A Modular Factory Planning Approach Based on Vertical Integration of the Information Flow

Max Hoffmann, Tobias Meisen, Daniel Schilberg and Sabina Jeschke

Abstract The increasing complexity of products and consumer interests is facing more and more challenges to production planning. An innovative approach, which facilitates efficient planning, is represented by a model-based approach using the concept of the Digital Factory. In order to realize the vision of virtual production, modular solutions like simulations or optimization tools are merged into a holistic model that provides a digital mapping of the entire production process. In this work, a framework is described, which is capable to integrate planning modules by using an integrative information model. Based on intelligence approaches, multiple data is linked to reach a vertical integration of the information flow. These cross-linked data structures facilitate a consolidation of data from different levels of the production monitoring and management layers. The provided information is used to establish decision support systems, which enable an entirely holistic factory planning. The advantages of the approach are demonstrated by a process chain formation use case.

Keywords Virtual Production Intelligence · Factory Planning · Digital Factory · Data Mining

1 Introduction

Due to the rising interests in a higher variety of products, the modularity of the production gains in importance. Thus, necessary modifications of the production structure and their impact to technical and economic aspects have to be taken into consideration during the planning. As the consideration of dependencies in a factory is highly complex, the planning has to be divided into distinctive planning steps. One approach to modularization of the planning was introduced by Schuh et al. [1]. The presented "Condition Based Factory Planning" splits the planning into distinctive modules in order to create more structured and systematic ways of planning. The advantages of such an approach are the determined procedure of planning projects and

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the possibility of splitting the process into working packages, which can be performed by experts. The drawbacks of this approach, however, consist in an insufficient consideration of interdependencies between the planning modules.

Thus, the goal of a holistic factory planning approach consists in the definition of an information model that contains not only the capabilities to integrate the different planning modules of the factory planning process, but also to manage the information generated and provided by various sources. In the present work, a software framework will be introduced that contains an information model, which serves interoperability between the modules of a modular factory planning approach.

2 State of the Art

Layout planning has emerged to one of the core elements in factory planning [2] and is carried out in several steps based on different planning modules. According to Guideline VDI 5200 [3], the layout planning is part of the conceptual planning of a factory and is performed firstly by determining the ideal layout. The derivation of the ideal layout is hereby comprised of structure planning and the dimensioning of resources. The ideal layout is initially designed using existing production data before it is adapted to other requirements of the production.

Existing production data or manufacturing information can for instance consist of product lists, processes, quantities and other variables of the Enterprise Resource Planning (ERP). Based on this data, several possible production configurations are selected and compared. Numerous heuristic and graphical methods have been carried out to support the determination of the ideal layout [4]. The considerations of boundary conditions as well as the communication flow are performed in later steps of the planning through the determination of the real layout [2]. A well-structured summary of the different approaches and factors influencing the layout planning is provided by Kampker et al. [5].

The step from the ideal to the real layout is usually influenced by the knowledge of experts as a core element in factory planning. As a consequence, the real layout is mainly shaped through experience values and it is documented in a qualitative and abstract form. Hence, in literature, there is a lack of explicit instructions regarding the compliance of conditions such as ensuring communication flows and the modularity of the production. Similarly, there are only few quantitative approaches for estimating the costs arising from the consideration of the boundary conditions [5]. Accordingly, the main challenge in layout planning is the quantitative measurability of various scenarios with the aim to determine an optimal solution. One approach to systematize the experts' knowledge and experience in the planning process consists in an establishment of Decision Support Systems.

According to Arnott and Pervan [6], Decision Support Systems (DSS) represent an information systems discipline that focusses on supporting and improving managerial decision-making. One of the most important development branches of the DSS central idea consists in the Executive Information Systems (EIS), which can be characterized as data-oriented DSS [7]. In the late nineties, a certain kind of DSS was introduced, which extended the idea of EIS to enterprise-wide reporting systems. These DSS are referred to as Business Intelligence (BI) systems. Due to their data-oriented, enterprise-wide character, BI systems can serve as decision support tools in heterogeneous environments. The underlying Intelligence concepts can be applied either on the economical optimization in a company or within the production environment. In terms of production planning, Intelligence systems are intended to process both historical data from the process and product development as well as real-time data from the production to guarantee data propagation to people, who are involved in the planning process, in an appropriate form [8]. The most important developments in this context consist of Operational Business Intelligence (OpBI) and Manufacturing Execution Systems (MES), which both serve a BI-like decision support within the production environment [9].

