Simulation in Produktion
und Logistik 2021
Jörg Franke & Peter Schuderer (Hrsg.)
Cuvillier Verlag, Göttingen 2021

Application of discrete-event simulation for factory planning – A case study

Anwendung einer ereignisdiskreten Simulation im Fabrikplanungsprozess – Eine Fallstudie

Meike Herbert, Andreas Selmaier, Felix Mühlmann, Jörg Franke, Institute for Factory Automation and Production Systems, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen (Germany), meike.herbert@faps.fau.de, andreas.selmaier@faps.fau.de, felix.muehlmann@fau.de, joerg.franke@faps.fau.de

Jens Fürst, Siemens Healthcare GmbH, Erlangen (Germany), jens.fuerst@siemens-healthineers.com

Abstract: During factory planning, production areas are dimensioned, structured and designed. Material flow simulation is part of the digital tool chain and intents to support factory planning processes. In this paper, a case study of planning a new factory in the medical technology industry is presented. A concept for the consistent use of digital data as a database for simulation is pointed out improving the information flow and transparency. Main objectives of the simulation study are the dimensioning of resources, optimization of sequences and processes as well as providing a three-dimensional visualisation. It is shown, how the discrete-event simulation study is integrated into the factory planning process. The application comprises the planning of the production area of high voltage tanks and the results of the simulation study are presented. Two examples are described in detail dealing with the impact of the shift work model and a comparison of different assembly concepts.

1 Introduction

Sustainable production and logistics systems are characterized by modularity, flexibility and adaptability. These characteristics have to be considered during planning processes in manufacturing industries. In greenfield scenarios, this planning process has less constraints than in existing factories and therefore, opens up opportunities for new production concepts. Besides Industry 4.0 and the transformation towards a digital industry, classical lean management is still the basis for factory planning processes.

Digital tools improve and shorten planning and development processes significantly. Research in the field of simulation has increased over the past years and many applications exist, for example in the area of factory layout planning (FLP) and material flow simulation (Mourtzis et al. 2014).

Designing factory layouts is a multidisciplinary and knowledge-intensive task. Fast changes in current global markets require agile planning, designing or reconfiguration of factory layouts (Mourtzis et al. 2014). In the planning phase, additional simulation tools are applied to e.g. simulate material flow systems, work systems and warehouse systems. The tools are used, for example, to plan human resource deployment, examine planning parameters or increase the efficiency with regard to the dimensioning, throughput or bottlenecks (VDI 3633 Part 1 2014).

Data integration into the factory model comprises data from different areas such as plant information, product and production information and sequence control information. During simultaneous engineering, where product and production development takes place in parallel, simulation tools that are integrated in the information technology environment are beneficial (VDI 3633 Part 1 2014).

During factory planning, the use of discrete-event simulation has to be considered to support decision-making processes. An integrated database should be used and a procedure for transferring the results of the simulation study into the layout planning process has to be applied.

In the presented case study, the use of material flow simulation for planning a new factory is shown for an application in the medical technology industry. A concept for tool integration is pointed out which enables improved information flow and data exchange. The simulation study is conducted for the existing production as well as for the production area in the new factory. Finally, the results of two specific issues are explained exemplary. In the simulation study of the existing production, the impact of the shift work model on the dimensioning of the capacities is analysed. Furthermore, the impact of different assembly concepts on the lead times is evaluated for the newly planned production area. The results of the simulation study are integrated into the layout planning process.

2 Discrete-event simulation for factory planning processes

Procedure models for the execution of a simulation study are described in VDI 3633 Part 1 (2014) or by Rabe et al. (2008) with focus on verification and validation. Data collection and preparation is necessary for each simulation study. Input data is generated manually, automatically or semi-automatically. Manual data collection and preparation is often time-consuming and error-prone. Therefore, automatic approaches are preferred with direct or indirect access to the basic data of the planning systems or IT systems. Data consistency and quality are still issues to be considered in practice. However, standardized interfaces are implemented and the data consistency is improved with the digital transformation (Mieschner and Mayer 2020).

