and variety to perform a reasonable analysis [3].

In this project the needed data was obtained by the logging devices of some processors when available, by time studies for most of the manual processes and with the help of the operators, experts and managers in some cases in which it was not feasible to collect it. For the ABX shop floor, there was available data for the new technologically adapted production lines but there was an important lack of data in the manual old production lines, for example there was no available operators' interruption data, hence it had to be collected manually by performing times studies for the different processes. In all the cases the data was verified by expert matters and mangers to ensure that no errors or non-reliable data was included.

Once the data from the real systems was analyzed, it was possible to introduce it in the simulation models. In these models, statistical distributions and probabilities have been used to model the different processing times in order to achieve the same behavior of the real production, staff and resources. This is explained in the following sub-chapter.

Model construction

Once all the objectives were defined and the process flows of the different production lines were designed, it was possible to start modelling the production and logistics flows of the ABX shop floor. All the information regarding the production was obtained by different sources. Several visits to the factory were made in order to meet all the different installations, resources and staff working with logistics and production. Previous work, investigations and developments in simulation and optimizations of manufacturing systems were studied at the same time to apply the knowledge in the simulation models. Every relevant process for the simulation was reflected in the model; in the same way, irrelevant processes for the purpose of this project were rejected.

According to Banks [18] a simulation project is compound by several steps. Once the problem, objectives, project plan, process flow diagrams and a base of the data collection are clear, it is possible to start with the model translation. This part involves converting the process flow diagrams into a computer-recognizable format. In this case were Flexsim and FACTS Analyzer the simulation software tools selected. At the beginning simpler production lines were built with FACTS to keep working or reject improvement ideas at an early state of the project. With FACTS it is possible to work with more generic models that allow the modeler to build simplified models without expending excessive time [1]. On the other hand, Flexsim allows the modeler to build detailed simulation models, almost 1 to 1 to reality, that represent the real system in an exact way; this is really convenient to estimate the real needs and characteristics of a non-existing system. For example, in order to find the best production methods for the production lines, FACTS analyzer was used at the beginning. Once the amount of possible systems to be analyzed was more specific, using Flexsim it was possible to build detailed simulation models of the hypothetical improved systems in order to know its requirements and potential outcome. These detailed 3D models also help to visualize all the processes in a realistic way being able to involve the different staff of the system in the improvement process.

In all the cases, the first step was to build the model with the simplest flow of pump variants and processes. When that model was working properly, it was time to introduce more variants, data statistical distributions, processes, staff and interruptions that are usually involved in the real system. Additional tasks depending on probabilities and the classification of different variants of products in main families of products for the different production lines were programmed. An example of the line 220 of the ABX shop floor is presented in Figure 1 and Figure 2.

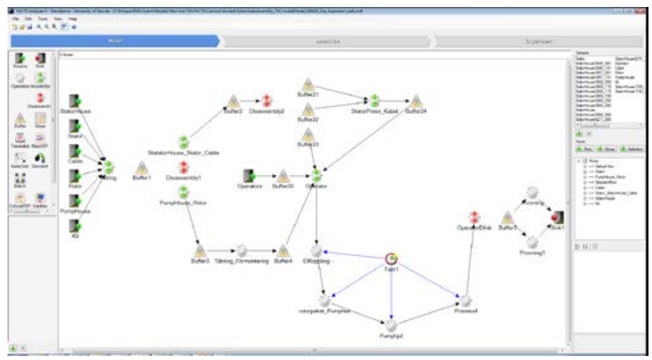

Figure 1. FACTS 2D model of the production line 220.

Figure 1 shows the simulation model built with FACTS of the line 220. There are six main parts of the pumps delivered by an AGV (Automated Guided Vehicle) to the production line in kitting boxes. There are two main flows of parts that after some processes meet in a carrousel-type manual assembly. Then the final product goes to the testing station. The same production line built with Flexsim is presented in the following Figure 2.

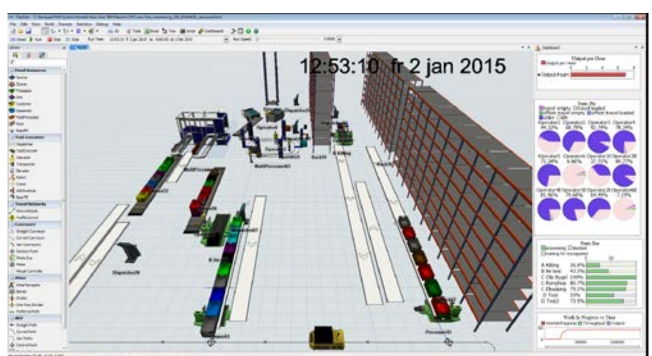

Figure 2. Flexsim 3D model of the production line 220.

In this case a more detailed 3D simulation model representing the same processes of the line 220 can be appreciated in the figure above. Once the simulation models were built, it was time to verify and validate them in order to check that they represent the real or hypothetical system in an accurate manner. This process is presented in the following sub-chapter, verification and validation.

