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Organized by:
Laboratory for Manufacturing Systems and Automation (LMS)
Director: Prof. George Chryssolouris

Conference Programme

Tuesday, 15 May, 2012				
17:00–19:00	**Onsite Registration**			
19:00–20:00	**Reception at "The MARGI" Hotel**			
Day 1: Wednesday, 16 May, 2012				
08:30-09:30	**Onsite Registration**			
09:30–10:00	**Opening Ceremony** Welcome by Prof. G. Chryssolouris CIRP President Address by Prof. A. Nee Conference Planning by Prof. D. Mourtzis			
10:00–10:30	**Plenary Session** **Keynote Paper: Manufacturing Skills and Competences for the Factories of the Future** D. Mourtzis, D. Mavrikios, N. Papakostas, G. Chryssolouris			
10:30–11:00	**Coffee Break**			
11:00–12:30	**Manufacturing Systems Design**	**Manufacturing Processes**	**Manufacturing Systems Planning & Control**	**Manufacturing Equipment Automation**
	Session A1	**Session B1**	**Session C1**	**Session D1**
	P01: Assessing Lean Systems Using Variability Mapping A. Deif	**P17: Analysis of Micro Burr Formation in Austenitic Stainless Steel X5CrNi18-10** D. Biermann, M. Steiner	**P04: Model of a decision support system for a least-cost and harmonized capacity adjustment in the short- and medium-term planning horizon** C. Morawetz, W. Sihn	**P24: Automated Driving by standardizing and scaling the manufacturing strategy** Z. Yang, P. Sachnik, D. Opritescu, R. Golle, W. Volk, H. Hoffmann, F. Schmiedl, M. Ritter, P. Gritzmann
	P03: A Simulation-Based Evaluation of Selective and Adaptive Production Systems (SAPS) Supporting Quality Strategy in Production J. Kayasa, C. Herrmann	**P15: Reduction of Burr Formation in Drilling using Cryogenic Process Cooling** D. Biermann, H. Hartmann	**P11: Operational planning of maintenance measures by means of event-driven simulation** B. Denkena, S. Kroening, K. Doreth	**P25: Online Evaluation Method of Machining Precision Based on Built-in Signal Testing Technology** F. Zhao, X. Mei, Z. Du, T. Tao, G. Jiang
	P36: A wed-based platform for customer integration in the decentralized manufacturing of personalized products D. Mourtzis, M. Doukas	**P34: Numerical Study on Shear Flow in Sliding Bearing with Partial Slip Surface** Q. Lin, Z. Wei, Y. Tang	**P27: A Reference Model For Collaborative Capacity Planning Between Automotive And Semiconductor Industry** M. Zapp, C. Forster, A. Verl, T. Bauernhansl	**P02: Defining Manufacturing Performance Indicators using Semantic Ontology Representation** G. Pintzos, M. Matsas, G. Chryssolouris

12:30–14:00	**Lunch Break**			
14:00–15:30	**Session A2**	**Session B2**	**Session C2**	**Session D2**
	P73: A case study on reuse of manufacturing knowledge within the defence industry with a comparison to automotive and aerospace practices L. Krogstie, P. Andersson	**P16: Size Effects in Micro Drilling Ferritic-Pearlitic Carbon Steels** M. Abouridouane, F. Klocke, D. Lung, O. Adams	**P110: Optimal Process Shift Design in Selective and Adaptive Production Systems** M. Colledani, D. Ebrahimi	**P54: Collaborative Factory Planning in Virtual Reality** N. Menck, X. Yang, C. Weidig, P. Winkes, C. Lauer, H. Hagen, B. Hamann, J.C. Aurich
	P19: The State of the Art and Prospects for the Future of Learning Factories U. Wagner, T. AlGeddawy, H. ElMaraghy, E. Müller	**P35: Numerical Simulation and Experimental Study on the Resist Filling Behaviour in UV-nanoimprint Lithography** J. Du, Z. Wei, Y. Tang	**P28: Benchmarking of Methods and Instruments for Self-Optimization in Future Production Systems** C. Wagels, R. Schmitt	**P18: Realistic Machine Simulation with Virtual Reality** R. Neugebauer, P. Klimant, M. Witt
	P108: Developing Competencies for Continuous Improvement Processes on the Shop Floor through Learning Factories – conceptual design and empirical validation J. Cachay, E. Abele	**P21: An Initial Study of the Effect of Using Liquid Nitrogen Coolant on the Surface Roughness of Inconel 718 Nickel-Based Alloy in CNC Milling** A. Shokrani, V. Dhokia, R. Imani-Asrai, S.T. Newman	**P93: A Model of Collaborative Enterprise Networks** H. Baum, J. Schuetze	**P32: Design and Development of an in situ Machining Simulation System using Augmented Reality Technology** J. Zhang, S.K. Ong, A.Y.C. Nee
15:30–16:00	**Coffee Break**			
16:00–18:00	**Session A3**	**Session B3**	**Session C3**	**Session D3**
	P71: Information Requirements for Motivated Alignment of Manufacturing Operations to Energy Availability M. Grismajer, G. Seliger	**P42: Thermal Aspects in Deep Hole Drilling of Aluminium Cast Alloy using Twist Drills and MQL** D. Biermann, I. Iovkov, H. Blum, A. Rademacher, K. Taebi, F.T. Suttmeier, N. Klein	**P29: Changeability in Structure Planning of Automotive Manufacturing** C. Loeffler, E. Westkaemper, K. Unger	**P40: Development of 5-axis Control CAM System for Multi-tasking Machine Tools** K. Nakamoto, K. Kubota, T. Ishida, Y. Takeuchi
	P09: An integrated setup planning and pallet configuration approach for highly automated production systems with energy modelling of manufacturing operations S. Pellegrinelli, A. Valente, L.M. Tosatti	**P97: Knowledge Integration in a Collaborative Machining Process Planning Environment** M. Helgoson, V. Kalhori	**P37: Ontology based Intelligent assistance system to support manufacturing activities in a distributed manufacturing environment** S. Minhas, C. Juzek, U. Berger	**P55: Design methodology for mechatronic active fixtures with movable clamps** T.N. Papastathis, O.J. Bakker, S.M. Ratchev, A.A. Popov