Common simulation tools provide an integrated 3D visualisation, which helps to improve the understanding, identify critical processes and enhance the communication to non-experts in simulation (Süß et al. 2009). It has also advantages for the layout planning process. Sender and Wanner (2013) present an integrated planning tool for capacity and layout planning, but the application is of the maritime industry considering the specific requirements. Dombrowski and Ernst (2013) present a simulation approach for layout planning comparing and evaluating different future scenarios with a case study of factory redesigning in a medium-sized company and changing requirements. Optimization algorithms for layout planning are integrated into the simulation, as for example described in an overall concept by Krüger (2019).

There are many different applications for discrete-event simulation in the literature, but only few examples deal with planning a new factory. The dependencies between simulation and layout planning have to be pointed out clearly. Furthermore, the database and consistency to other engineering and planning tools is of particular importance in the factory planning process.

A case study of a simulation for planning a new factory is presented in the following going into the aspects of the required database and data consistency as well as the dependencies to the layout planning process. Based on the findings of the application in the medical technology industry, the main objectives, procedures and results of the simulation in the factory planning process are presented.

3 Case study

The main objectives of factory planning are, in summary, ensuring economic efficiency, flexibility and adaptability as well as attractiveness, lately complemented by the objective of energy and resource efficiency (Grundig 2018). These objectives are also pursued in the planning and design of a new plant, such as the technology center of Siemens Healthineers in Forchheim, Germany. The so-called High Energy Photonic (HEP) Center is designed as a lean, digital factory, where X-ray tubes and high voltage generators will be produced (InFranken 2020).

A systematic analysis and evaluation of the assembly and production operations using a discrete-event simulation supports the production planning and optimization for the new factory. In the following, the application, procedure and results of the simulation study of a defined production area are pointed out.

3.1 Requirements and objectives

While there are confined space conditions in existing production areas that result in restrictions of the layout design, new opportunities for space allocation and layout design arise in the planning of the future plant. This enables an optimal arrangement of the equipment in accordance with the material flow. In addition, it opens up the possibility of further extending production capacities.

The application in this case study comprises a defined production area of medical technology products. The production area and the corresponding products are characterized by the following characteristics:

- 19 different products of two product groups that are high voltage tanks (HVT) and single tank units (STU) are assembled in a serial production with small quantities.
- The operations are structured in pre-assembly, assembly, technology zone and final assembly operations.

- The production area is characterized by long assembly times of several hours, high lead times of up to a few days due to long drying times. Requirements on cleanliness and quality are high. Sequences are less transparent due to multiple machine operation in the technology zone.
- The process sequences vary strongly for each product.
- Changes in the product portfolio, increasing quantities and shorter assembly times characterize the changing conditions in the next years.

The main objectives of the simulation study are dimensioning, optimization and visualisation, as depicted in Figure 1. System dimensioning concerns all resources that are needed in the future scenario such as workstations, machinery, equipment and buffers, but also the human resource deployment. Utilizations are extracted and bottlenecks can be identified. The results of the analysis are integrated into the layout planning process. The consideration of flexibility and adaptability in the layout is crucial for a sustainable future-oriented design. Therefore, different scenarios with increasing quantities and changing product portfolio are evaluated.

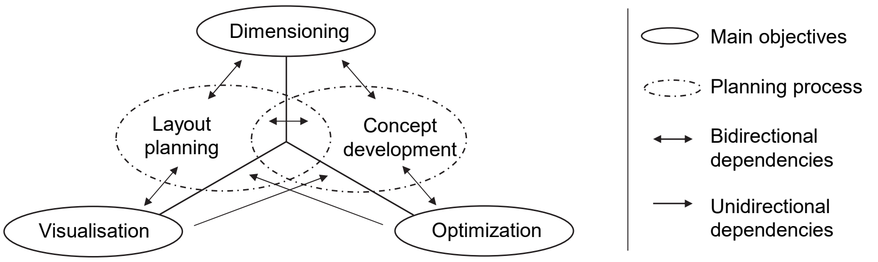

Figure 1: *Overview of the objectives for the simulation study and their effect on the planning process*

The development of the production concept is also a part of the planning process. This comprises the determination of all parameters that are relevant for the production. Two examples are shown in this case study (cf. chapter 3.3) analysing working time models and comparing different assembly concepts. The concept development has an effect on the dimensioning and layout planning, but the analysis mainly aims at an optimization of the system. The results of the optimization are transferred to the layout design. In general, the optimization process is performed to improve chosen (key) performance indicators (KPI).

