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Integrated Production Program and Human Resource Allocation Planning of Sequenced Production Lines with Simulated Assessment

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Abstract. The personnel flexibility of car manufacturers is used mostly as reactive means, in order to be able to realize the planned production program. The approach of trying to combine production planning with human resource planning is pursued within the scope of the Eurostars research project "Advanced Production Program and Personnel Assignment Planning" (A ProPer Plan). This approach combines the advantages of car sequencing with the advantages of the mixed modeling approach by coupling optimization with simulation. The solution constitutes an iterative planning process, where an optimized sequence is examined by simulation for feasibility regarding personnel flexibilities. The contribution points out, how such an integrated solution was realized and which results could be obtained with real time data of manufacturers of vehicles.

Keywords: Car Sequencing, Personnel Assignment Planning, Simulation.

1 Introduction

The European automotive industry is characterized by complex products, which enable wide customer individuality of vehicles. Production planning therefore has to distribute the different vehicle variants on the assembly line throughout the day so that bottleneck resources are evenly utilized and capacity peaks can be avoided. In this stage there already are complex planning logics, which take into account block constraints, space constraints and transition restrictions. By integrating human resource allocation planning the bottleneck and capacity can be influenced deliberately, which can lead to relocation of the bottleneck if human resources can be relocated in order to relieve an acute bottleneck. The integrated planning of human resource allocation and production therefore expands the freedom of planning.

The content and results of this article were compiled within the framework of the research project “Advanced Production Program and Personnel Assignment Planning” (A ProPer Plan; funded within the Eurostars Programme which is powered by EUREKA and the European Community). The goal of A ProPer Plan is to create a
tool, which allows the integration of the human resource allocation plan with the short-term production plan and to achieve optimal production results with high adherence to delivery dates.

2 Tasks of Production Scheduling

2.1 Synchronized Production Lines

This subject encompasses synchronized production lines where orders are planned in a sequence. Synchronized flow production is a flow-oriented production system where parts are being moved by means of a transportation system (usually an assembly line) through the production stations arranged in sequence, in which the machining time is restricted by a cycle time (Boysen, 2005a, p. 8). Synchronized flow production is mostly encountered in the automotive and electrical industries. The project focuses on the planning of the final assembly in vehicle and vehicle component plants where variant flow production with low automation and high labor intensity exists.

Sales prognosis, installation rates, and monthly production and sales quantities serve as input for production planning. Restrictions which have to be taken into account are minimum line load resulting from the model mix problem (provision for the production factor resources), the capacity of plants with regard to annual working hours (staff) and potential bottlenecks on the supplier side (material). Planning results are detailed, for example weekly production plans for the production plants. The task of operational production planning is to decide the types and quantities of model variants to be assembled from the existing model portfolio (Meyr, 2004). That way the order backlog of a month is being broken down into single day and shift plans using production planning (Monden, 1993, p. 67). In doing so the predetermined capacity has to be complied with using the available production cycles and the availability of incoming components must be considered (Scholl, 1999, p. 111).

Production planning is usually continuous. The allocation of orders to week or day periods or to shifts is also called slotting. Continuous planning can be added to slotting until the sequence is fixed, which balances the orders based on capacity and material criteria. Individual orders can thereby be moved to a period different from the initial planned production period by taking into account other detailed restrictions. This shifting, which results from an adjustment, is also called balancing. Fixing the order sequence assigns a decided production cycle to each order from the order pool. The methodology for implementing and the objective of sequencing can vary and lead to three different classes of optimization models, which are outlined in the following section.

2.2 Sequencing

Comprehensive scientific literature exists for the planning task of sequencing in the automotive industry. In place of them we want to point to the works of Decker (1993), Lochmann (1999), Scholl (1999), and Boysen et al. (2009). In principle one can differentiate between three methods.
Fig. 1. Planning processes of sequenced assembly lines

**Level Scheduling.** The so-called level scheduling, which descended from the well known Toyota Production System (Monden, 1993), targets the distribution of demand for each material as evenly as possible. Different models and algorithms were proposed. An overview of the research papers for level scheduling can be found in Boysen (2005a, p. 217, 2005b).