	P26: Multiple-attribute decision making for an energy efficient facility layout design L. Yang, J. Deuse **P47: Distributed Optimization of Energy Portfolio and Production Planning for Multiple Companies under Resource Constraints** T. Nishi, E. Sekiya, S. Yin	**P56: Carbon Emission Assessment to Support the Planning and Operation of Low-Carbon Production System** X. Shi, H. Meier **P61: Suitability of the ISO 10303-207 Standard for Product Modelling of Line Linked Micro Parts** K. Tracht, F. Weikert, T. Hanke	**P43: Game Theoretic Approach for Global Manufacturing Planning under Risk and Uncertainty** S. Yin, T. Nishi **P53: Throughput time characteristics of rush orders and their impact on standard orders** D. Trzyna, A. Kuyumcu, H. Lödding	**P60: Robot Path Correction Using Stereo Vision System** G. Michalos, S. Makris, A. Eytan, S. Matthaiakis, G. Chryssolouris **P75: High Speed Vision based automatic Inspection and Path Planning for Processing conveyed Objects** M. Weyrich, Y. Wang, J. Winkel, M. Laurowski
Day 2: Thursday, 17 May, 2012				
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09:00–10:30	**Session A4**	**Session B4**	**Session C4**	**Session D4**
	P12: Automatic simulation model generation based on PLC code and MES stored data G. Popovics, A. Pfeiffer, B. Kádár , Z. Vén, L. Kemeny, L. Monostori **P31: Simulation Methods for Changeable Manufacturing** A. Seleim, A. Azab, T. AlGeddawy **P41: Development of PSS Design Support System: Knowledge-based Design Support and Qualitative Evaluation** F. Akasaka, Y. Nemoto, R. Chiba, Y. Shimomura	**P06: Analysis of Machine Influence on Process Stability in Sheet-Bulk Metal Forming** B.A. Behrens, R. Krimm, T. Matthias, V. Salfeld **P63: Effect of Cutting Conditions on Machinability of Superalloy Inconel 718 during High Speed Turning with Coated and Uncoated PCBN Tools** V. Bushlya, J. Zhou, J.E. Staehl **P78: Reliable Copper Spot Welding with IR Laser Radiation through Short Prepulsing** A. Moalem, P. von Witzendorff, U. Stute, L. Overmeyer	**P08: Implementation of a comprehensive production planning approach in special purpose vehicle production** S. Auer, W. Mayrhofer, W. Sihn **P109: User friendly framework for measuring product and process novelty in the early stages of product development** G. Ringen, H. Holtskog, K. Martinsen **P44: Strategic planning of global changeable production networks** G. Lanza, R. Moser	**P33: Robot Path and End-effector Orientation Planning using Augmented Reality** H.C. Fang, S.K. Ong, A.Y.C. Nee **P62: Evaluating changeability corridors for sustainable business resilience** T. Bauernhansl, J. Mandel, S. Diermann **P79: Gathering alternative solutions for new requirements in manufacturing company: Collaborative Process with Data Visualization and Interaction Support** S. Sadeghi, C. Masclet, F. Noel

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11:00–12:30	**P87: Manufacturing Complexity Review Challenges and Outlook** K. Efthymiou, A. Pagoropoulos, N. Papakostas, D. Mourtzis, G. Chryssolouris **P67: Testing Complexity Index - A Method for Measuring Perceived Production Complexity** S. Mattsson, P. Gullander, U. Harlin, G. Bäckstrand, Å. Fasth, A. Davidsson **P39: Structural Complexity Assessment: A Design and Management Tool for Supply Chain Optimization** V. Modrák, P. Semanco	**P57: Preliminary Study on Chemical Figuring and Finishing of Sintered SiC Substrate Using Atmospheric Pressure Plasma** K. Yamamura, Y. Yamamoto, H. Deng **P104: Forming Process Integrated Induction Brazing** J. Avemann, R. Willy, G. Zhao, P. Groche **P80: Investigation of the material removal efficiency during Femtosecond Laser machining** P. Stavropoulos, K. Efthymiou, G. Chryssolouris	**P50: Design and planning of decentralized production networks under high product variety demand** D. Mourtzis, M. Doukas, F. Psarommatis **P65: An evolutionary approach for global production network optimization** G. Schuh, T. Potente, D. Kupke, R. Varandani, C. Hausberg **P48: Computational Evaluation of Order Selection Methods in Dynamic Supply Chains** Y. Tanimizu, B. Orita, Y. Shimizu, C. Ozawa, Y. Maeda, K. Iwamura, N. Sugimura	**P106: Optimal Design of Machine Tool Bed by Load Bearing Topology Identification with Weight Distribution Criterion** B.T. Li, J. Hong, Z.L. Wang, W.W. Wu, Y.B. Chen **P13: A Cost Model for Determining an Optimal Automation Level in Discrete Batch Manufacturing** J.E. Staehl, P. Gabrielson, C. Stael, C. Andersson **P59: Cooperating machines for reconfigurable assembly operations, review and technological challenges** S. Makris, G. Michalos, A. Eytan, G. Chryssolouris
12:30–14:00	**Lunch Break**			
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14:00–15:30	**P46: Intelligent management of manufacturing knowledge: Foundations, motivation scenario and roadmap** M. Landherr, C. Constantinescu **P51: Software evaluation criteria for rapid factory layout planning, design and Simulation** N. Shariatzadeh, G. Sivard, D. Chen	**P81: An Empirical Study of the Energy Consumption in Automotive Assembly** A. Fysikopoulos, D. Anagnostakis, K. Salonitis, G. Chryssolouris **P86: Improved tribotesting for sheet metal forming** L. Kirkhorn, K. Frogner, M. Andersson, J.E. Staehl	**P77: Hybrid Production Strategy between Make-to-Order and Make-to-Stock – A Case Study at a Manufacturer of Agricultural Machinery with Volatile and Seasonal Demand** J. Koeber, G. Heinecke **P82: Efficient Scheduling Rule for Robotic Flexible Assembly Cells Based on Fuzzy Approach** K. Abd, K. Abhary, R. Marian	**P45: A function based approach on designing intelligent flexible automated manufacturing environments** M.S. Essers, T.H.J. Vaneker **P84: Modelling and Theoretical Analysis of Membership-type Services in Manufacturing Industries** K. Okuda, N. Nishino, K. Ueda