The visualisation increases the comprehension of processes and different production concepts, especially for non-experts in simulation. Furthermore, the three-dimensional visualisation is connected to the layout planning process and shows the arrangement of resources in 3D, which is beneficial for a newly planned production area. In order to obtain a realistic visualisation of the production area, not only standard objects of the simulation tool are used, but also 3D objects that are modelled using external computer aided design (CAD) tools.

3.2 Procedure of the simulation study

The simulation study is performed in the factory planning process. The integration of engineering tools effecting the generation of a database for the simulation is described. Moreover, the dependencies between simulation and layout planning are pointed out in detail.

3.2.1 Simulation database

Material flow simulation is a part of the digital tool chain comprising CAD, factory and line design, material flow optimization, robotics and automation simulation and further engineering tools. The use of these tools is based on a production data management (PDM) system to ensure data consistency in the whole planning process. The data is structured in bill of materials (BOM), bill of resources (BOR) and bill of processes (BOP). In this context, Figure 2 shows the structure of the simulation database, the future concept of an integrated tool landscape and the data sources of the case study.

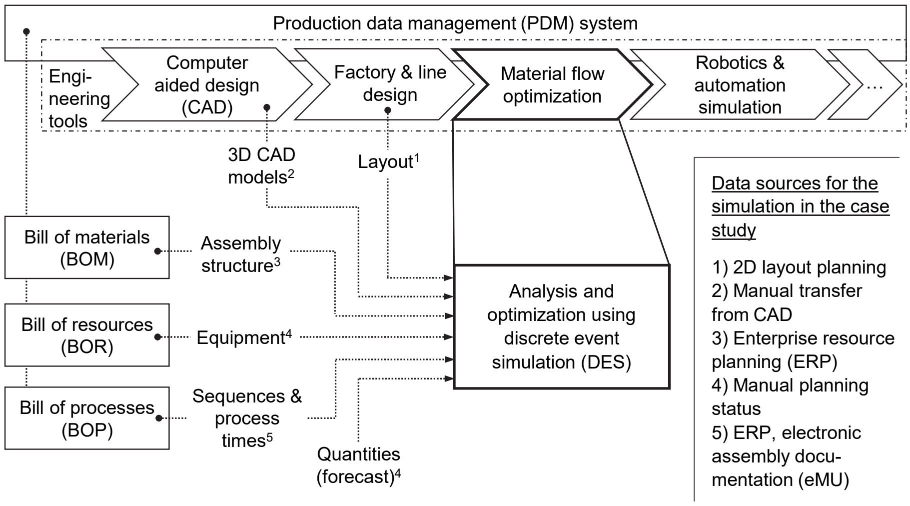

Figure 2: *Towards consistent use of digital data as a basis for material flow simulation*

3D CAD models of facilities and equipment are used to enable 3D visualisation in the simulation. While layout planning is performed in a 2D tool today, an integrated engineering tool for 3D line design will be used in the future. Furthermore, BOM, BOR and BOP provide important data for the simulation that are information on the assembly structure, equipment, sequences and process times. In this case study, data is collected from other planning tools such as Enterprise resource planning (ERP), or documents such as the electronic assembly documentation. Furthermore, the manual planning is performed using spreadsheet programs.

Data collection is characterized by high manual effort for the case study, but the factory planning process will be improved by an integrated tool landscape. Due to the central provision of technical data and models, the transparency and continuous reuse of digital data is increased. Tool and process discontinuities with manual data transfers are avoided and the simulation study is performed with an enhanced integration and visualisation.

3.2.2 Supporting layout planning by simulation

In factory planning, the use of simulation supports the layout planning process. A systematic analysis and evaluation of different scenarios provide the basis for decision-making in designing layouts. In simulation, the dimensioning of resources is conducted, an optimization of the processes is performed and a three-dimensional visualisation is provided, which improves layout planning. The results of the simulation study are integrated into the layout design. Specific aspects that are examined in the simulation study for factory planning are depicted in Figure 3.

