SIMULATION AND VISUALIZATION TO SUPPORT MATERIAL FLOW PLANNING IN A METAL CONSTRUCTION COMPANY

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ABSTRACT
This paper describes application of simulation and visualization techniques to support factory restructuring, material flow planning, and warehouse design in a family-owned metal construction company. Particular challenges lay in dynamically changing market situation at both customer and supplier sides, space-consuming dimension of the materials to be handled, and ill-structured information base for order management, production planning and control, and inventory management. This project is used as example for more generally discussing current situation of Digital Factory implementation especially in small and medium-sized enterprises. In the end, the paper concludes on barriers eventually hindering a consistent application of this comprehensive concept and underlines specific advantages from using simulation and visualization in the given context.

Keywords: Digital Factory, material flow planning, logistics simulation, 3D visualization

1. INTRODUCTION

A small family-owned metal construction company employs about 10 manufacturing workers and 3 logistics workers. They produce about 1,400 customer-specific metal constructions of different design, size and features according to the make-to-order principle. Final assembly and usage of the aluminium constructions in the building is done by company-own assembly workers directly on the construction site. Because of the close link to the construction sector and the dependency on the overall progress in the construction that is strongly influenced by external conditions and other parameters, delivery and assembly deadlines are highly dynamic and hardly predictable in nature. This might lead to a delay in being called to the construction site or to an earlier demand for using the aluminium construction in the building. Because of this, but also due to large-scale seasonal variations hardly to be predicted the company needs to be flexible and reactive in fulfilling customer orders.
Production is characterized by a high vertical range of manufacture with a manufacturing step from the middle of the product engineering process being outsourced. Production steps are organized in technologically sound manner and do not show any capacitive bottlenecks. In contrast to this, material flows and the link to the warehouse have not been treated well. This results in a high degree of non-transparency in material staging and a large percentage of idle performance mainly in storing, retrieving and restoring not to be quantified so far.
However, the project's exceptionality does not only come from constraints described above and the strong market dependency with regard to customer orders and procurement policy. On top an enterprise of this size and from this industrial sector typically lacks access to simulation and visualization as methods to accompany planning and development. Only CAD is regularly used for designing customer-specific constructions. This strongly product-focused approach is symptomatic; neither product process organization nor its systemic tool-based support gain the same amount of attention. Chances from pervasively applying models, methods and tools to represent, analyse and provide information on a factory in its entirety of product and production process are not understood. Instead they are seen as unrealistic and straining after effect.
This observation leads to the question for why the Digital Factory concept still is not applied in practice in large scale more than one and a half decades after first discussions on this topic arose. After briefly presenting the concept's background and state-of-the-art (Section 2), this question is going to be addressed in Section 3 of this paper in both ways in the context of small and medium sized enterprises (SME) in general and with regard to the company under investigation in particular. Section 4 explains application of simulation and visualization in the project presented above, discusses effects resulting from applying those methods, and indicates limitation of their use. The paper concludes with a reflection on barriers hindering pervasive implementation of the Digital Factory concept particularly in an SME and derives recommendations for action to overcome them (Section 5).

2. THE DIGITAL FACTORY CONCEPT

Digital Factory is a phenomenon having its background in computer-aided and computer-integrated technologies and advanced virtual reality (VR) technologies. It entitles the virtual environment for the lifecycle design of manufacturing processes and manufacturing systems using simulation and VR technologies to optimize performance, productivity, timing, costs, and ergonomics (Gregor and Medvecky 2010). According to the respective guideline by VDI (2008, p. 3) "Digital Factory is the generic term for a comprehensive network of digital models, methods and tools – including simulation and 3D-visualisation – integrated by a continuous data management system. Its aim is the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory in conjunction with the product." This concept is illustrated by Figure 1.