**Mixed-Model Sequencing.** The so-called mixed-model sequencing aims to prevent capacity overloads in the flow system. Sequence-related capacity overload of the workstations or workers are to be minimized by exact scheduling of the different variables at the stations and by taking into account the variant dependent machining time, length of workstations, and cycle times (Wester and Kilbridge, 1964; Thomopoulos, 1967; Bard et al., 1992, 1994; Tsai 1994; Scholl et al., 1998; Boysen, 2005b).

**Car Sequencing.** Also capacity oriented, car sequencing tries to avoid these detailed entries by prohibiting partial sequences with capacity overload via \( H_0: N_0 \) sequence rules. A sequence rule of 1:3 relating to the sunroof option states that of three back-to-back components only one can have the sunroof option. Otherwise capacity overload occurs. Solution techniques for car sequencing can be found in Drexl and Kimms (2001), Gagné et al. (2005), Drexl et al. (2006), Gravel et al. (2006), as well as Fliedner and Boysen (2008).

While level scheduling is mostly used at Asian automotive manufacturers like Toyota (Monden, 1993) and Hyundai (Duplaga et al., 1996), capacity overload oriented methods are used more at Western manufacturers like Renault (Gagné et al., 2005). Nonetheless, Western European automotive manufacturers focus on offering customized design options for vehicles (Sihn et al., 2009). BMW offers its vehicles in
up to $10^{32}$ variants as a result of a multitude of individually selectable options (Meyr, 2004). In order to avoid the high data collection effort, almost all of the Western European companies use the car sequencing method.

### 2.3 Production Cycle

In sequenced production lines the cycle determines the productivity. The cycle is a parameter of sequenced production lines and implies the periodic constant feed of orders in production. The period length is the cycle. This requires, however, a constant cycle at least over the particular planning horizon of a shift. This can be assumed for the majority of assembly lines in the passenger car and power train production, whereas in the truck assembly cycle times dependent on vehicle length are prevalent.

Equally spaced surface sections, which are travelled per cycle, can be calculated for uniform cycle lengths. These are called stations. The length of a station depends on cycle and cycle speed. The depth of a station depends on the product to be produced (engine, axle, passenger car body, etc.). The arrangement into stations has organizational reasons in that it facilitates the assignment of human resources, materials, resources, etc. on the lines into sections. As will be shown, the assignment of tasks on the station level is not always helpful, because station overlapping processes and organizational forms are difficult to display.

The workload of a cycle results from the ratio of the sum of the process times (work content) to the cycle time and is stated in percentages. This workload is distributed among the required number of workers. Depending on the product variants and configurations, the workloads sometimes vary considerably per station. The goal of human resource allocation planning is to utilize the workers as equally as possible across the sequence of variant rich products.

### 3 Capacity and Human Resource Planning Functions

Human resource demand planning and human resource allocation planning are part of capacity planning, which has to meet market demand with adequate production capacity. While human resource demand planning clarifies how many human resources with which qualifications are necessary, the task of human resource allocation planning is to utilize the existing staff optimally. When balancing capacity, the capacity flexibility plays a key role, because the actual market behavior cannot be forecasted accurately and the demand fluctuations have to be absorbed within bandwidth. Because the assembly lines in the automotive industry are human resource-intensive, this is where the biggest leverage for flexibility in the operational hours can be assumed.

The working hour flexibility varies with lead times, which is necessary for implementing capacity adjustment measures: Capacity increases through new line installations can only happen long-term, because 2 to 3 years of lead time is necessary. Annual hours of work and weekly hours of work flexibility can be varied mid-term through agreements with the workers council. Short-term model mix fluctuations can be balanced with human resources that can be assigned to different workstations (so-called “floaters”). Floaters can be utilized for different reasons and under different demand scenarios.
Use of a floater to balance the processing time at workstations when capacity overload threatens.