	P52: Product Design Leverage on the Changeability of Production Systems G. Schuh, J. Arnoscht, M. Völker	**P90: Measurement of Cutting Edge Temperature in Drilling** T. Beno, U. Hulling	**P89: Real–Virtual Fusion Production Scheduling Using Social Contract-based Approach – Effectiveness of Adjusting Virtual System Size** N. Fujii, Y. Qian, T. Kaihara	**P07: CAx Process Chain for Two Robots Based Incremental Sheet Metal Forming** H. Meier, J. Zhu, B. Buff, R. Laurischkat
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	Session A7	**Session B7**	**Session C7**	**Session D7**
16:00–17:00	**P91: Enterprise Strategic Flexibility** A. Arafa, W.H. ElMaraghy	**P85: On the investigation of the structural behavior of robots while machining** C. Doukas, J. Pandremenos, P. Stavropoulos, P. Fotinopoulos, G. Chryssolouris	**P68: From task allocation towards resource allocation when optimising assembly systems** A. Fasth, J. Provost, M. Fabian, J. Stahre, B. Lennartson	**P101: Personalised Trachea Stent Designer, a Knowledge Feature** D. Ugarte, A. Izaguirre, A. Rosell
	P58: Organizational Comprehension of Manufacturing Strategy – A Case Study of a SMME N. Edh, M. Winroth, K. Säfsten	**P49: Experimental Investigation of the Plasma Arc Cutting Process** K. Salonitis, S. Vatousianos	**P74: Knowledge Management in Lean Production Systems** U. Dombrowski, T. Mielke, C. Engel	**P38: On a Predictive Maintenance Platform for Production Systems** K. Efthymiou, N. Papakostas, D. Mourtzis, G. Chryssolouris
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Day 3: Friday, 18 May, 2012				
	Session A8	**Session B8**	**Session C8**	**Session D8**
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	P66: A holistic view on design and development of manufacturing systems H. Nylund, P.H. Andersson	**P96: Social aspects of Process Monitoring in Manufacturing Systems** K. Martinsen, H. Holtskog, C.E. Larsson	**P20: Agent Oriented Construction of A Digital Factory for Validation of A Production Scenario** M. Matsuda, K. Kashiwase, Y. Sudo	**P30: A Function Block Enabled Robotic Assembly Planning and Control System with Enhanced Adaptability** L. Wang, M. Givehchi, B. Schmidt, G. Adamson

	P70: Methodology for the assessment of changeability of production systems based on ERP data G. Schuh, T. Potente, S. Fuchs, C. Hausberg **P14: The Role of Randomness of a Manual Assembly Line with Walking Workers on Model Validation** A. Al-Zuheri, L. Luong, K. Xing	**P99: Collaborative Digital Data Management for Design and Production** B.E. Biçici, C. Cangelir **P05: 3D Nesting of Complex Shaped Objects** D. Lutters, D.C. ten Dam, T. Faneker	**P100: Manufacturing Execution Through e-FACTORY System** A. Köksal, E. Tekin **P10: Integral Analysis of Labor Productivity** T. Czumanski, H. Loedding	**P95: Bionic Based Energy Efficient Machine Tool Design** R. Neugebauer, M. Wabner, S. Ihlenfeldt, U. Friess, F. Schneider **P94: Virtual Ergonomics and Time Optimization of a Railway Coach Assembly Line** A. Marzano, K. Agyapong-Kodua, S. Ratchev
10:30–11:00	**Coffee Break**			
11:00–12:30	**Session A9**	**Session B9**	**Session C9**	**Session D9**
	P69: Method for Multi-Scale Modelling and Simulation of Assembly Systems M. Neumann, C. Constantinescu, E. Westkaemper **P72: Intelligent Utilisation of Digital Databases for Assembly Time Determination in Early Phases of Product Emergence** O. Erohin, P. Kuhlang, J. Schallow, J. Deuse **P98: Matching Demand and System Structure in Reconfigurable Assembly Systems** D. Gyulai, Z. Vén, A. Pfeiffer, J. Váncza, L. Monostori	**P107: Designing for Additive Manufacturing** B. Vayre, F. Vignat, F. Villeneuve **P76: Design Architectures in Biology** J. Pandremenos, E. Vasiliadis, G. Chryssolouris	**P103: Planning of Reconfigurations on Manufacturing Resources** F. Karl, G. Reinhart, M.F. Zaeh **P102: Model for the valuation of a technology established in a manufacturing system** G. Schuh, J. Schubert, M. Wellensiek	**P22: Improvement potentials in Swedish electronics manufacturing industry – Analysis of five case studies** R. Sundkvist, R. Hedman, P. Almström, A. Kinnander **P88: Closed Loop Engineering – A relational model connecting activities of a product development process** L. Krogstie, K. Martinsen
12:30–13:00	**Closing of the 45th CIRP CMS 2012 in Plenary Session**			
13:00-14:00	**Quick Lunch**			

Implementation of a comprehensive production planning approach in special purpose vehicle production

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Abstract
The European vehicle industry employs a cascading planning process, for medium-term sales and operations and medium- to short-term production planning. Due to a lack of coordination and feedback between the different planning phases, costly problems in production arise. This paper describes an integrated planning solution for the harmonisation of sales, purchasing, supply chain and production planning along the planning cascade. By harmonizing long-, medium- and short-term planning, cost savings and additional value potential can be realized. The basic approach for harmonized planning is illustrated with a case study from special purpose vehicle production.

Keywords:
Planning, Sequencing, Automotive

1 INTRODUCTION

Due to expensive production infrastructure and volatile customer demand, sales, operations and production planning are key functions in automotive production, particularly in special vehicle manufacturing. As illustrated in Figure 1 the industry employs a cascading planning process, for medium-term sales and operations and medium to short-term production planning.

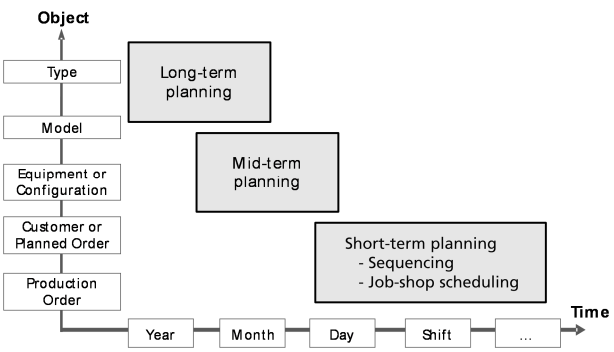

Figure 1: Cascading planning process

A problem of cascading planning is a lack of coordination and feedback between the different planning phases. This can cause costly problems in production, originating from unfeasible production programs requiring permanent ad-hoc troubleshooting caused by unavailable resources or limited supplier capacities. Such problems could be avoided, if restrictions were discovered during long-term planning, since this would leave time to build up the necessary resources. Such a fragmented planning cascade often manifests itself in disjointed IT-systems. Moreover, the problem is aggravated by the fact that IT-systems frequently correspond to existing organisational structures and changes to the overall planning procedure come at a very slow pace. This situation is especially true for the automotive and special purpose vehicle industry, but can also be found in other industrial sectors. These problems were the trigger for a project that intends to develop a solution that assists in overcoming this chasm.

