Sihn/Kuhlang [Ed.]

Sustainable Production and Logistics in Global Networks

43rd CIRP International Conference on Manufacturing Systems
26 – 28 May 2010, Vienna

Proceedings

Fraunhofer

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

nwv neuer wissenschaftlicher Verlag

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Fraunhofer

PROCEEDINGS

International Conference on Manufacturing Systems

Organised by

Vienna University of Technology
Institute of Management Science
Division Production Engineering and System Planning

Fraunhofer Austria Research GmbH
Division Production and Logistics Management
www.fraunhofer.at / office@fraunhofer.at

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nw neuer wissenschaftlicher Verlag
TECHNIK
Vienna · Graz 2010

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

ISBN 978-3-7083-0686-5
Neuer Wissenschaftlicher Verlag GmbH Nfg KG
Argentinierstraße 42/6, 1040 Wien
Phone: +43 1 535 61 03-24, Fax: +43 1 535 61 03-25
e-mail: office@nwv.at

Geidorfgürtel 20, 8010 Graz
e-mail: office@nwv.at

Internet: www.nwv.at

Druck: Széchenyi István Nyomda Kft., Győr (HU)

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Integration of Personnel and Production Programme Planning in the Automotive Industry

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Abstract

To produce highly customised products, the European automotive industry employs complex supply structures. In particular JIS-fabrication of different types of vehicles on the same assembly line increased manifold the complexity of both production planning and supply logistics, demanding sophisticated IT-support for production planning. Often, separate systems are used to plan personnel capacity and production programmes. Usually, human-resource allocation planning is done very inefficiently by assigning personnel capacity "en bloc" to the assembly lines, independently from actual capacity requirements. This causes imbalances in the form of idle workers or overloaded work stations. This paper will explore an approach to integrate human resource allocation and production programme planning into one common planning platform, in order to utilise existing optimisation potential.

Keywords:

Integration, Planning, Sequencing

1 INTRODUCTION

Traditionally, the European automotive industry has produced highly customised products and especially the Original Equipment Manufacturers (OEM) are characterised by complex supply structures that enable "just in time" (JIT) and "just in sequence" (JIS) vehicle assembly. However, the JIS-fabrication of various types of vehicles on the same assembly line increased manifold the complexity of both production planning and supply logistics, necessitating sophisticated IT-support for production planning (programme building, sequencing, scheduling and material supply). Further, this type of production requires highly skilled employees and constant training and education, resulting in high flexibility among the manufacturing workforce. Such personnel is often hard to obtain and also expensive, resulting in pressure to optimise human-resource allocation planning.

The overall human-resource allocation planning is frequently done very inefficiently by assigning personnel capacity "en bloc" to the different workstations, independently from actual capacity requirements. This situation is especially true for the automotive industry, but can also be found in other industrial sectors. Further complications arise due to competing spheres of influence and resulting organisational structures. This often leads to separate systems for the planning of personnel capacity and production programmes, resulting in an inefficient gap between the different IT-systems.

The concept described within this paper uses the case of sequencing in the automotive industry, as a specific case for detailed production planning in combination with the problems arising from independent human-resource allocation planning. Currently, none of the commercially available IT-systems for JIS-production planning offers an integration of human resource allocation and production programme planning. This can be explained by the growing complexity of the planning problem, when increasing the degrees of freedom in optimisation. However, the industry recognises the need for integrating human resource allocation and production programme planning into a common planning platform that will allow the exploitation of additional cost savings.

This paper gives an overview of current planning approaches and outlines an integrated solution for production programme and personnel assignment planning. Further, a solution to the problem will be presented that is currently validated with real-time data and under real-time conditions.

2 DEFINITION OF PLANNING MODEL

The overall challenge of the planning processes in the presented case in the automotive industry is to utilise the existing resources at the requested demand for cars as optimal as possible. Within this planning process (including all planning tasks along the planning cascade) it is requisite to match the demand in form of the production programme with the existing production factors (material, personnel, resources).