Assignment of floaters to big orders with high expenditure, who will attend to the whole assembly line or just parts of it.

Assignment of floaters for production stations that require special skills which are only rarely needed (technologically contingent floater assignment).

Floater as backup capacity for work absences, vacation, illness, etc.

The first two assignment scenarios use the free capacity of a floater at the time of occurrence. The two latter floaters functions don’t serve to support the sequencing via a (operational short-term) capacity increase. Therefore they are not pictured in the following model, but are only considered as input parameters (number of floaters). Sometimes a short-term capacity increase is also possible through production during breaks.

4 Correlation between Production Program and Human Resource Allocation Planning

In car sequencing, balancing based on key features (called heavy items) already takes place when assigning orders to order inventory. These product features are gradually being broken down into more detail in the subsequent planning steps. The bridging of sales demand (market demand) and production supply (production elements) occurs via product features. The sequencing rules, which are described on product features level, represent implied capacity restrictions within production. For this reason sales demands are described in terms of product features and the restrictions resulting from capacity and material related limitations of the production system are translated into the language of the product features.

Balancing is now carried out subject to the planning horizon and the available product feature data. The product features from the production plan are extracted from the available order data. Only the variant information of products, which passes a possible capacity limit, is important. Looking at the past is very important here: frequency distribution of variants is known from experience. If a variant occurs more often and as a result load peaks occur, a sequencing rule is added which can be taken into account during the next sequencing run. A forward-looking prognosis of the load distribution of assembly lines through the currently planned sequence, like in mixed model sequencing, is not possible.

The following links arise between production planning and human resource and human resource allocation planning:

- Mid- and long-term human resource planning provides the capacity framework for mid- and long-term production planning.
- In the short- to mid-term horizon, human resource planning follows production planning and only influences it indirectly.
- In the short- and mid-term horizon, the consideration of human resource restrictions happens through indirect rules and strategies in production planning, e.g.:
  - Equal distribution strategies for labor intensive tasks
− Spacing rules for labor intensive tasks
− Transition rules for labor intensive tasks
− No direct human resource restrictions are taken into account in production planning.
− Little or no direct coordination between human resource allocation planning and production planning happens in short-term planning and order processing.
− During temporary production bottlenecks, the response is usually human resource measures and not an adjustment of the production plan.

These observations suggest that an integrated planning approach, which allows direct influence of human resource aspects on the short- and mid-term production planning process, is able to open up additional optimization potentials. Provision for human resource flexibility in production planning requires that

− The impact of production planning on the capacity demands per order are known
− The skills and availability of human resources as well as flexibility of their deployment are known, and
− The interaction of process demands and the availability of human resources in the dynamic sequence of the order sequence are analyzed.

The process data per order is necessary for this kind of planning. Because the orders are already specified at the time of sequencing, the capacity demand per workstation and order and therefore the impact of the order sequence on capacity demand can be determined. The discrete event simulation lends itself to the prognosis of load distribution insofar as further analysis of floater assignment and situational decisions are to be conducted. Mapping in a simulation model also has the advantage of simplifying
scenario generation, and the resulting data can be used as an assessment function for higher-ranking optimization. This approach was implemented by combining a revised flexis AG sequencing optimization solution with a simulation model validated by means of real-time data from an automotive manufacturer. The following section describes the basic model foundations and the interaction with the sequencer. The benefits of car sequencing are hereby expanded by the aspect of human resource allocation planning and checked for feasibility with dynamic testing.

5 Solutions Approach

The sequencing solution gets a list of the valid production constraints as well as a continuously running order pool. Besides the technically necessary constraints, there are now additional constraints resulting from the calculated human resource allocation. The human resource allocation results from a preliminary human resource based analysis of the order pool. In doing so, the workload included in the order pool is balanced with the human resource capacity for the same period.