This paper briefly discusses planning restrictions, their originators and connections between single planning tasks and the correlation of restrictions between different planning horizons. A comprehensive planning approach serves as the basis of a software tool that will harmonize the planning tasks over the different planning horizons from sales planning to assembly line sequencing.

The paper focuses on the suitability of the approach for special purpose vehicle production. The presented case study covers the entire analysis and implementation process in a special purpose vehicle production. It is the last step of an ongoing international research project called Harmonised Planning of Sales, Purchasing, Supply Chain and Production (HarmoPlan). The project develops an integrated planning solution for the harmonisation of sales, purchasing, supply chain and production planning along the planning cascade from long-, medium to short-term planning, resulting in the realisation of cost savings and additional value potential. The project focuses on the planning process of the final assembly in vehicle and component manufactories where variant flow production with low automation and high labour intensity exists [1].

When it comes to lead time and productivity the special vehicle sector lags behind in comparison to the rest of the automotive industry. On one hand, the differences are caused by variations in product structure and product range. On the other hand, a lot of potential for optimization stemming from the overall organization of production and especially with respect to consistency and transparency of the planning process is not utilized in the special vehicle sector. Major car manufacturers have very high standards concerning organization of production and are currently working on the optimized use of IT for the harmonization of long, medium and short term planning.

Special purpose vehicles are often produced in a site assembly or semi-series assembly setting without a fixed production cycle, due to a low degree of transparency of parts availability and use of personnel in the planning process. The spread of required times for assembly in a line for special purpose vehicles is a multiple of that of an assembly line for passenger cars due to option-related work content. This is especially a problem for short-term production planning to find the correct sequence order and the appropriate use of personnel.

Today, large components are sourced from Asia for cost reasons resulting in very high replacement times, i.e. the replacement time for special drive chains for construction machines is between six months and one year. With such extended delivery times transport times by ship and truck of about 2 months are a considerable delay, and require careful planning. Hence, harmonized planning of special vehicle production holds enormous potential for performance improvements and cost savings.

2 PLANNING APPROACH FOR SPECIAL VEHICLE PRODUCTION

As mentioned above, in the automotive industry and particularly in special purpose vehicle production a cascading planning process is prevalent. Although each company has its own peculiarities, such a cascading planning process follows a pretty similar pattern. Figure 2 describes a generic planning process that illustrates the "common ground" of a possible harmonized planning process for sequenced, automotive production in Europe:

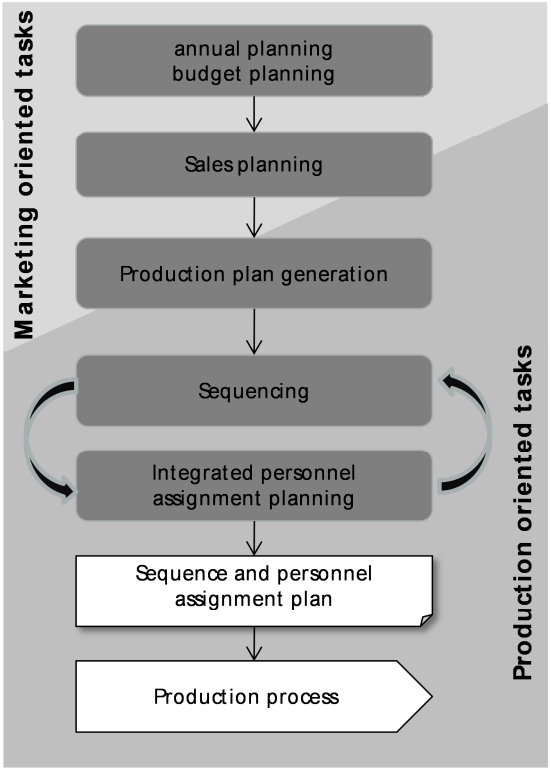

Figure 2: Generic planning process

Based on a continuous market analysis the company has to decide, which brands are to be produced. The results will be put in the brand strategy, which subsequently will trigger the annual and budget planning resulting in a sales forecast. The sales forecast has a rolling horizon with a planning period of about seven to ten years.

Next sales planning specifies the models by their main criteria (engine type, auto body, gear box, no. of axles for truck assemblies, etc.) and assigns potential production sites to models and production volumes. The choice of a particular production site is decided by location-specific costs and other conditions (i.e. planned or existing production sites, available suppliers, local labour market, site-specific strength and weaknesses, etc.).

The input data for production program planning usually are sales forecasts, which are broken down into monthly sales quantities and production rates. Restrictions to be considered are minimum line load levels resulting from the model mix problem (provision of the production factor resources), the capacity of plants (annual working hours of workforce), technical solutions in the line (equipment) and potential bottlenecks on the supplier side (material).

Production program planning is usually done continuously and the production program is split up into daily or weekly order pools. The allocation of orders to weeks, days or shifts is dubbed *slotting* and order pools are calculated using an average process time per vehicle. Usually at this point planned or real customer orders have been placed, although sometimes the orders within the daily or weekly order pools are not fully specified dummy orders. Their specifications include only items as engine type or number of axles for truck assemblies. If a real customer order is placed an eligible dummy order is removed and will turn into a fully specified customer order [2].

After slotting the planning continues until a sequence is found, that does not violate any capacity or material restrictions. This is done by moving individual orders within the sequence to a different time period in order to accommodate the restrictions mentioned above.

The shifting of orders is called balancing. To increase the level of detail, attributes such as colour, transmission, sunroof, etc. are added. This enables a detailed analysis of the work content per vehicle and the generation of balanced sub-order pools on the basis of days or shifts.