The generic planning model for the automotive industry as shown in Figure 1 was derived matching current theoretical thinking with practices of the European automotive industry (OEMs of passenger cars and trucks). In this model, the different planning tasks are allocated to different planning levels (e.g. strategic, tactical, operational) and horizons (e.g. short-term, mid-term, long-term). The planning tasks with a long-term horizon deal with planning objects such as number of cars to be produced in the next period. For a shorter planning horizon the level of detail needs to be increased with a simultaneous reduction of uncertainty [1]. The closer one gets to the prospective production start date the more the flexibility and adaptability of the production factors decreases, in order to meet the requirements of the planned production programme.

The model is a cascading planning process divided into four main steps with dedicated tasks, horizons, planning objects as well as input and output data. The four steps cover the mid- and short-term planning horizon and are defined as slotting, balancing, sequencing and re-sequencing.

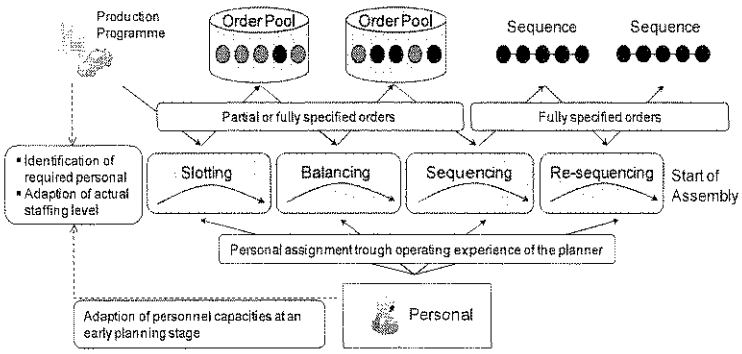

Figure 1: Current Planning Process.

Inputs for the entire planning problem are sales forecasts, broken down into a defined production output per month in form of not fully specified orders. These orders contain just main attributes such as vehicle or engine type. Each order pool is calculated using an average process time per vehicle (h/vehicle). Forecasts are planned with rolling horizons and are periodically updated (i.e. every three months). The planning input for the first step (slotting) is the preview of the production programme for the following period (e.g. three months) broken down into the forecasted monthly demand. Subsequently, the four different steps are presented in more detail. The defined planning horizon, frequency and time scale for each planning step are examples and can vary on a small scale from case to case.

2.1 Slotting

Planning Horizon: three month before start of assembly

Planning Frequency: each month

Time Scale: week or day

Output: production programme for the following month in defined "slots"

Description: In this planning step the production programme is split up into daily or weekly order pools. At this point usually no or just a few customer orders have been placed. Thus, the orders within the daily or weekly order pools are not fully specified dummy orders. Their specification level includes only items as engine type or number of axles for truck assemblies. If a real order is based by a customer, an eligible dummy order is replaced and hence will turn into a fully specified customer order.

2.2 Balancing

Planning Horizon: 2-12 weeks before start of assembly

Planning Frequency: weekly

Time Scale: day or shift

Output: balanced weekly pool of dummy or customer orders divided in defined sub slots (e.g. day or shift)

Description: In this step, the replacement of dummy orders by customer orders is an ongoing process. Getting closer to the start of production, the

not yet replaced dummy orders have to be specified in more detail, to achieve proper planning results. For this reason, attributes such as colour, transmission, sunroof, etc. are added. This level of detail allows to analyse the work content per vehicle and to generate balanced sub-order pools based on days or shifts.

2.3 Sequencing

Planning Horizon: 0-12 days before start of assembly

Planning Frequency: daily

Time Scale: cycle time

Output: Exact production sequence for the following days

Description: Finally, all dummy orders have to be replaced by real customer orders or if not possible, it has to be decided if the dummy order is terminated or a vehicle is produced to stock. However, at this point the vehicle has to be fully specified to enable the planning of the order sequence.

Basically three different main sequencing methods can be distinguished, level-scheduling, mixed-model sequencing and car-sequencing [2].