A combination of the technologies described above could lead to a flexible layout planning. However, the central problem is the rather unsystematic way factory planning projects are currently performed. In order to realize a more flexible and consequently complex production while keeping the modular factory planning approach, systematic ways of data management have to be carried out.

3 Virtual Production Intelligence

The systematic way of planning described above can only be realized through an aggregation of data taken from different planning modules and IT tools into one embedded system. However, the consolidation and propagation of data from different levels and layers of the production is difficult due to the heterogeneity of the underlying information systems. Accordingly, the problem that needs to be solved in this context is to ensure interoperability between information systems used within various methodologies of data generation and data aggregation [10]. In addition, inter-operability has to be established between various modules of the factory planning process as the complexity of the planning is managed by the modularization of the planning into sub-processes.

An integrative solution to serve interoperability between heterogeneous, distributed systems is presented with the adaptive information integration [11]. A framework based on this approach allows the creation of an integrative information model in connection with a common data basis, which contains both input and output data from various applications in a structured form [12]. This framework and the according information model enable an establishment of BI approaches into the domain of virtual production and are referred to as "Virtual Production Intelligence (VPI)". The VPI allows a merge of heterogeneous planning, simulation and optimization tools. Based on the information model, a platform has been carried out that is capable of integrating information from different corporate and production processes as well as simulations into a common data basis. This multi-dimensional data basis

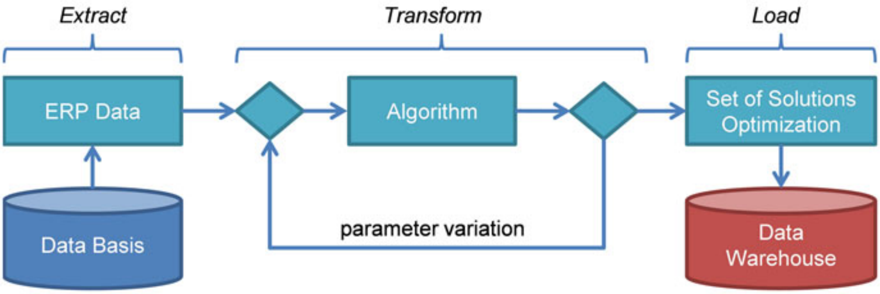

Fig. 1 Extract-transform-load process in order to perform a multi-dimensional optimization

enables a vertical flow of information from all levels of production management and operations due to the integrative methodology of the information model.

In order to integrate data into the data basis, Extract-Transform-Load (ETL) processes are carried out. In these processes, data has to be extracted from a corresponding application. In a further step, it is transformed in accordance to the information model and finally loaded into a data warehouse system (see Fig. 1). Thus, on the one hand, interoperability is guaranteed, and, on the other hand, the architecture of software systems do not need to be adjusted to be applicable in the overall planning context.

In addition, the framework contains a front-end solution in the form of a web interface. The interface is intended to show the aggregation as well as the user- and role-specific representation of the resulting data generated on the basis of various applications. It provides an end-to-end view of all important data of the planning suitable for the current user. The user can thus make sound and quantitatively reliable decisions concerning the planning progress and is hereby also supported by underlying analysis methodologies that are embedded in the information platform. Based on the interface, cross-module connections in the factory planning can be identified and integrated in the evaluation of the overall project. Due to the detected dependencies between the determining variables, formal, quantitative relations between different planning modules can be derived. This allows the realization of effective intelligence systems, which can serve as a support tool in decision-making during the planning process, thus enabling a more flexible production.

4 Use-case Layout Planning

With regard to the ideal layout optimization heuristic approaches are usually applied. The results of such heuristics rely on qualitative estimates, which are then further developed using semi-analytical or iterative mathematical techniques to gain an “optimal” solution of the problem. In layout planning, the procedure is usually designed in a way that the number of segments is defined in advance. According to the requirements of the products to be manufactured, process chains are formed, in which the largest possible number of these products can be mapped.