At last, all planned orders have to be substituted by actual customer orders. If this is not possible, it has to be decided, if a planned order is removed or if a vehicle is produced on stock. For order sequence planning the vehicle has to be fully specified. In principle three different sequencing methods can be distinguished:

- level-scheduling,
- mixed-model sequencing and
- car-sequencing [3].

Derived from the Toyota-Production-System, level scheduling aims at achieving a level spread of material demand [4]. In contrast mixed-model sequencing intends to reduce resource overload within the system resulting in an exact schedule for each type and station under consideration of the type specific work content [5] [6]. Car-sequencing also tries to eliminate overloads without a detailed consideration of work load, stations or cycle times due the definition of an extended constraint catalogue, i.e. such a constraint could be that just one car with a sunroof is allowed in a row of three cars [7] [8].

The project presented in this paper follows the car-sequencing approach, since this sequencing method is broadly employed by various European OEM.

In order to enable suppliers to produce and deliver their parts just-in-sequence, the resulting sequence is fixed and no further changes in the sequence are allowed. This time period where no changes in the production program should occur, is called "frozen zone" and typically is a few day or one to two weeks before the actual production of the order. Fixing the order sequence assigns a decided production cycle to each order from the order pool [9].

After fixing the sequence, personnel assignment planning is performed. In order to arrive at an optimized sequence an iterative-recursive procedure for personal assignment is employed, as is indicated by the circular arrows in Figure 2. which is explained in detail below Figure 5.

According to Figure 1 all these planning tasks have to deal with different planning objects and different levels of detail considering a high number of different planning

constraints. In order to harmonize all these planning tasks in a continuous planning work flow and planning tool these different planning constraints and their originators were mapped. An overview of the different planning constraints can be found in Figure 3.

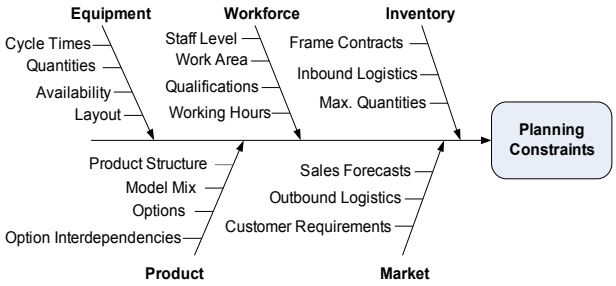

Figure 3: Planning constraints and their originators

The upper three branches represent the fundamental production factors that describe the production system:

- equipment
- workforce
- inventory

The lower branches describe the output of the production system (product) and all customers and their requirements (market). A detailed description of the mentioned planning constraints and their originators was part of the research project [10].

A major concern are shifting responsibilities and various levels of abstraction along the planning cascade (i.e. the sales department plans on the level of no. of cars to meet market requirements, production planning is dealing with planning objects as car configurations or bills of material to utilize production capacities). The challenge is being able to handle the resulting complexity of the planning problem in a tool that harmonizes long-, mid- to short-term planning. The presented approach will show a realistic solution to convert planning constraints for the use in each planning task.

As every single planning step deals with various input data depending on the planning horizon the planned quantities are presented as monthly, weekly and daily volumes or order pools in long- and mid-term or as order sequences in short-term planning. To align existing capacities with customer requirements and to identify bottlenecks as early as possible, constraints need to be defined for each planning step and each required configuration. Thus, the constraints caused by the earlier described originators are stored in a so called “constraint manager”. It collects the constraints and stores them in a standardized format and it is important that the reason for each constraint is traceable within the database.

If a planning task has to be executed the constraint manager allocates just the relevant constraints out of the constraint database. If a constraint can’t be fulfilled the planner needs to identify the cause, in order to set possible measures to widen the bottleneck – or to solve the problem by re-planning considering the constraints. Figure 4 shows the concept of the planning workflow that will be covered within one planning tool.

The solution and planning approach described above would be suitable for a planning process in the automotive industry and in passenger car assembly lines. In order to fulfil the requirements of a special vehicle production described in the introduction the sequencing process has to be adapted to allow a best possible allocation of human resources.

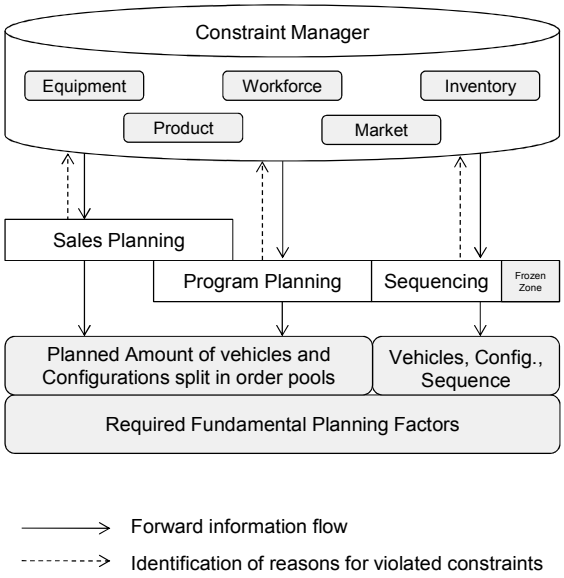

Figure 4: Proposed planning approach

Hence, the solution of another research project – Advanced Production Programme and Personnel Assignment Planning (A ProPer Plan) – executed by the same consortium can be integrated in the planning tool. Figure 5 shows the basic approach of A ProPer Plan:

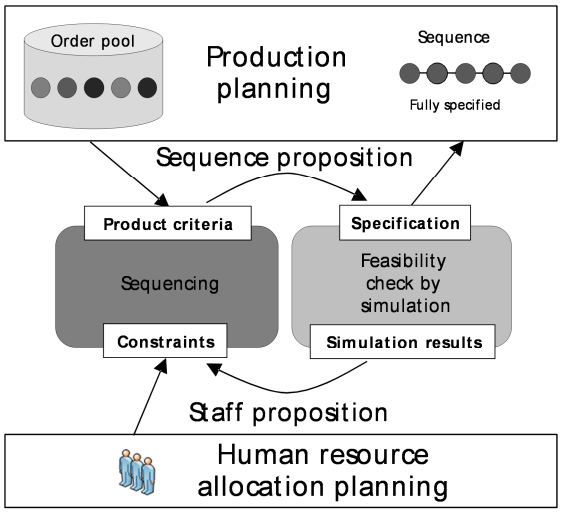

Figure 5: Solutions approach of A Proper Plan [2]

The goal of A ProPer Plan was to create a tool, which allows the integration personnel assignment planning with short-term production planning to achieve optimal production results with high adherence to delivery dates. The sequencing solution receives a list of the valid production constraints and a continuous order pool. Besides the technical constraints, there are a number of additional limitations resulting from the calculated personnel assignment planning. Personnel assignment planning is a result from a preliminary human resource based analysis of the order pool. This is done to balance the workload in the order pool with the human resource capacity for the same period. The solution uses discrete event simulation on a standard computer with a valid runtime license of the software simulation SLX.