Level scheduling – based on the principles of the Toyota-Production-System – is a method that aims to achieve a smooth distribution of the material demand [3]. Another sequencing method is the mixed-model sequencing that reduces overload of resources in the system. An exact schedule of each type and station under consideration of the type specific work content is calculated [4] [5].

The approach of this paper focuses on car-sequencing as a sequencing method used by various European OEM that took part in the requirements definition phase. Car-sequencing is a constraint based approach that also tries to eliminate overloads without a detailed consideration of work load, stations or cycle times. Therefore, a constraint catalogue is defined and implemented into the sequencing tool. In order to define a realizable sequence such a constraint could be that just one car with a sunroof is allowed in a row of three cars [6] [7].

In order to enable suppliers to produce and deliver their parts just in sequence the result of this planning task is fixed in the so called "frozen zone" of several days. Within this horizon no changes in the production programme should occur.

2.4 Re-Sequencing

Usually the re-sequencing step is not necessary. If any turbulence such as missing parts, machine failures or express orders necessitates a change of the production plan within the frozen horizon, a re-sequencing under consideration of the problems mentioned above is executed.

2.5 Consideration of Human Resources in the Planning Process

Currently the planning of personnel can be described by two planning functions. At a very early planning stage when just forecasts for the following period exist, the required staffing level is identified by an aggregation of the required assembly time for each variant for a defined period. With this information the present staffing level is adapted.

In the ongoing planning process the manning level for each work station is defined once for the forecast order mix of the assembly line. In the production planning process the personnel capacities are considered indirectly within the constraints of the sequencer. These constraints are defined based on the operating experience of the planner. As a result, not all dependencies and dynamic effects are described within the constraint catalogue, leading to "hot" and "cold-spots" throughout the assembly process.

Existing planning systems do not allow the analysis of the planned sequence concerning idle times and overload of personnel capacity in detail. Hence, it is not possible that staff flexibilities are planned in advance to smoothen the production process. To meet this challenge the following planning approach proposes the integration of personnel allocation in the production planning process for an optimised utilisation of capacities.

3 PROPOSED APPROACH

The car sequencing problem alone is already NP-hard (non-deterministic polynomial-time hard) [8]. Adding personnel planning to the car sequencing problem increases the complexity considerably. Hence it seems sensible not to solve the integrated problem, but rather keep the two subproblems (production scheduling and personnel planning) separate. This approach allows the reuse of the existing sequencing solver.

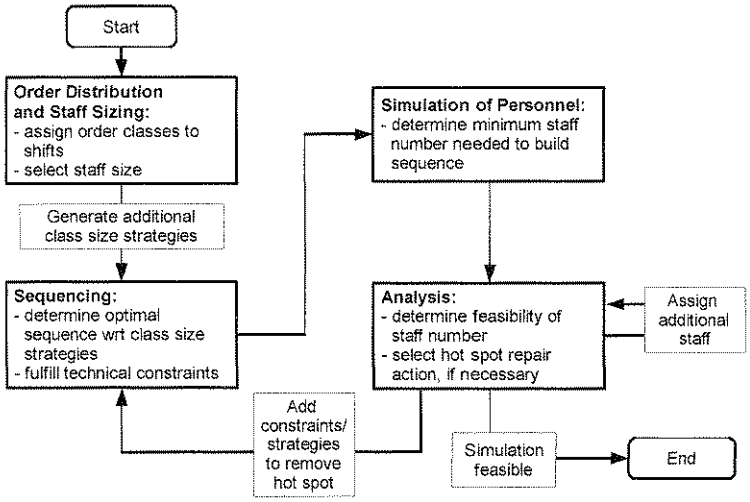

Figure 2: Workflow in Planning Process.

The planning process (Figure 2) partitions into four distinct steps: order distribution and staff sizing; sequencing; personnel simulation; analysis and repair. The first step distributes the orders to shifts and assigns the minimum number of staff required to build the orders. It is a relaxed version of the integrated problem. Sequencing computes an order sequence that fulfils the technical constraints while minimising the deviation from the

order mix established in the first step. Personnel simulation determines the minimum number of staff necessary to put the sequence into execution. Finally, hot spots where the simulation required more staff than was assigned during the order distribution and staff sizing are analysed and repaired.