The issue of this approach is to embed the planning results into the overall workflow of the layout planning. An evaluation of each supply chain configuration with respect to the real layout is usually associated with a high effort as the results of different planning scenarios with different parameters have to be manually entered into further planning tools. An evaluation of all scenarios is thus connected with unreasonable efforts, so that the factory planner usually defines a determined solution before continuing with further optimization steps. This way of determining a fixed solution is problematic as other possible solutions are ignored for the rest of the planning and will not be further evaluated. Therefore, an integrative data basis is needed, which allows for the consideration of all possible configurations within the upcoming planning steps.

Using the Virtual Production Intelligence Platform, possible planning scenarios are transferred and consequently considered in further planning steps. In order to demonstrate the related benefits, an algorithm has been developed, which performs a process chain determination based on historical production data. Similarities and regularities within these chains are identified through quantitative measures that have been implemented based on counting methods, through which an evaluation of the process chains is also performed. The main process chains, which were identified during the assessment, are evaluated using statistical and heuristic methods. Furthermore, they are modified using an iterative optimization algorithm until a determined coverage of the products is guaranteed. The results of the proposed algorithm can be seen as the optimal solution of the production structure configuration – that is the ideal layout – for a specific production list and parameterization.

The algorithm of the process chain optimization tool has been integrated into an Extract-Transform-Load (ETL) process in order to reach a modular storage of the optimization results. The procedure of the process chain optimization has been divided into several steps:

1. The existing production data is loaded from the Enterprise Resource Planning database and is used for the generation of process chains (*Extract*).
2. Then, the algorithm is executed in the *Transform process*.
3. A possible parameter variation can be performed by changing the number of main chains for each optimization run. Consequently, the algorithm is carried out for any specified number of main chains and determines and optimal solution for this specific parameterization.
4. The results of each optimization run are stored in a multidimensional database, hence a Data Warehouse (*Load*), so that the results of each scenario are mapped into the data basis.
5. Through a web-based User Interface, the user receives the results, which are tailored to his corresponding parameter selection (see Fig. 2).

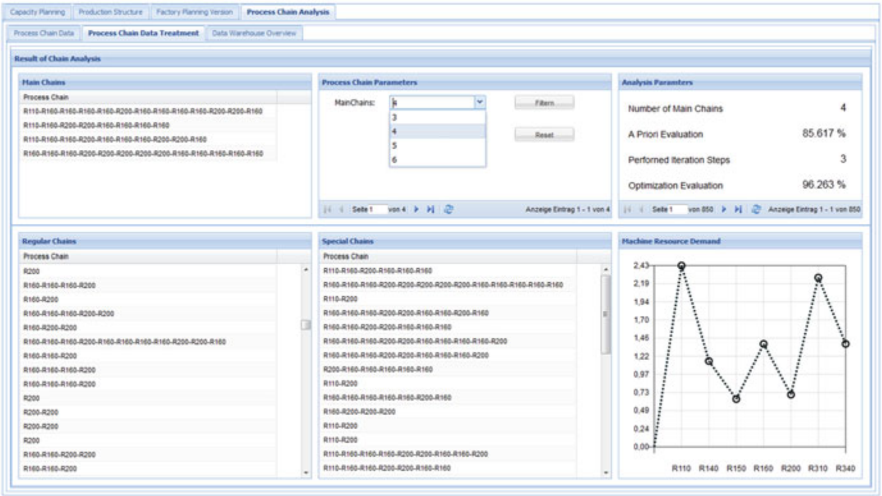

Fig. 2 User-interface for the management of process chain optimization scenarios

In the top left corner, the main process chains for the selected parameters are shown. In the middle, the user can select parameters out of the relevant parameter range. The upper right corner shows the quantitative results of the optimization. Within this corner, firstly, the chosen parameter is visualized. Secondly, the evaluation before applying the algorithm is pointed out as well as the number of needed iteration steps and the final results of the optimization.

The lower left corner of the web application interface shows the product chains that can be produced using the determined main process chains. The “Special Chains”, which are shown in the middle of the lower part, make up an amount of about 3.7 %. These chains cannot be manufactured using the main process chains without making additional logistical efforts. In the lower right corner, a graph is depicted which shows an example of the current resource demand of the different manufacturing machines, which can also influence the results of further calculation steps.