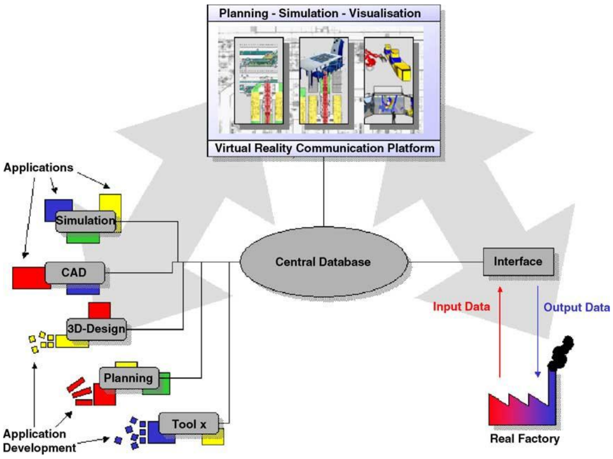

Figure 1: The Vision of the Digital Factory (Bracht and Masurat 2005, p. 327)

All computer-aided tools necessary for planning new products and production plants as well as for factory operation are interlinked through a central database. The entire factory is is represented in a consistent VR model which can be applied continuously all the way from the product idea to the final dismantling of the production plant and buildings. Those digital models form the basis for interdisciplinary cooperation among various experts from product design to inspection of new or modified factory. (Bracht and Masurat 2005)
Consequently, integration is one of the main pre-conditions for implementing the Digital Factory concept. According to Delmia (2010) there are three main elements to be integrated:

- *digital product* with its static and dynamic properties;
- *digital production planning*;
- *digital production* with the possibility of utilizing planning data for growing effectiveness of enterprise processes.

VDI (2008) integrates the following processes in the Digital Factory concept:

- *product* development, test, and optimization;
- *production process* development and optimization;
- *plant* design and improvement;
- *operative production* planning and control.

Plant design and optimization focuses on the optimization of material flow, resource utilization and logistics of all levels of plant planning from global production networks through local plants down to specific lines in order to improve production layout, assure machines and equipment being at the right place, have sufficient materials handling equipment available, optimize buffer dimensions, keep product handling at minimum etc. (Kühn 2006) Here, main focus is put on modelling and simulation techniques as they enable dynamic analysis to ensure that plant design problems and waste are discovered before the company ramps-up for production.
Even though simulation and visualisation play a major role in the Digital Factory concept, the integrative approach in terms of both elements covered and processes supported differentiates the Digital Factory from related concepts like the Virtual Factory or the Smart factory.
The *Virtual Factory* concept dating back to the 1990s is a major driver for the move towards integrating VR and discrete event simulation (DES). Jain et al. (2001) define the *Virtual Factory* concept as an "integrated simulation model of major subsystems in a factory that considers the factory as a whole and provides an advanced decision support capability." In this concept DES is a core component of a holistic model of the factory where DES enables an integrated view encompassing all major subsystems to be formed (Turner et al. 2016). Later concepts also address interoperability of the Virtual Factory at data level, service level, and process level. However, The Virtual Factory is, and should be, "a VR representation" for a factory, with 3-D environments and visualization essential for understanding and knowledge share (Jain and Shao 2014).
The *Smart Factory* is strongly related to Industry 4.0 – the fourth industrial revolution. Production and administrative processes are meshed with each other via IT systems in order to optimize the use and capacity of machines and lines. This way agile production systems are created responding to fast changing consumer markets. The factory can be modified and expanded at will, combines all components from different manufacturers and enables them to take on context-related tasks autonomously (James 2012). Therefore, Turner et al. (2016) see the Smart Factory as practical implementation of the Virtual Factory concept – enabling next generation factories being able to produce customized and small-lot products efficiently and profitably (Wang et al. 2016).
Comparing the concepts introduced so far their different focusses become obvious. Whereas the Smart Factory allows for semi-autonomous decision making in physical factory operation, the Virtual Factory aids the

decision-making process by means of simulation and 3D visualization. The Digital Factory spans from product development to plant design and production planning and control, i.e. it supports planning and development alongside the entire product life cycle including related resources and their operation to prepare physical (even smart) factory operation. The Digital Factory is a planning tool in its widest sense.
At the beginning of the new Millennium Digital Factory as a vision got a boost. Research and development activities focussed on how to implement its concepts, methods and tools into practice inside and across companies and industrial sectors. In Germany, this development was mainly driven by large enterprises, first of all from the car manufacturing sector, as they were absolutely sure about tremendous advantages from letting this vision come to life. Today, we can state the Digital Factory being well established in those enterprises with the Smart Factory still being a vision for future even there (Strehlitz 2016). Application examples from other countries and industrial sector, e.g. from the aerospace industry (Caggiano et al. 2015) or tricanter production (Kyncl et al. 2017), support this situation analysis on Digital Factory implementation. In contrast to this, current situation of Digital Factory implementation is very much different when looking into small and medium-sized enterprises (SMEs).