The calculation of an optimized sequence is then carried out, taking into consideration all technical and human resource related production constraints. Subsequently, the calculated sequence regarding the human resource scenarios at the individual station groups is reviewed in a simulation. The simulation model maps the variant dependent assembly processes per order and takes into consideration the existing human resource capacities. Each order consists of a multitude of executions which result in different process times depending on the product variant and (optional)
equipment. One or more employees are necessary per execution. This process and organizational data is available per order. The order sequence is the result of sequencing and serves as input for the simulation.

Human resource allocation takes place during simulation runtime, namely at the moment when the execution within the simulation is one cycle before to start. The employees which have been scheduled for the execution and have been combined as a team are allocated. The company’s goal is to engage its employees in the same activities, because experience has shown that in doing so a high level of quality and therefore less rework is necessary. Each execution is assigned to a team. If the sum of the process requirements is higher the sum of the team capacity, the team has the possibility to predraw or to extend the work in predecessor or successor cycles within given time constraints. If there are not enough unused employees available the team has to use floaters. Floaters are assigned to groups, which are responsible for a number of teams. If a floater is not available the simulation model generates one (virtual floater). The simulation calculates the feasibility of the sequence at hand and calculates the additionally required employees in case the assigned human resources are not enough. This information can now be relayed back to the previous sequencing task. This starts an iterative process where the sequence solution together with the defined human resource allocation is passed to the simulation and which now reveals the expected workload with the help of the fully specified order data.

![Diagram](image)

**Fig. 4. Iterative planning processes**

The implementation of the planning system follows these planning principles:

- The integrated planning system expands the proven workflow of production planning by a human resource optimization component which provides dynamic human resource optimization rules and parameter adjustments for sequencing.
– By analyzing the work content for the order pool and the order sequence and by comparing them with the existing human resource capacities and deployment scenarios, the system calculates the best response possibilities to the detected bottlenecks.

– To create an optimal order sequence also with respect to human resource allocation, relevant rules and parameter calibrations are generated for the chosen response options and taken into consideration in the next optimization run.

– The simulation of the assembly processes, based on the work schedule data, each variant and its lead time per execution are taken into consideration. In doing so a highly exact forecasting of employee workload for a given sequence is possible.

– This course is repeated until a solution is found which is optimal under production as well as human resource planning aspects.

This approach combines the advantages of car sequencing with the advantages of the mixed modeling approach. The advantage in car sequencing lies in the restriction on few product features in order to limit the data to the relevant criteria. With this restriction, optimization algorithms are capable of solving the sequencing task in finite time and acceptable quality. A further analysis of labor times per variant and station allows the prognosis of load profiles. Additional potential is tapped through the repetitive interplay between optimization of features and the feasibility prognosis based on labor time data. An efficiency increase of the human resource allocation is thus possible.

### 6 Results

The sequencing solution and the simulation application were first developed independently and validated with the help of test data. The existing flexis sequencing solution was expanded to take into account the aspects of human resource restrictions. The simulation application was realized in the simulation software development environment of SLX (Henriksen, 1997). This simulation program distinguishes itself through fast calculation and flexible mapping of model requirements. The run times of the simulation model are less than 10 seconds for 500 orders and 100 executions. A post-process animation in the Software Proof allows the transactions to be visually inspected. The delivery of data takes place via ASCII tables. An iterative integration into an optimization loop with the sequencer is therefore viable, while also regarding solution generation times.

The simulation results show promise with regard to transparency and analysis options of transactions in allocation and utilization of employees. It was demonstrated that in combination with the sequencing solution a balancing of load fluctuations and a reduction of overloading and underutilization of up to 30% is possible. With it comes an increase of staff utilization.

The results, however, are based on (realistic) test data which have not been tested in a real life scenario. The results were therefore presented to automotive manufacturers to get feedback from users on the solution approach and to ask for real time data. So far one manufacturer of sport utility vehicles and one of commercial vehicles have agreed to provide real time data of the final assembly line.

