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Combination of planning methods in a comprehensive production planning approach for sequenced production lines

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ABSTRACT

Medium-term sales and operations as well as medium to short-term production planning in customer order driven production processes are performed using a cascading planning process. A lack of coordination and feedback between different planning phases causes problems with a negative effect on costs in production that originate from unfeasible production programs. Based on a system for the classification of planning restrictions the planning process will be controlled utilizing a newly developed combination of the methods of Linear Programming and Constraint Programming. The result is a formal logic to combine the different planning horizons and the two sets of planning methods.

1. Introduction

In the European automotive and mechanical engineering industry an effective management of order processing, in particular regarding data processing and information exchange will be an increasing success factor [1]. In these industrial sectors various systems for sales planning, purchasing, production and supply chain management are employed, which are often poorly synchronized or even incompatible [2].

That entails, it is common to plan the different steps in a chain sequentially while at the same time, in the whole planning process, a broad variety of types and combinations of options have to be considered. One of the planning requirements is a high accuracy concerning i.e. workstations, human resources and material. Currently planning, especially in the automotive sector, but in different industries as well, is conducted in cascades. This poses the problem of a lack of coordination and feedback between the planning steps, which may cause contradictions in the production programs. As a result, short-term troubleshooting has to take place and additional or different resources must be procured [2].

The aim of this paper is to describe a method of achieving a harmonized planning process for sequenced production lines through the combination of planning methods and the timely consideration of constraints of a cascadic planning. The solution presented herein represents a tool with which different domains communicate with each other. The tracking of bottlenecks and timely detection of problems will be ensured, enabling a proper reaction.

Therefore Section 2 summarizes the relevant planning processes for order driven production in sequenced production lines. The gap of existing solutions and the reason for the development of the method are depicted. In Section 3 the principles of existing solving algorithms are described and possibilities of an integration of sequencing rules in program planning are shown. Section 4 describes how the planning processes and the combination of program planning and sequencing steps will be executed. Section 5 summarizes the results and gives an outlook to further activities.

2. Planning process for sequenced production lines

In customer order driven production processes the key target of planning is to align market requirements with available production factors. Production restrictions in long- and mid-term planning are fixed and production factors are limited according to context-related restrictions [3].

In Fig. 1, a planning cascade of a synchronized production line is described, where several production factors have to be taken into account on different levels of aggregation [4]. Depending on the planning horizon, the planning process starts from rough estimations and ends with the manufacturing- or the assembly process. Tasks and restrictions have to be adjusted to avoid conflicts such as bottlenecks or under-utilization of the production factors.

The planning process starts with a market analysis. After that follows an annual budget planning that results in sales forecasts, which are continuously updated. This step is succeeded by the generation of a rough production plan allocating, for example, production orders to order pools. Finally in the short term planning horizon a detailed order sequence has to be defined.

The planning gradually gets more detailed with each step. For example, in the very beginning (program planning) dummy orders are assumed, based on various sales prognoses etc. gradually being replaced by real orders, the further the planning proceeds [5]. Simultaneously, the constraints for the planning process become tighter with the production date approaching.

The development of an integrated planning approach as the basis of a software tool that harmonizes the planning tasks over the different planning horizons is subject of an ongoing research project called HarmoPlan. This paper presents the application of the new developed integrated planning approach that is based on a

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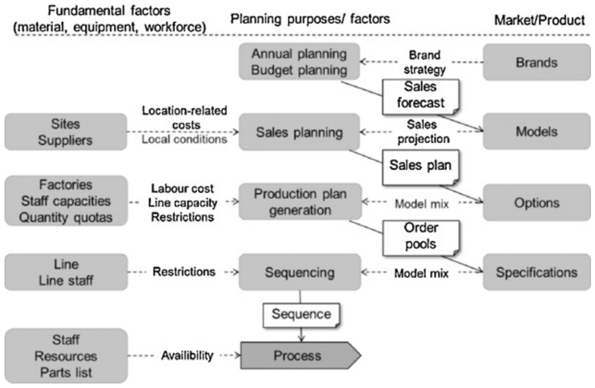

Fig. 1. Planning tasks and interrelationship with fundamental factors, product and market [4].

classification of the origins of planning constraints. The resulting software tool is to bridge the usually employed planning cascade.