3. DIGITAL FACTORY IN AN SME CONTEXT

Answering the question for the current level of practical implementation of the Digital Factory concept in SMEs is challenging as those companies do not report in wide scale about how they apply Digital Factory methods and tools.
Bierschenk et al. (2004) run a survey to get a glimpse on the current state of the Digitial Factory in SMEs. As result it became clear that SMEs do not follow large companies in implementing the Digital Factory concept. High costs (64%) and unclear benefits (73%) were identified as main barriers, even though SMEs already saw the enormous potential in terms of savings and increasing competitiveness.
Bracht and Masurat (2005) warned about the particular importance of integrating the fundamental idea of the Digital Factory into the supply chain for gaining competitive advantage. SMEs need to keep up with modern planning procedures for dimensioning their storage and distribution concepts or deriving new organizational structures. This will result in enormous savings in time and costs. However, the efforts necessary for implementation have in part been underestimated and are still underestimated. Especially costs for purchasing suitable software tools are still relatively high. Whereas large enterprises are able to handle those costs, for SMEs they form a large obstacle causing disproportionately high investments.
Five years later, Bracht and Reichert (2010) renewed this message and predicted an increased need for implementing digital methods not only in product development, but also in process, production, and factory planning. For ensuring their own survival in a globalized world SMEs face the inescapable necessity of introducing the Digital Factory.
However, Schallow et al. (2014) still report about lacking implementation of the Digital Factory in SMEs. According to their survey about 45% of participating SMEs even see “Digital Factory” as a buzzword only. Authors conclude that the majority of digital tools available at the market are not suitable for SMEs. This statement first of all refers to tools supporting factory planning, e.g. process simulation or 3D layout planning. Here, costs for purchasing tools and qualifying employees in using them does not pay back to an SME. On top, frequency of planning tasks is rather small making it more difficult to create a sufficient experience base with employees. In contrast to this, the degree of integration of digital tools in product development and production is already quite high. This strong focus on “digital islands” reported by about 94% of SMEs in the study goes in line with media or software disruption. About 88% of the companies criticize a lack of standards regarding interfaces and data (Schallow et al. 2014). Comprehensiveness as required by VDI (2008) obviously does not exist in SMEs.
Similar findings result from analysing more than 200 student projects run with companies when preparing Bachelor or Master thesis at the Technical University of Applied Sciences in Wildau. About 20% of all projects were run with OEMs, but just five projects were allocated in the Digital Factory context, mainly for 3D planning or simulation of robot behaviour and transformation processes. None of these five thesis projects was run in an SME which confirms the weak picture about the reality of Digital Factory in those companies. SMEs usually point on missing tools and doubt about a substantial need for them within the specific company context. Planning problems are seen as simple enough to solve them without support by digital tools. For eventually appearing planning mistakes that could have been avoided e.g. by use of simulation it is almost impossible to specify resulting additional costs. Because of these difficulties in giving proof of economic benefit they also do not see any economic advantage in implementing the Digital Factory concept or even introduce digital tools for planning support in their processes. Instead SMEs look for methods and tools helping them in better managing daily production and reducing order lead-time, production costs or capital lockup.
The general state-of-implementation of the Digital Factory concept in SMEs as elaborated so far now forms the starting point for discussion in the context of a project run with a family-owned metal construction company. Here, as in many other companies, clear advantages from digital product development are well known. Computer-Aided Design (CAD) techniques are taken for granted to have detailed technical drawings directly created by the designer of customer-specific aluminium constructions and also to share them with others in a company-wide collaboration approach. In

contrast to this neither Enterprise Resource Planning (ERP) nor Production Scheduling and Control (PSC) systems are used in this company to digitally support the company's business processes. Simulation and visualization techniques are fully unknown creating a lot of scepticism towards their use in the project. Therefore, apart from solving the initial problems concerning factory layout, material flows and warehouse capacity, major challenges throughout the entire project consisted in introducing simulation and visualization at all, raising awareness on the required database, and building trust in results from their application.

