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Editorial

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Welcome to the 45th CIRP Conference on Manufacturing Systems (45th CIRP CMS 2012).

Our society faces challenges, requiring innovative solutions: Returning to growth and to higher levels of employment, combating climatic changes and using our natural resources more wisely, are grand challenges that also provide powerful opportunities for manufacturing. Economies, around the world, need to move towards strategies based on ***innovation***.

The ***45th CIRP CMS 2012*** provides an international forum for the exchange scientific knowledge and industrial experience, regarding ***innovation*** for the Manufacturing of the Future. Through the *CIRP Conferences on Manufacturing Systems* academia and industry address research, education and dissemination issues, related to manufacturing.

The papers of this Conference address a wide variety of research topics: Manufacturing processes and systems modeling, simulation and optimization, Nanomanufacturing, Rapid Manufacturing, Novel manufacturing processes for advanced materials, Advanced machine architectures and control technologies, Manufacturing systems planning, control and scheduling, Manufacturing networks, Supply Chain and Global Production Management, e-Manufacturing, Logistics and manufacturing data management, Flexible and reconfigurable manufacturing systems, Lean production, Agile manufacturing for turbulent markets, Adaptive manufacturing Systems, Concurrent Engineering, Quality Engineering, Innovative metrology, Energy-efficient processes and systems, Life cycle design and manufacturing, Virtual reality and manufacturing, Digital manufacturing, Digital Knowledge based tools, Collaborative design, Intelligent manufacturing of smart & new products, Human factors, Manufacturing education and training, Methods & tools for Knowledge Management & skills adaptation.

We wish to acknowledge the members of the International Program Committee for having devoted their time to making this event successful. Finally, we thank YOU for your participation, and hope that you find your interactions with this community to be an enriching experience.

Professor G. Chryssolouris
Professor D. Mourtzis
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Chairs, 45th CIRP CMS 2012

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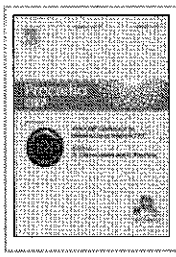

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Implementation of a Comprehensive Production Planning Approach in Special Purpose Vehicle Production

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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

Expensive production infrastructure and volatile customer demand make sales, operations and production planning key functions, particularly in special vehicle production. The industry employs cascading planning for medium-term sales and operations and medium/ short-term production planning.

A major problem is a lack of coordination and feedback between planning phases, causing costly troubles, from unfeasible production programs requiring permanent ad-hoc troubleshooting caused by unavailable resources or limited supplier capacities. Such problems could be avoided, if bottlenecks 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. Since they often correspond to existing organisational structures changes to the overall planning procedure come slowly. This 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 discusses planning restrictions, their originators and connections between single planning tasks and the correlation of restrictions between different planning horizons. An integral planning approach serves as the basis of a software tool that harmonizes the planning tasks over the different planning horizons. The case study investigates the approach for special purpose vehicle production and covers the entire analysis and implementation process. It is the result of a project called Harmonised Planning of Sales, Purchasing, Supply Chain and Production (HarmoPlan), which developed an integral 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

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special vehicle sector lags behind the automotive industry. Differences are caused by variations in product structure and range. Further potential for optimization stemming from the overall organization of production and especially due to planning consistency and transparency is not utilized. Major car manufacturers have very high standards concerning organization of production and work 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. for special drive chains for construction machines it 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 1 describes a generic planning process that illustrates the "common ground" of a possible harmonized planning process for sequenced, automotive production in Europe.

Based on a continuous market analysis the company decides, 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 particular production site is decided on location-specific costs and other conditions (i.e. planned or existing production sites, available suppliers, local labour market, site-specific strength and weaknesses, etc.).

Input data for production program planning usually are sales forecasts broken down into monthly sales quantities and production rates. Restrictions 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).

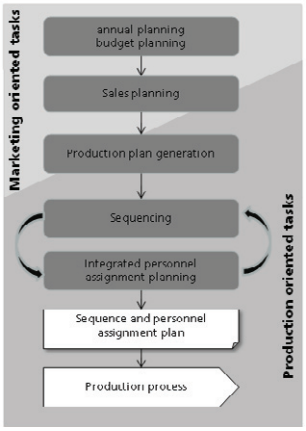

Fig. 1. Generic planning process

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. At this point planned or real customer orders have been placed, although sometimes the orders in daily or weekly order pools are not fully specified dummy orders. 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 transmission, colour, sunroof, etc. are added. This enables a detailed analysis of work content per vehicle and generation of balanced sub-order pools based on 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.

To enable suppliers to produce and deliver their parts just-in-sequence, the resulting sequence is fixed and no 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 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. To harmonize all planning tasks in a work flow and tool the different planning constraints and their originators were mapped. And are represented the fundamental production factors that describe the production system:

- equipment
- workforce
- inventory

Furthermore the products and all customers and their requirements cause constraints. A detailed description of the mentioned planning constraints and their originators was part of the research project [10]. 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.