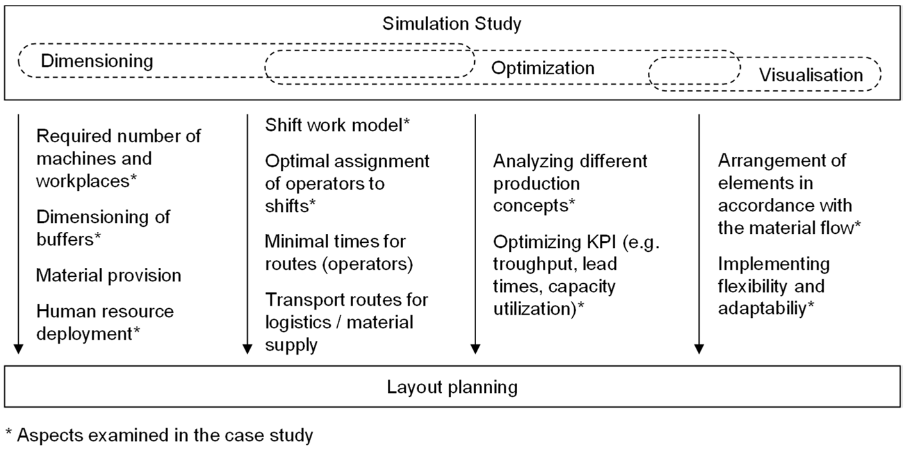

Figure 3: *Aspects investigated in the simulation study effecting layout planning*

The aspects include the dimensioning of resources such as machines, workplaces, buffers and systems for material provision. For human resource deployment, the number of required operators has to be determined. The shift work model is analysed and the optimal assignment of operators to the shifts are determined depending on the process sequences. The routes and distances that the workers have to walk in the production area are analysed. Furthermore, logistics aspects are analysed such as the transport routes and further aspects concerning material supply. Various scenarios are examined e.g. comparing different production or assembly concepts. Optimization measures are based on an evaluation of KPI. A main aspect for layout planning is the arrangement in accordance with the material flow and also the implementation of flexibility and adaptability in layout designs. The simulation (and visualisation) of processes support the understanding of complex sequences in production and helps to evaluate future scenarios (e.g. with different products, processes and quantities).

3.3 Application, results and discussion

The simulation study is carried out for the production area considering the approaches described above. The tool Tecnomatix Plant Simulation is used for the material flow simulation. Different scenarios are evaluated based on KPIs such as throughput, lead times or capacity utilisation. In the following, two specific issues will be addressed as an example that are a comparison of the shift work models and a comparison of different assembly concepts. Afterwards, the results of the whole case study will be summarized and discussed.

3.3.1 Impact of the shift work model on the dimensioning of the capacities

The simulation study enables the analysis of the current state. After parameter variation and evaluation of the results for different scenarios, conclusions are drawn and transferred to the factory planning process. The comparison of different shift work models is one issue of interest, which can also provide insights of the current situation in the production area.

A short-term change in the shift work schedule became particularly relevant for many companies of the manufacturing industry in 2020 due to the Covid-19 pandemic. The challenge was to adapt existing processes with the aim of providing greatest possible safety for their employees, in particular in production. This resulted in a short-term switch from 1-shift to 2-shift work schedule in order to isolate groups of people from each other and to be able to keep greater distances to each other. It is possible to examine the impact of the shift work model in the simulation without having to make changes in the production itself. Furthermore, an analysis and evaluation is equally relevant for the current situation and for the future factory.

Therefore, the impact of the shift work model is examined in the case study. Two scenarios are compared using the simulation of the production area with constant amount of workers and quantities of products. Table 1 shows a comparison of the utilization of four workstations / machines for 1-shift and 2-shift work model The listed workstations or machines reach their capacity limit of up to 100 % in the first scenario of 1-shift work model. This would result in the necessary measure of doubling the capacities to ensure the completion of orders and balanced production processes.

Table 1: *Comparison of capacity utilisation for 1-shift and 2-shift work schedule*

Workstation	Utilisation (1 shift)	Utilisation (2 shift)	Measure for 1-shift scenario
1	96 %	56 %	Doubling of capacities
2	100 %	84 %	Doubling of capacities
3	95 %	66 %	Doubling of capacities
4	100 %	88 %	Doubling of capacities

However, the analysis encourages the planner to look for the reasons of the high utilisation rate of several stations in the 1-shift scenario. On the one hand, bottlenecks in the production area are identified. On the other hand, the results provide indications of possible deficiencies such as modified operations. One example is that, in practice, an operation might not be performed at the assigned workstation. It happens that the operator performs the task at a different place to avoid congestion at the designated workstation. Such deficiencies are revealed by the simulation study for the current situation and should be considered in resource planning.