Verification and validation

Before starting with the what-if scenarios, it was necessary to ensure that the model was correctly built and the results were accurate enough. Verification is a determination of whether the computer implementation of the conceptual model is correct [3]. The input parameters and logical structure of the model have to be correctly represented in the model to validate it [18]. In this case, to perform the verification, every different pump and staff of the model was followed during a few simulations to ensure they performed their tasks and processes as they should. The number of resources, personnel, models and variants and schedules was also revised.

Validation is a determination of whether the conceptual model can be substituted for the real system for the purposes of experimentation [3]. It is usually one of the most difficult steps in a simulation project. During the validation process, a constant communication between the programmer and the stakeholders was established. During several meetings the results of the simulation were presented and requested for feedback in order to calibrate the model and to be able to obtain the desired accurate results which represent the behavior of the real system.

VALIDATION AND RESULTS

In the following table, table 1, the validation results of the production line 220 built with FACTS are compared with the data of the real system. Please note the data has been modified proportionally due to secrecy issues.

	Line 220
Real system	176.26
FACTS model	170.82

Table 1. Validation results of the production line 220.

This table represents the amount of pumps produced every hour by the real system (first row) and by the simulation model (second row). As it is possible to appreciate, the model represents the real system in an accurate manner, being the difference lower than a 5%. Once the models were validated and verified it was possible to start with the design of the what-if scenarios. These scenarios are explained in the following sub-chapter with a focus on the production line 220.

System analysis and results

Once the simulation model was verified and validated, a system analysis of the model was implemented to start finding possible weaknesses of the system. This analysis was done by going through the simulation trying to find bottlenecks and shifted bottlenecks in the processes. One of the weaknesses of the system that was detected with the help of FACTS was a carrousel-type of manual tasks within the production line. This carrousel was compound by 5 main tasks performed by three operators. The tasks were balanced for three operators with the automated carriers of the pumps moving in a synchronized manner stablishing the pace of the carrousel.

Performing a bottleneck analysis it was detected that this carrousel was slowing down the production. In the following Figure 3 a chart of the bottleneck analysis is presented. The processes with higher bars on the left side of the picture represent the main bottlenecks of the line.

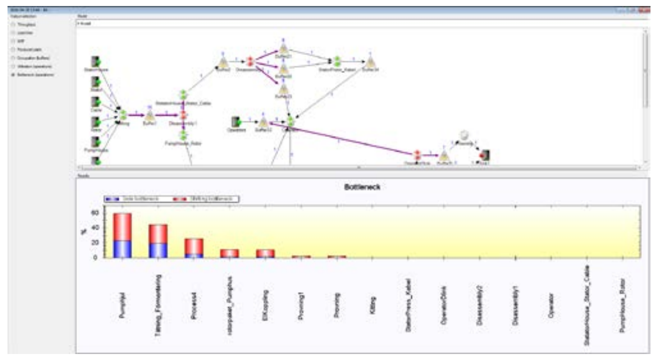

Figure 3. FACTS bottleneck analysis of the line 220.

As mentioned before, the main bottleneck of the system was identified to be located within the carrousel of manual processes. Some production experts of the factory stated that an extra operator was already tried at the carrousel but the production did not improve. However, performing a what-if scenario in the simulation models where the processes were optimally balanced for four operators instead of three, the results of increased productivity were significant. These results are shown in the following table:

	Line 220
Original model	170.82
What-if scenario	218.42

Table 2. What-if scenario results of adding an extra operator.

In this table it is possible to appreciate the production in pumps per hour of the original system simulated (first row) compared with the what-if scenario of adding an extra operator in the carrousel (second row). The result concludes that the production of that line could be increased by more than 25% adding an extra operator and balancing the tasks in the carrousel. Ongoing what-if scenarios are focused on the layout configuration, different production systems and on the internal logistics methods to feed the lines.

Different possibilities of grouping the production lines in order to reduce their number and required space and logistics are also being analyzed with what-if scenarios. Some of these studies are aimed to be continued by SBO by the complexity of the system and the amount of possible solutions if several improvement objectives are considered.

CONCLUSIONS AND ONGOING/FUTURE WORK

It has been demonstrated with the case study that what-if scenarios can be a really useful tool to increase the production and efficiency by implementing modifications on the system without disturbing it. Great improvements can be implemented without spending too many resources or time. Ongoing development of this project is implementing SBO in those cases where what-if scenarios can become a really tedious and time consuming task, for example determining the optimal amount of buffers and their capacity between the different processes of the lines.

SBO is usually a requirement when complex systems with high product mix and a low-volume of customized products want to be improved significantly. The obtained results as well as the promising results of this approach can serve to stakeholders and decision makers to increase the productivity and efficiency of different and complex production systems around the world.

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