5 Conclusion and Outlook

Based on a use case it was shown that the use of Intelligence concepts – in particular the VPI – result in far reaching benefits in factory planning. Because of the use of the VPI platform, various constraints and parameters can be considered in the planning process. This enables an integrated, holistic view of the various scenarios of a factory planning project so that individual modules of the production planning can be evaluated in the overall context of the planning. Quantitatively reliable and sound statements over the planning success can thus be made at any time.

In the context of optimized production planning, the next steps will consist in expanding the concepts presented both in terms of algorithmic and methodological aspects. In this connection, the process chain term has to be extended in terms of its dimension. The resulting multi-dimensional process chains allow the consideration of temporal constraints between the manufacturing steps of a product and thus provide a holistic mapping of the production structure. Thus, in production, cycle times will be harmonized by a parallel connection of machinery resources and waiting times are minimized. This enables a user configurable, modular design of a multi-variant production.

On the methodological side, the presented concepts of the vertical integration of production data have to be realized by extending the VPI Platform in terms of the data flows from the MES and the field level. These information need to be processed and aggregated automatically so that they are available within the ERP system and production planning. Only through the interoperability between these systems, an integrated digital mapping of the production is possible. This provides the basis of intelligent tools for the planning and decision support in order to ensure a continuous improvement and further development of the production planning process.

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References

1. Schuh, G., B. Franzkoch, P. Burggräf, J. C. Nöcker, and C. Wesch-Potente. 2009. Frei konfigurierbare Planungsprozesse in der Fabrikplanung. *wt Werkstattstechnik online* 99 (4): 193–198.
2. Wiendahl, H.-P., J. Reichardt, and P. Nyhuis. 2009. *Handbuch Fabrikplanung: Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten*. München: Hanser.
3. Guideline VDI 5200. 2011. Fabrikplanung - Blatt 1 - Planungsvorgehen.
4. Singh, S. P., and R. R. K. Sharma. 2006. A review of different approaches to the facility layout problems. *The International Journal of Advanced Manufacturing Technology* 30 (5–6): 425–433.
5. Kampker, A., K. Kreisköther, P. Burggräf, A. Meckelnborg, M. Krunke, S. Jeschke, and M. Hoffmann. 2013. Value-oriented layout planning using the Virtual Production Intelligence (VPI). POMS 2013 - Twenty Fourth Annual Conference, Denver, Colorado, U.S.A. Production and Operations Management Society.
6. Arnott, David, and Graham Pervan. 2005. A critical analysis of decision support systems research. *Journal of Information Technology* 20 (2): 67–87.
7. Fitzgerald, G. 1992. Executive information systems and their development in the U.K.: A research study. *International Information Systems* 1 (2): 1–35.
8. Kemper, H., and B. Henning. 2006. Business Intelligence and Competitive Intelligence: IT-basierte Managementunterstützung und markt-/wettbewerbsorientierte Anwendungen. *HMD Praxis der Wirtschaftsinformatik* 43 (247): 7–20.
9. Eckerson, W. W. 2007. Best practices in operations BI: Converging analytical and operational processes. TDWI Best Practices Report, WA: Renton.
10. Schilberg, D., T. Meisen, R. Reinhard, and S. Jeschke. 2011. Simulation and Interoperability in the Planning Phase of Production Processes. *Proceedings of the ASME 2011 International*

Mechanical Engineering Congress & Exposition, IMECE 2011, November 11–17, Denver, Colorado, USA.

11. Meisen, T., P. Meisen, D. Schilberg, and S. Jeschke. 2012. Adaptive information integration: Bridging the semantic gap between numerical simulations. *Lecture Notes in Business Information Processing* 102:51–65.
12. Reinhard, R., T. Meisen, T. Beer, D. Schilberg, and S. Jeschke. 2011. A Framework Enabling Data Integration for Virtual Production: In: Enabling Manufacturing Competitiveness and Economic Sustainability. *Proceedings of the 4th International Conference on Changeable, Agile Reconfigurable and Virtual Production (CARV 2011).*