In the first step, the data for a simulation of the assembly were defined. The data acquisition is still in progress. Meanwhile, the first simulations of two or three stations show the possibilities of simulation to analyse and evaluate the human resource
allocation planning. There are several parameters which have fundamental influence on process requirements and capacity demands in every station. One can distinguish following primary key drivers.

**Production programme:** The sequence of orders determines the process requirements over time. To build an order sequence is in the responsibility of order management.

**Staff assignment:** The prognosis of the process requirements in every station offers new possibilities to plan the work schedule of floater. A floater has to observe his working area to react in case of overwhelming process requirements at a station. The visualisation of the process requirements and the expected utilization of the team member of every station given in advance, the floater know when he will be needed (time, station). It is the task of the production management to plan the floater.

**Process planning:** A work plan consists of a number of process steps; the sum of all process time steps represents a task time, depending on vehicle type and station. Every task is assigned to a station. The tasks can be divided by splitting process steps in two tasks or they can be merged by aggregating two tasks to one task, depending on what the line planner has to take into account like technology restrictions, etc. Nevertheless, in most cases, the aggregation of process steps are not done in a similar way, more often it depends on how a planner is used to build tasks. But there is a great influence on the staff utilization in choosing different methods to build a task. If the task times are too long, it can happen that a staff member cannot start a task because of lack of sufficient rest cycle capacity. The division of small tasks leads to better fits, but can be critical, if the number of tasks is too high, because of the negative influence on the working quality.

**Cycle time:** The cycle time determines the productivity. The assignments of tasks to stations can vary if the cycle time will change.

The production programme, the staff assignment, the process planning and the cycle time are correlated mutually. If you change e.g. the cycle time, it will be necessary to review the utilization of your staff and perhaps to rearrange the processes of your work plans. To do this, you must have the knowledge about the technologies, the restrictions and the no-goes of an assembly line and its organisation. That’s why the improvements in planning of the production programme and human resources allocation planning forces all planning experts to work together. The planning process is iterative whereas the simulation serves as a decision support system by visualizing the results of utilization and productivity.

The developed solution for integrated human resources and production planning will be analyzed extensively by evaluating the results with these industry partners and testing their deployment potential and suitability.

### 7 Summary and Outlook

European automotive manufacturers continuously invest large sums into initial and continuing training of employees which lead to above average flexibility of production workers in international competition. At present, however, it is only used as a reactive tool in implementing the planned production program in the production halls. This
way a high-cost human resources flexibility is retained instead of integrating the planning of production and human resource allocation and reaching an overall optimum.

The approach of trying to combine production planning with human resource planning is pursued within the scope of the Eurostars research project "Advanced Production Program and Personnel Assignment Planning" (A ProPer Plan). In doing so, the causal correlations between production program and production factors are detected. Existing sequencing solutions are expanded by human resource related restrictions and an iterative solution loop with simulative evaluation is integrated. The simulation allows the feasibility testing of the proposed sequence and clearly shows where under utilization and overload will occur.

Altogether, the following benefits of integrated human resources and production planning ensue:

- Transparency increase of human resource allocation and assembly process
- Balancing of load fluctuations and reduction of cold spots by up to 30%
- Increase of staff utilization
- Proof of buildability of a production program

By combining car sequencing and the mixed model approach wisely, further potential in and applications for integrating production program and human resource allocation planning can be found. The result is the logistical and economical optimization of the production process supported by simulation. The payoff is a significant increase in the hours per vehicle efficiency.

Within this project of integrating production programme and human resource allocation planning in the short term planning horizon several topics for further research where uncovered. The main problem of several European OEM’s that took part in the project is the missing integration of the different planning tasks combining the long-, mid- and short-term planning horizon in one integrated planning environment. To solve these problems together with the automotive industry several research activities are going to be initiated.

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