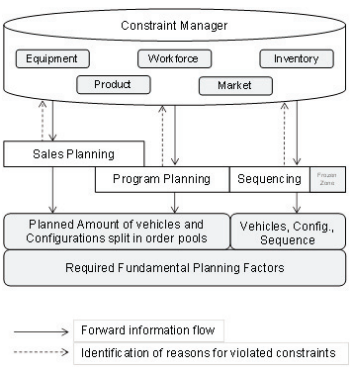

Fig. 2. Proposed planning approach

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 2 shows the concept of the planning workflow that will be covered within one planning tool.

3. Case study

The case study illustrates the implementation of the system at a company in the special vehicle sector, which is an internationally oriented corporation with over 40 production locations worldwide. The product spectrum is divided in two divisions, agricultural and construction equipment. The 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 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, of which one is investigated in detail. The product spectrum on this line encompasses 15 types of vehicles with options, of which the customer can choose up to 100 options. The monthly output of the 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 forecasts to this team, which plans the proposed sales with a rolling horizon of at least one year. In December of each year, the annual budget for the year after next is produced. 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 quantities to be produced per week. It 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 planned orders and some orders have 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.

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.

Detailed planning in form of sequencing for the assembly lines, the pre-assembly and the paint shop is 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.

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.

3.3. Procedure for the implementation Analysis

Analysis:

The initial situation was analyzed 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 encompasses:

- Product structure
- Part lists structure
- Planning constraints in 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, which requires a precise definition of future planning horizons/ tasks. 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, execution 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 known utilities constitute a major reorientation for the organization. Hence, 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 sequencing and personnel planning in the best possible way, a reorganization of the work plan's structure and the respective data management of individual process times is necessary. 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.

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 performed necessary adjustments, it is now possible to run the sequence planning automatically. Through a 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 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 respond early to possible shortages and initiate 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 and interfaces 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.

		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	
	...								

Fig. 3. Constraint conversion matrix

To be able to use sequencing rules in the earlier planning tasks, they have to be mapped into the restriction planning tools database, where it is also defined how different restrictions can be converted.

Figure 3 indicates which attributes are necessary for a complete definition of a sequencing rule or for a program planning restriction. 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 3 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.
- Loss of employees is easier to compensate, as the knowledge is kept 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.
- Possibility of an early response to potential bottlenecks due to identification by the planning tool.

The research project is currently in its final phase.

Next steps are the transfer of the prototype into a marketable planning system. The knowledge gained in this project, allows the evaluation of other fields of application apart from sequenced production in future research projects.

References

[1] Boysen, N., Fliedner, M., Scholl, A., 2009, Sequencing mixed-model assembly lines: Survey, classification and model critique, European Journal of Operational Research, 1922: 349-373.

[2] März, L., Tutsch, H., Auer, S., Sihn, W., 2010, Integrated Production Program and Human Resource Allocation Planning of Sequenced Production Lines with Simulated Assessment, Advanced Manufacturing and Sustainable Logistics, 408-419.

[3] Boysen, N., 2005, Produktionsplanung bei Variantenfließfertigung, Zeitschrift für Planung und Unternehmenssteuerung 16, 53-72.

[4] Monden, Y., 1993, Toyota Production System: an integrated approach just-in-time, 2. Aufl. Norcross.

[5] Wester, L., Kilbridge, M., 1964, The assembly line model-mix sequencing problem, Proceedings of the third international conference on Operations Research, 247-260.

[6] Boysen, N., 2005, Reihenfolgeplanung bei Variantenfließfertigung: Ein integrativer Ansatz, Zeitschrift für Betriebswirtschaft 75, 135-156.

[7] Dincbas, M., Simonis, H., Van Hentenryck, P., 1988, Solving the Car-Sequencing Problem in Constraint Logic Programming, Proc. ECAI '88, 290-295.

[8] Solnon, C., Cung, V.D., Nguyen, A., Artigues, C. 2008, The car sequencing problem: Overview of state-of-the-art methods and industrial case-study of the ROADEF'2005 challenge problem, European Journal of Operational Research, Volume 191, Issue 3, 912-927.

[9] Auer, S., Winterer, T., Mayrhofer, W., März, L., Sihn, W., 2010, Integration of Personnel and Production Programme Planning in the Automotive Industry, Sihn, W., Kuhlang, P., Proceedings: Sustainable Production and Logistics in Global Production Networks, NWV, 900-908.

[10] Auer, S., März, L., Tutsch, H., Sihn, W., 2011, Classification of interdependent planning restrictions and their various impacts on long-, mid- and short term planning of high variety production; 44th CIRP Conference on Manufacturing Systems, Madison, Wisconsin; New Worlds of Manufacturing, N. Duffie.

[11] Auer, S., Mayrhofer, W., Sihn, W., 2011, Beyond the planning cascade: Harmonized planning in vehicle production, 7th International Conference on Digital Enterprise Technology, Athens.

[12] Mayrhofer, W., März, L., Sihn, W., 2011, Planning assistance for pearl chain forecasts and personnel assignment planning of sequenced assembly lines, CIRP Annals - Manufacturing Technology, Volume 60, Issue 1, 2011, 481-484.