Subsequently, the optimized sequence is computed. With a focus on technical and human resource related production constraints the calculated sequence is reviewed by means of a simulation regarding assignments of personnel at the individual station groups. Within the simulation model the variant dependent assembly processes are mapped according to the order taking into account available personnel.

The allocation of personnel is performed in the simulation run. One of the company's goals is to schedule the employees to the same activities, since this has proven to result in higher quality and less rework. If there are not enough idle employees available the team has to use a floater. A floater is an experienced person with a wide range of capabilities that is not assigned to a specific team but to a number of teams.

One result of the simulation is the feasibility of the sequence at hand and it also determines additionally required employees in case the assigned personnel is not sufficient. This information is then fed back to the sequencing procedure and starts an iterative process where the sequencing solution in combination with the defined personnel allocation is fed into the simulation. This now reveals the expected workload with the help of the fully specified order data. The implementation of the planning system follows these planning principles:

Such an integrated planning system expands the proven workflow of production planning with a component for the optimization of personnel assignment providing dynamic personnel assignment optimization rules and parameter adjustments for sequencing. The analysis of the work content of the order pool and the sequence and subsequently comparing it with available personnel capacities and deployment scenarios, allows the system to compute the best response options for the detection of bottlenecks. In order to create an optimized order sequence also with respect to allocation of personnel, relevant rules and parameter calibrations are created for the selected response options which will be the basis for the next optimization run.

The simulation of the assembly processes is based on the work schedule data considering each variant and its lead time per execution. This enables a highly accurate forecast of workload per employee for each specific sequence. This procedure is continuously replicated until an optimized solution with respect to production as well as personnel assignment planning is found.

The presented approach synergetically combines the car sequencing and the mixed modelling approach. Car sequencing focuses on few product features in order to limit the data to the relevant criteria. This enables the optimization algorithms to solve the sequencing task in finite time and acceptable quality. The further analysis of labour times per variant and station enables the forecasting of load profiles. Additional potential is tapped through the repetitive interplay between optimization of features and the feasibility prognosis based on labour time data. An efficiency increase of the human resource allocation is thus possible. [3]

The Combination of the research projects HarmoPlan and A ProPer Plan perfectly fits to the requirements of the special vehicle Production. The suitability of this approach is proven by the following case study.

3 CASE STUDY

The subsequent case study illustrates the implementation of the system described above at a company in the special vehicle sector. The company is an internationally oriented corporation with over 40 production locations worldwide. The product spectrum is divided into two divisions, agricultural and construction equipment. The described planning process was developed in the division construction equipment. In a first step, an integrated planning process from sales planning to sequence planning for four factories is devised. Subsequently the solution is intended to be rolled out to the remaining production locations of the corporation. Since the allocation of the products to the single factories is explicitly defined, sales planning is also located in the same factories. This is an advantage for the prototypical implementation and the validation of the procedure.

The case study describes an integrated process using an example factory with seven synchronized/clocked final assembly lines. One of those seven lines is investigated in detail. The product spectrum on this assembly line encompasses 15 types of vehicles with according options of which the customer can choose up to 100 options and special equipment. The monthly output of the assembly line is about 400 vehicles per month. The case study describes the initial situation, the approach towards the design of a harmonized planning process and the implementation using the planning solution.

3.1 Initial Situation

The planning team consists of six planners who perform long and medium term planning as well as detailed planning. Sales planning transmits their forecasts to this team, which plans the proposed sales with a rolling horizon of at least one year. In December of the current year, the annual budget for the year after next year is produced. Hence, there are between 24 and 12 months of information available for planning procedure. This annual plan is divided into a weekly grid and provides information about each assembly line and vehicle type regarding the quantities to be produced per week. This plan includes planned orders and as soon as a customer order exists, a suitable planned order will be replaced manually by the customer order. This list also contains a capacity estimate for the required personnel. Currently this is only available in Excel, since the ERP system does not contain any time related data. The times are kept in a separate Excel file and are available in detail for each step of the assembly. This is an important point concerning future short-term personnel assignment planning.

The current one-year plan in Excel is continuously updated with the ERP system and thus newly received customer orders are recorded immediately. The planning horizon of this annual plan therefore is completely filled with orders. Some of them are on one hand planned orders and on the other hand customer orders with an explicit customer demand. Delivery dates are given in a granularity of weeks. Thus, the planned completion date is always the Friday of each week of delivery. The two order types differ as follows:

- Planned orders exist for each vehicle type and week. For each vehicle type a projected number of vehicles for a specific week is cumulated. The underlying bill of materials is a maximum bill, which contains a percentage distribution reflecting probabilities of deployment of the various options and trim levels.
- Customer orders are fully specified orders and always have lot size one. The bill of materials for such orders provides the needed parts for building this vehicle.

At this point of time, the work plans reflect only very rough assembly times of the main tasks. There is no allocation of times to the individual workstations on the assembly

line. Therefore, a calculation in terms of personnel capacity is not feasible in the ERP system.

The detailed planning in the form of sequencing for the assembly lines, the pre-assembly and the paint shop are also the responsibility of the aforementioned planning team. This planning is also performed in Excel. The first step in this process is the assigning of exact dates (with an accuracy of one day) for a period of four weeks prior to the start of production. These dates are next transferred to the ERP system. If this four week plan still contains orders without a customer, the planner has to decide whether the vehicle is removed from the production program, or if it is produced on stock. If the vehicle is produced on stock, the order has to be fully specified.