4. SIMULATION AND VISUALIZATION SUPPORT IN A COMPANY PROJECT

The presented project aimed at supporting warehouse planning and material flow-oriented factory re-engineering. In order to determine weak points and identify potential for improvement, the project started with comprehensively analysing the current situation of production process, material flows, inventory and the factory as a whole. From this, various fields requiring action got derived. The warehouse was overcrowded with many materials being stored on floor space in front of the cantilever racks and between workstations. Material flows were quite complex and non-directed; many materials were moved forth and back just passing the warehouse without any storing necessity (see Figure 2). In contrast to this, the production process run smoothly with all workstations showing quite some spare capacity. Because of this, situation analysis resulted in expressing the urgent need for clearing material flows by re-locating workstations and warehouse, i.e. improving factory layout. Furthermore, the company was told to introduce accompanying measures like definition of standard processes or unlinking warehouse management from a particular person.

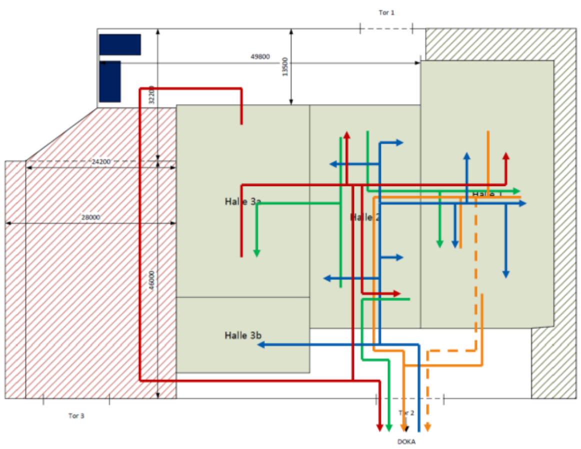

Figure 2: Initial Material Flows

To support factory and warehouse planning as well as layout re-design application of simulation and 3D visualization techniques were suggested. This was not caused by process complexity inside the factory, but much more by the unclear situation in terms of available data. Despite of tremendous efforts in the analysing phase, it was practically impossible to get reliable data on storage/retrieval activities in the warehouse, inventory level per material, warehouse refilling processes including related purchasing decisions, manufacturing order management etc. On top of this unclear in-house situation there are various external influences hardly to predict, like customer behaviour or development of the aluminium market.

Against this background simulation experiments should help in comparing layout variants according to material flow efforts needed to assure a given production output. In the context of warehouse planning inventory development over time should be investigated in order to derive required warehouse capacity, the needed buffer space or additional floor space to provide workstations with material, and determine appropriate purchasing behaviour. Due to missing process data extreme situations were planned to be simulated to analyse their impacts on system performance. However, in the end not even this quite rough analysis of the factory was possible by use of simulation since minimum simulation database was not existing and could not be estimated at meaningful level. As a consequence, developed factory layout variants were compared in an analytical way and by means of static visualization only (see Figure 3). To eventually make simulation possible in future (and to move company management into the 21st Century) the company got a long list of what urgently needs to be done in order to set up information flows and data management of standard level in production companies.