In 2-shift operation, the utilisation is significantly lower. In this scenario, bottlenecks of the listed workstations or machines do not occur. This effects resource planning and dimensioning significantly; unnecessary investments are avoided.

The simulation study enables the identification of bottlenecks, in the current state and in future scenarios. The impact of the shift work model on resource planning is shown. In the planned factory, there will be 2-shift work. For further planning, increasing quantities have to be considered which will lead to higher utilisation of the workstations. Therefore, further scenarios should be analysed for the dimensioning of resources.

3.3.2 Comparison of different assembly concepts

A second example of the simulation study deals with the comparison of different assembly concepts. The assembly operations are mainly performed on individual workstations. In the current state, only some components are pre-assembled on different workstations. The pre-assembled components are supplied to the workstation (consumption-controlled). New orders with batch size 1 are initialized at the main assembly workstations.

Analysing the assembly processes, further sub-assemblies are identified that can be pre-assembled and supplied to the main workstations. In this new scenario, the pre-assembly is extended for most products, which leads to a reduction of main assembly times and to a higher utilisation rate of the workstations for pre-assembly operations. This scenario is depicted in Figure 4.

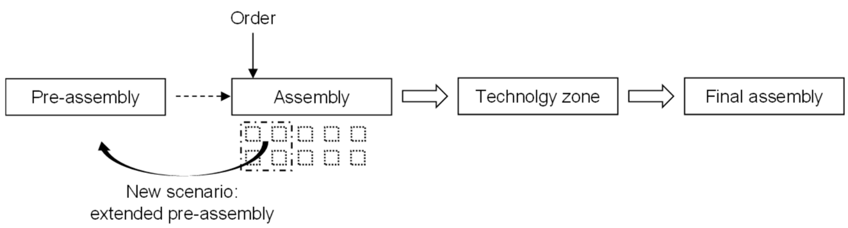

Figure 4: *Overview on the operations showing the scenario of extended pre-assembly*

The lead time, that is the time between the initialization at the assembly operation and the completion of the order, is reduced. Figure 5 shows the expected reduction of lead times obtained in the simulation. A reduction of lead times is expected for almost all products of up to 23.5 %. Lead times are reduced by 6.5% on average for all products.

In the current state, the lead times are not precisely recorded. However, it is possible to determine the lead times und to compare the different assembly concepts using simulation.

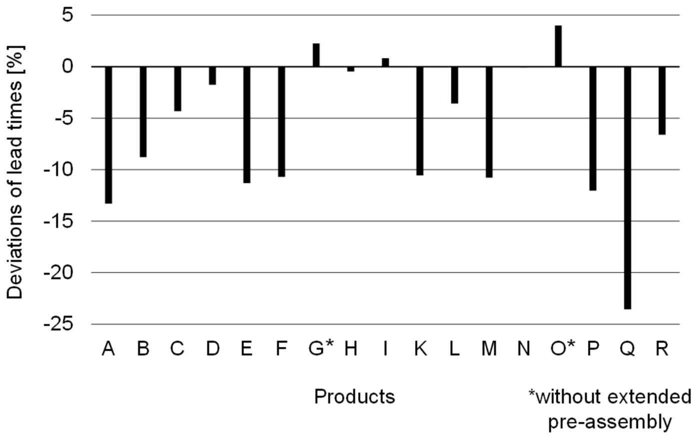

***Figure 5:** Deviation of lead times between scenario 1 and 2 for all products*

3.3.3 Conclusion and Discussion

The examined production area is a complex system and therefore, suitable for an analysis using simulation. There are different assembly operations, high variation of sequences and multiple machine operations resulting in less transparency. Simulation is a method to manage the complexity in the production area. Bottlenecks are identified and the amount of required resources are determined. The simulation study supports manual planning and reveals errors in the planning process. The manually planned capacities are validated and unnecessary investments are avoided. Different scenarios can be compared easily without having to make changes in the production itself. In addition, the simulation tool provides a 3D visualisation of the production area, as depicted in Figure 6.