Finally, for a period of 2 weeks prior to the start of production exact production sequences are planned. These sequences exist only in Excel and will be distributed to the respective foremen of the assembly lines and team leaders in the various production areas. For this sequencing process no planning framework exists and the planners generate the production sequence to the best of their knowledge and beliefs. Figure 6 gives a summary of this planning procedure:

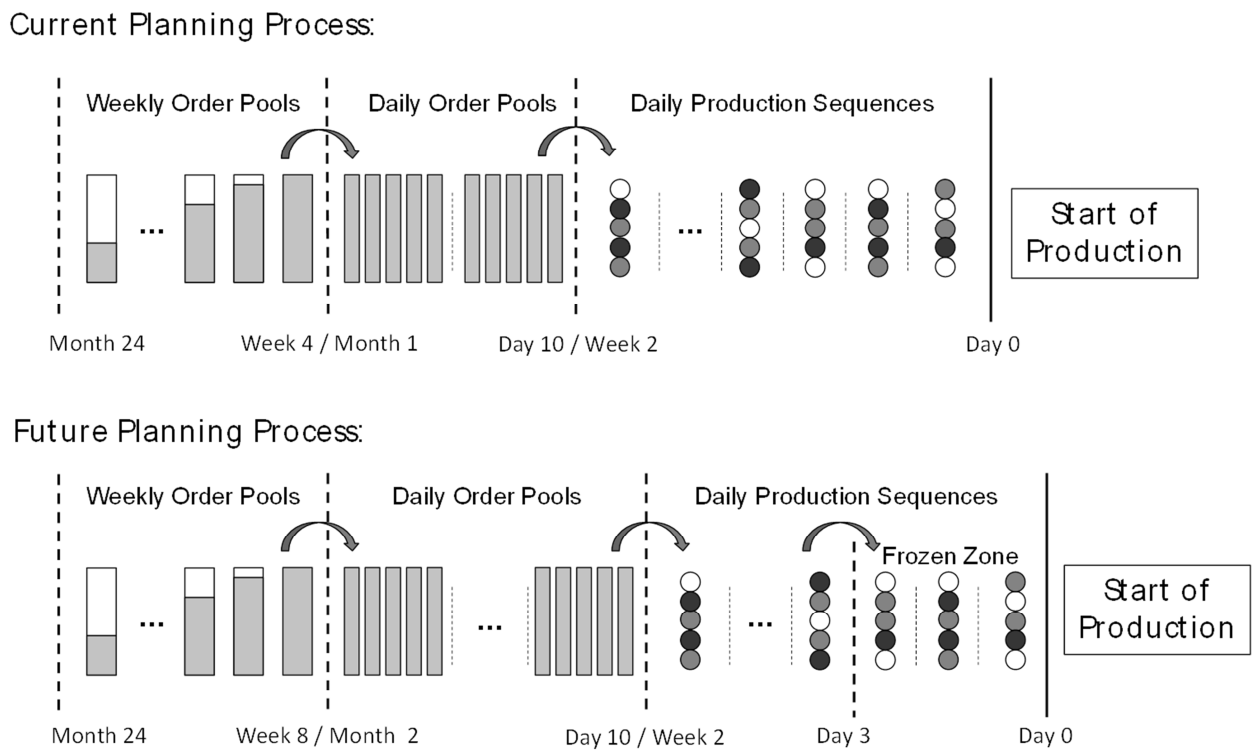

Figure 6: Synopsis of the planning procedure

Currently logistics is working with picking lists from the ERP system. However, since the ERP system only provides dates with the accuracy of a day, currently a just-in-sequence delivery is not possible. Due to increasing quantities and variants in the near future, this type of inbound delivery will be an absolute necessity. Certain sequence lists for large supplied parts (e.g. cabins) are still created manually in Excel and transferred to the suppliers sometimes via email. In future this should be possible via a simple IT-system.

Despite a very high planning effort the current instability of the planning process leads to missed cycles due to missing parts. The reasons for the missing parts are that they were not provided by the supplier or were not delivered to the assembly line in the factory in time. This results in permanent troubleshooting of the planners in the short-term planning process.

Another problem is personnel assignment planning for the lines, since the current planning process does not allow an accurate forecast of the load peaks. The assembly line foremen and team leaders have no means to optimally allocate their station personnel and their jumpers. Furthermore, this lack of transparency also strongly requires optimization efforts in long-term planning of material supply, personnel and overall resources.

3.2 Objectives

As part of the implementation project in the company, the whole planning system is to be optimized. The main goal is to make the planning process more robust and to reduce the manual planning effort as much as possible. That means in the short term to introduce an automated system with regard to sequence generation and to optimize personnel assignment. Subsequently, the high number of interfaces in the planning cascade should be eliminated or automated. The developed solutions of the two research projects A ProPer Plan and HarmoPlan are capable of solving the problems presented above.

3.3 Procedure for the Implementation

Analysis:

The initial situation mentioned above was analyzed by using a specially developed method. A critical success factor is process mapping. Another decisive factor is the correct and complete identification of existing systems and interfaces as well as the timeliness and accuracy of the available data [11]. The data used for analysis encompasses:

- Product structure
- Part lists structure
- Planning constraints in the different planning horizons
- Options and build rates of the different options
- Existing sequencing rules
- Process times
- Routing

Target conceptual design:

After the analysis phase the new planning process has to be re-conceptualized. This requires a precise definition of future planning horizons and planning tasks (Figure 6).

In the case of long-term planning, based on weekly pools no change is necessary in terms of planning horizons. In order to get an earlier reading with respect to load and material demand the planning horizon for a planning based on daily order pools will be adjusted from four weeks to eight weeks. In addition, the sequence will also be planned for two weeks into the future, but the last three days prior to start of production will be a so-called frozen zone, to provide more stability and enable just-in-sequence deliveries.

For a rapid application of the concept's implementation started right after having prepared the process conceptual design. For the conceptual design it is crucial which systems contain the respective planning data and which planning activities are performed with which planning tool. The approach and the architecture of HarmoPlan provide that as much data as possible is being kept in the master ERP system and can be accessed via interfaces if required. This applies to all data starting with the factory calendar, available capacities, order information, bill of material and work plans. Thus, the tool to be developed in HarmoPlan will only be a complementary tool that, in terms of a bypass, transfers the data from the ERP, takes over the planning and scheduling tasks and finally re-transfers the detected exact dates back to the ERP system. Data that are not collected and administered in the leading ERP system have to be bound within the planning tool. Predominantly, these are sequencing rules.

Introducing a new planning process or tool and replacing well-known utilities constitute a major reorientation for the organization. Hence, the implementation is split into phases, starting with the processes that show the highest potential, which are sequencing and personnel planning.