Using a branch-and-check decomposition approach [9], one could think of the order distribution and staff sizing problem as the master problem to the sequencing and personnel simulation sub-problems, while sequencing is the master problem to the personnel simulation sub-problem.

Full integration would require jumping back from the analysis step to the order distribution step if staff numbers are increased for a shift, in order to set such a constraint and resolve the order distribution and staff sizing problem. It is questionable whether this is worthwhile, though, since the trade-off between the expensive order distribution and staff sizing step and the possibly marginal effects on the distribution of difficult orders among the shifts is unclear. Therefore, it was decided to implement the workflow without such a loop unless empirical data would show the necessity for it.

To reduce the scale of the problem, not individual orders but members of order classes are scheduled. A class of orders contains all orders that are indistinguishable for the planning process, i.e. all orders with the same set of attributes. The orders in a class will be mapped to the positions of the class members in the schedule at the end of the planning process.

3.1 Order distribution and staff sizing

The first step in the planning workflow is the order distribution and staff sizing. This step distributes the orders (or, more precisely, the anonymous members of the order classes) that are slotted in the selected time horizon into shift buckets such that capacity constraints are fulfilled and the personnel cost is minimised. This step is performed for each station group. The (high-level) constraints for this problem are:

Minimise $cost$ subject to (1)

$$cost = \sum_{s \in Shifts} Pc_s p_s \tag{2}$$

$$p_s = y \quad \Rightarrow \quad t_{cs} = t_c(y) \quad \forall c \in Classes \tag{3}$$

$$\sum_{c \in Classes} t_{cs} x_{cs} \leq Ct_s \quad \forall s \in Shifts \tag{4}$$

$$\sum_{c \in Classes} x_{cs} = Cn_s \quad \forall s \in Shifts \tag{5}$$

Here, x_{cs} is the number of orders in class c assigned to shift s, and t_{cs} is the time needed to process an order of class c in shift s. This time $t_c(y)$ depends on the number of staff p_s and their distribution to the stations in the group that this equation system is solved for. Ct_s is the maximum amount of work time that is available in shift s, and Cn_s is the build rate for shift s. Assuming that for each class the staff is optimally distributed to the stations, the orders in the class are processed with as little time as possible.

The sum of staff numbers multiplied with a shift's personnel cost factor Pc_s is to be minimised.

Solving this equation system will lead to a super-optimal distribution of staff to station groups, since an optimal distribution of staff to stations is assumed for each order class. Moreover, an equation system for each group of stations is solved and no interdependencies between stations groups are taken into account. It is therefore likely that for a given solution to the order distribution and staff sizing problem no feasible sequence can be found. However, this approach allows for an increase in staffing levels 'from below' in the analysis step until a feasible distribution is found.

Note that the equations (3) and (4) are not linear. However, it is possible to reformulate them using a Special Ordered Set (SOS1) [10]. Therefore, the order distribution and staff sizing problem can be solved using a linear programming solver while still getting an integer solution.

3.2 Sequencing

The second step in the planning workflow is sequencing, i.e. the scheduling for a sequential production. Here flexis's existing car sequencing algorithm is reused as a 'black box' solver. The solver's algorithm is based on Constraint Programming, which has several advantages. It is a well-controlled, exact (non-randomised) solving process, and adding custom constraints is easy. The solver has a number of available rules besides the standard 'sequence' constraint (called 'among_seq' in the global constraint catalogue, http://www.emn.fr/x-info/sdemasse/gccat/, and also known as H0:N0 constraint), which usually exist in two implementations: as constraint and as heuristic. While the constraints restrict the order class domains at the sequence's positions, the heuristics define an order on the domain in which the order classes are selected. The sequencing solver returns a solution that fulfils the constraints and minimises the heuristics' evaluation values.