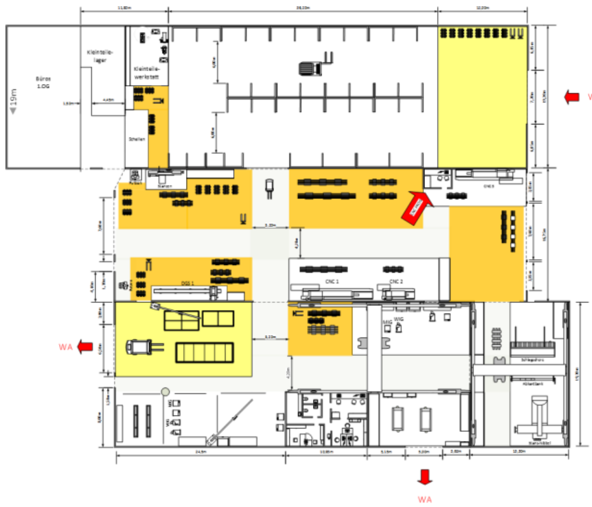

Figure 3: Layout after Re-design

3D visualization aimed to virtually analyse handling operations for large-size materials and semi-products in an environment with narrow aisles and gate of limiting size. For this, the chosen layout (see Figure 3) was represented in a dynamic VR model with all materials handling equipment operating according to their technical characteristics (see Figure 4). Here, simple tests for collision using geometric covers gave proof of the proposal's functionality. Furthermore, the 3D model clearly illustrated the well-structured design of the factory and the dynamic VR scene with its possibility to fly over or walk through became the decisive tool to immediately get production workers and logisticians convinced about the usefulness of the proposed changes. In the end, even the very sceptic company owner agreed on the need for change when seeing his new factory in a close-to-real way.

Figure 4: VR Scene of the Factory after Re-design

With this the project demonstrated the powerfulness of digital support in different planning stages. Of course, this is no news to the scientific community nor to large companies with own simulation and visualization departments having implemented the Digital Factory concept already. For a small company like the one under investigation this finding forms a huge step towards a paradigm shift. Additionally this project is a good example for reminding of the need to question if a problem is worth to be simulated. Because of the confusing, ill-structured initial situation in the factory simulation seemed to have been needed. In the end it turned out that to some extent simulation became obsolete in the problem solving process due to the use of appropriate software for (static) visualization and after re-structuring the factory following a logistics-oriented design. Nevertheless, simulation still would have been (and is) on the agenda for answering all questions related to dynamic forecasting and system performance analysis. In the course of the project the company understood the general importance of a sufficient database and looks for further digital planning and scheduling support by means of simulation once a reliable simulation database has been created.

5. CONCLUSIONS

The presented project is a simple example for applying the Digital Factory concept in a small enterprise from a traditionally rather innovation-hesitant industrial sector. Due to an almost completely missing simulation database purposeful simulation model-building and simulation-based experimentation were impossible. Even though this created quite some extra challenges to the project, the company – after many discussions – learned significant lessons from this. In the end, a solution to the initial problems was proposed on the basis of which the company completely re-organised and re-designed factory layout, processes, material flows, and warehouse solution. Visualization models helped in presenting problems and ideas during project evolution, but even more important they finally were the clue to convince the company owner of the solution's functionality, effectiveness and future-orientation. Whereas all proposals got implemented by now, the project also initiated additional change. Processes are going to be standardized; preconditions for an up-to-date and comprehensive data management are on the way to enable order tracking, stock monitoring, and procurement management. Last but not least, the company after all is strongly interested in applying simulation methodology for system performance limit determination and further process optimization.

This example, at a first glance, seams to put the Digital Factory concept into question rather than supporting the need and usefulness of its implementation. At a closer look it demonstrates the opposite. Even a small family-owned enterprise far away from a high-technology business lacks digital support in adjusting the factory and its processes to current and future needs.

The digital factory concept is an integrated approach to enhance the product and production engineering processes. Simulation is a very important key technology in the overall concept and can be applied in virtual models on various planning levels and stages to improve the product and process planning. Pre-condition for properly applying simulation technology in this context is a sound simulation data base.

According to the vision presented in this paper, nowadays an integrated concept of digital validation should form the methodological basis of all factory and material flow planning activities in large-scale industrial enterprises and company groups at least. However, to expect something similar with regard to SMEs seems to be illusionary. Here, an ongoing learning process is still needed to introduce certain aspects and specific parts of the Digital Factory concept fitting the particular needs and opportunities of the company.

Latest surveys on the potential future of the Digital Factory give a quite optimistic outlook. According to Geissbauer et al. (2017), for example,

- 91% of industrial companies are investing in creating Digital Factories in the heart of Europe,
- 98% of industrial companies expect to increase efficiency with digital technologies,
- 90% of industrial companies believe that digitization offers them more opportunities than risks.

As digitization does not only refer to the Digital Factory concept supporting planning processes, but also to the Smart Factory idea leading to the next evolutionary step in factory operation, another boost in integrating digital tools also in SMEs is to be expected in the coming years.

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