Implementation sequencing and workforce planning:

To be able to accomplish the sequencing and personnel planning the best way possible, a reorganization of the work plan's structure and the respective data management of individual process times is necessary.

First, the processing times are currently not administered in the ERP system, but in Excel. Further, work plans are not cut into separate assembly stations. These data have to be combined; therefore, more accurate work plans including associated process times have to be prepared. Hence, the assembly line has to be divided into stations; processes and their associated process times have to be allocated to the particular stations.

Within the planning tool, sequencing rules for the assembly lines have to be configured. These could be space constraints defining the distance between two vehicles with the same attributes (e.g. only every second excavator may have a two-door cabin, or a heavy vehicle must not follow a heavy vehicle). In general, planners have such practical rules in mind and these rules have to be written down, or individual processes have to be evaluated and – if necessary - rules for the individual work stations have to be defined. This is done by means of the simulation tool developed in the research project AProPer Plan. [12].

For a prototypical implementation, the first step is very simple: Interfaces between the ERP and the planning tool will be created. In this case, the communication flow runs through the import and export of CSV files. Next, one may think about an optimized version of interfaces.

Having updated the data, captured restriction rules and created capacities within the planning tool, data from the ERP can be transferred into the planning tool and the test phase may start.

Having finished the test phase and resulting adjustments, it is now possible to run the sequence planning automatically, simplifying the planner's work effectively. Through the coupled simulation of the production sequence regarding personnel utilization at the individual stations of the assembly line, now detailed information about upcoming capacity bottlenecks are available in advance. Hence, jumper staff may be pre-allocated, especially supporting the production's line leader.

Through a re-import of the planning results into the ERP system, to-the-minute target-times are now available for individual orders. On the one hand, these are start dates for the production as well as further dates for the separate assembly stations. In this way, accurate material requirement dates are determined - the ERP system is now able to accurately plan the pre-assembly by backward scheduling. Furthermore, accurate single picking lists can be generated for a JIS supply.

Implementation of medium and long-term planning

HarmoPlan's approach is to provide all restrictions for the respective planning task. Within the prototypical implementation it could be pointed out that passing restrictions on to following planning steps only is necessary if major changes become apparent. This functionality would complicate the planning tool's architecture and therefore it is not included. If there is the need for major changes in the sequencing of orders, it is possible to repeat the preceding planning process to save the planning result in that way.

It is very important to identify bottlenecks of sequencing rules in the preceding planning tasks. Hence, one is able to response early to possible shortages and to initiate appropriate countermeasures in time.

For the formation of daily order pools in a planning horizon between 2-8 weeks before production start and the composing of weekly order pools in preceding weeks and months, the planning tool has to be configured to that effect. Again, interfaces have to be defined. Necessary data are factory calendar, capacity data for each assembly line and the orders (plan orders and customer orders). The contract attachments and its maintenance will be operated in the existing ERP system as usual. HarmoPlan's planning tool will also be able to detect lists for missing parts and material shortages but in that case, the ERP system undertakes these tasks. This function is foreseen in the planning tool, as common ERP systems are not efficient enough for the explosion of complex code-based bills of material. For this special case study the bills of material are not included to the planning tool; functions relating procurement and logistics are taken over by the ERP.

To be able to use sequencing rules in the earlier planning tasks, they have to be mapped into the restriction

planning tools database. Within the planning tool it is also defined how different restrictions can be converted.

Figure 8 indicates which attributes are necessary for a complete definition of a sequencing rule or for a program planning restriction.

		Sales Planning	Program Planning			Sequencing			
	Constraint Type	...	Capacity Con-straints (lower limit)	Capacity Con-straints (upper limit)	...	Block Con-straint	Space Con-straint	Space Con-straint 2 Values	...
General Attributes	Name		X	X		X	X	X	
	Description		X	X		X	X	X	
	Constraint Type		X	X		X	X	X	
	Assembly Plant		X	X		X	X	X	
	Sales Region		X	X		X	X	X	
	Vehicle Type		X	X		X	X	X	
	Validity Period		X	X		X	X	X	
	Value1		X	X		X	X	X	
	...		X	X		X	X	X	
Sales Specific Attributes	...								
Program Planning Specific Attributes	Minimum1		X						
	Maximum1			X					
	Classification1		X	X					
	Penalty1		X	X					
	...								
Sequencing Specific Attributes	Value2							X	
	Minimum2					X	X	X	
	Maximum2					X	X	X	
	Block Length					X			
	Block Distance					X			
	Classification2					X	X	X	
	Penalty2					X	X	X	
	...								

Figure 7: Constraint conversion matrix

This matrix maps the kind of program planning restriction necessary to represent the sequencing rule. Furthermore, it contains a logic how such a rule is converted, illustrated by a simple example: A sequencing rule states that between two labor intensive vehicles at least two simpler vehicles have to be built to meet the indicated cycle time. This rule is only appropriate for sequencing. For the planning of daily and weekly pots, it would mean that the rule would have to be reworded: A maximum of 1/3 of the vehicles in one order pool may be labor intensive vehicles. Exactly these logics are deposited within the matrix or the restriction manager of the planning tool.

Figure 7 shows a matrix with details including the various restrictions and mandatory attributes for Sales Planning, Program Planning and Sequencing:

Having finalized all configurations, a test phase is proposed for the entire planning tool. After eliminating all possible early failures, dynamic interfaces between the ERP system and the planning tool can be established. Although the affected employees were involved into the implementation, an extensive employee training regarding the future planning process and the correct software deployment has to be enforced.

4 SUMMARY AND CONCLUSION

In summary the described solution enables the design of a continuous and harmonized planning process, effectively covering the different planning horizons (long-, medium- and short-term) ensuring the exploitation of the following potentials:

- Laborious media discontinuity and workarounds can be eliminated.
- The data management is structured.
- A loss of employees can be compensated more easily as the knowledge is not only kept in minds, but in the system.
- The planning effort can be reduced immensely; hence, the planning team can save up to two employees or use them for other activities.
- There may be an early response to potential bottlenecks, as these are identified by the planning tool.

The research project is currently in its final phase. Next steps are now the transfer of the prototype into a marketable planning system. With the knowledge gained from this project, it is planned to evaluate further fields of application apart from sequenced production lines and to tackle these within the context of future research projects.

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