Within this project, constraints and heuristics that model technical restrictions are augmented with heuristics that model the solution of the order distribution and staff sizing process: for each station group, and for each shift, a certain number of orders of each class is expected. For each station group, the shifts will map to stretches of sequence positions. For neighbouring groups, these stretches are offset by a specific number of positions. Obviously, since heuristics are used to model the order distribution solutions, it allows the sequencing algorithm the flexibility needed to find a solution that fulfils the technical constraints while staying as close to the desired distribution as possible. Additional 'uniform distribution' heuristics will ensure that orders will be spread out as evenly as possible, which eases the assignment of staff in the next step, where the sequence is tested for feasibility with respect to the staff numbers.

3.3 Personnel Simulation

Once the sequencing solver has returned a solution that is technically feasible, it must be checked whether enough staff is assigned to each station group so that the sequence can be put into execution. This step is performed by simulating the execution. For each order in the sequence, the workflow through the stations is simulated, and at each station, the neces-

sary number of personnel is 'requested' that allows to perform the production steps for the order's type within the cycle length, or in as short time as possible if the cycle time is always too short for a given type of order.

It is assumed that no 'base' number of staff is assigned to a station group, but that instead an unlimited number of stand-by personnel is available. This ensures that only the minimum number of staff is requested that is needed to execute the sequence. Note, however, that there is no upper limit for the requested staff. Therefore, more staff can be requested than was assigned during staff sizing.

The output of the simulation step is an array that lists for each station group and each cycle start time, the minimum number of staff required to put the sequence into execution.

3.4 Analysis and Repair

In the final step of the planning process, the staff numbers requested in the simulation is compared to the staff numbers computed in the staff sizing process. This is done by running a Constraint-Programming-based solver that distributes the number of staff, which were assigned to a station group in the staff sizing step, to the individual stations of the group such that the number of hot spots is minimised. Hot spots are stretches of time where more staff has been requested at a station group than were assigned during staff sizing. If staff has to stay at a station for a minimum or exact amount of time, then this will be taken into account.

Hot spots need to be repaired by the human planner, since the evaluation of the possible actions cannot be automated in a satisfactory way. The planner will be shown a list of hot spots together with possible repair actions, and select one of these for application. Possible repair actions are: (1) assign more staff to a station group within a shift or (2) add constraints to move apart the types of orders causing a hot spot.

Two kinds of additional constraints are possible: increasing minimum distance between certain types of orders, or disallowing an order class within a certain range of sequence positions. If it is selected to add constraints in order to remove a hot spot, a new sequencing is required, since these constraints will have nonlocal effects, i.e., adding such a constraint will possibly affect parts of the sequence that were not part of a hot spot. The workflow will return to the sequencing, and continue from there.

If additional staff was assigned, it would normally be necessary to return to the order distribution and staff sizing step. However, it is expected that the effects of additional staff are only marginal and local to the shift that contains the hot spot. Further, it is not necessary to run another personnel simulation, since all personnel was modelled as stand-by staff, anyway. The additional staff will alleviate the hotspot, and will only possibly lead to underutilisation of staff during the rest of the shift. If the underutilisation is too severe, adding constraints to remove the hotspot will be the better course of action, though.

When the simulation does not request more staff than was assigned to a station group in staff sizing (or as increased by repair action), then the sequence is feasible with respect to the assigned staff. The solution is then returned.

4 CONCLUSION

The presented approach is combining the advantages of car-sequencing and mixed model sequencing. Furthermore, the integration of personnel planning in the planning process will help to raise the following potentials:

- Verification if the production plan can be realised with the available resources.
- An increase of transparency in the whole assembly process and especially the staff assignment.
- Smoothing of work load fluctuations and reduction of hot- and cold spots resulting in higher utilisation of human capacities.

Currently the model is validated with real production data of an industrial partner. By using real-life load scenarios the reliability of the prototypical solution is tested. This will allow the project partners to gauge the potential of the chosen approach and enable fine-tuning. The first results are very promising that the solution will lead to the expected improvements.

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