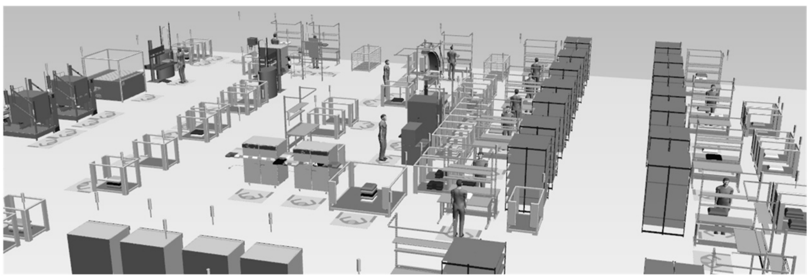

***Figure 6:** Visualisation of the production area in Plant Simulation*

The results of the simulation study are integrated into the planning process. Due to the high percentage of manual assembly operations, the recorded times are fluctuating in practice, for example due to the dependence on the level of experience of the workers. Such deviations have to be taken into account when evaluating and interpreting the results. The generation of an adaptable simulation model creates long-term benefits. If modifications are made during planning, the changes can be tested and evaluated with little effort using the adaptable simulation model.

4 Summary and Outlook

In this paper, a case study on simulation for factory planning is presented. It comprises the planning of a new factory in the medical technology industry. Requirements, objectives, procedures and results of the simulation study of a production area are presented. The database is pointed out and a concept for integrating engineering tools is described. A central provision of technical data and models improves the information flow and data exchange avoiding manual data transfers. The simulation study supports the layout planning process providing a basis for dimensioning of resources, optimization of processes and a 3D visualization. The results of the simulation study are presented exemplary showing the impact of shift work model on the dimensioning and a comparison of different assembly concepts.

Layout planning will be performed for further production lines supported by simulation studies. The interfaces within the integrated tool landscape are under development and will be evaluated in future applications. Future research will be on the implementation of optimization algorithms.

References

Dombrowski, U.; Ernst, S.: Scenario-based simulation approach for layout planning. Procedia CIRP 12 (2013) pp. 354-359.

Grundig, C.-G.: Fabrikplanung – Planungssystematik Methoden Anwendungen. München: Hanser 2018.

Krüger, T.: Entwicklung einer Gesamtmethodik zur Kombination von mathematischer Anordnungsoptimierung und Materialflusssimulation für die Produktionslayoutplanung. Düren: Shaker 2019.

Mieschner, M.; Mayer, G.: Bereitstellung und Verwaltung von Simulationseingangsdaten. In: Mayer, G.; Pöge, C.; Spieckermann, S.; Wenzel, S. (Eds.): Ablaufsimulation in der Automobilindustrie. Berlin: Springer 2020, pp. 319-332.

Mourtzis, D; Doukas, M., Bernidaki, D.: Simulation in manufacturing: review and challenges. Procedia CIRP 25 (2014) pp. 213-229.

InFranken: Siemens Healthineers baut 24 Meter hohes Technologiecenter in Forchheim, 2020. https://www.infranken.de/lk/forchheim/siemens-baut-24-meter-hohes-technologiecenter-in-forchheim-art-5136063, accessed May 5th, 2021.

Rabe, M.; Spieckermann, S.; Wenzel, S.: Verifikation und Validierung für die Simulation in Produktion und Logistik - Vorgehensmodelle und Techniken. Berlin: Springer 2008.

Sender, J; Wanner, M.-C.: Integrierte Kapazitäts- und Layoutplanung. Zeitschrift für wirtschaftlichen Fabrikbetrieb 108 (2013) 3, pp.109-112.

Süß, T.; Fischer, M.; Huber, D.; Laroque, C.; Dangelmaier, W.: Ein System zur aggregierten Visualisierung verteilter Materialflusssimulationen. In: Gausemeier, J.; Grafe, M. (Ed.): Augmented & Virtual Reality in der Produktentstehung, Band 252, Paderborn HNI Verlagsschriftenreihe 2009, pp. 111-126.

VDI 3633 Part 1: Simulation of systems in materials handling, logistics and production, Fundamentals. Berlin: Beuth 2014.