This can be achieved by shifting later occurring constraints to an earlier planning stage. Therefore, the so called Constraint Manager is required. This newly developed tool combines necessary constraints in a standardized format and even enables tracing the originator of each of these constraints. The application of filters winnows irrelevant constraints, leaving the focus on the important ones. The constraint Manager even indicates the necessity for preplanning by searching for a reason as soon as a constraint is ignored or exceeded [3].

3. Solving algorithms

In the following, typical algorithms and solving solutions are presented, which are used for dealing with problems in program planning and sequencing. After that a possibility to draw restrictions from sequencing to the earlier stages of program planning is introduced. This systematic supports the basis to approach the planning problem. Subsequently, the paper focuses on the description of how the single planning tasks in the planning system have to be integrated to be used operatively. That means how the restrictions have to be defined so that they can be executed in both planning problems.

3.1. Program planning

Usually, short-, mid- and long-term production planning are being distinguished in planning. While long- and mid-term planning most notably are determined in a qualitative way, the short term planning determines the production program quantitatively (quantity per time).

In the relevant literature several approaches and algorithms for the planning tasks can be found. The following basic mixed-integer programming model for master scheduling, suggested by Boysen et al. [6] is proposed to minimize deviation costs.

The objective function (1) considers deviation costs for all orders i assigned to period t ($x_{it} = 1$). The variables in the equation are the number of product orders N ($n = 1,\ldots,N$) (2) which have to be regarded and the planning periods T ($t = 1,\ldots,T$) (3).

$$\text{Minimize}\, z_i = \sum_{t=1}^{N}\sum_{t=1}^{T} c_{it}x_{it} \tag{1}$$

$$\sum_{t=1}^{T} x_{it} = 1 \quad \forall_i = 1,\ldots,N \tag{2}$$

$$\sum_{i=1}^{N} x_{it} \le P \quad \forall_t = 1,\ldots\ldots,T \tag{3}$$

For the calculation of the deviation costs, inventorying holding costs, the date of delivery and late delivery penalty costs are being taken into account. x_{it} is the factor for the information, if an order i is allocated with a time period t. $x_{it} = 1$ if this is true and $x_{it} = 0$ if there is no allocation (5). If Eq. (2) is fulfilled, it is guaranteed, that every order is fulfilled in one certain production period, while Eq. (3) simply states, that a limited amount of production period P must not be exceeded.

Further, B_{qt} from Eq. (4) deals with the availability of components. It stands for the number of available components which states a maximum. The coefficient of demand b_{iq} states, that if a certain component is a part of an order, it can either be 0 or bigger. Q stands for the sum of all relevant components of a product whilst q is one specific component [6].

$$\sum_{i=1}^{N} b_{iq} \times x_{it} \le B_{qt} \quad \forall q \in Q_i t = 1,\ldots,T \tag{4}$$

$$x_{it} \in \{0,1\} \quad \forall_i = 1,\ldots,N;\ t = 1,\ldots,T \tag{5}$$

3.2. Sequencing

For solving the sequencing problem, three different solutions are described in the literature.

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 [7]. Another sequencing method is the so called mixed-model sequencing that reduces overloads of resources in the system. Therein an exact schedule of each type and station, under consideration of the type specific work content, is calculated [8–12].

Within the research project HarmoPlan a constraint programming approach for the car sequencing problem is used. The restrictions for the car sequencing are on the one side that an order is connected to a certain type v ($v = 1,\ldots,V$) in the cycle t ($t = 1,\ldots,T$) which is expressed by x_{vt} and can take the value 0 or 1. On the other side it has to be assured, that in each cycle exactly one option is being produced. If a constraint is added, that assures, that only H_o products in a series of N_o products have the same option o, the result is a model for the sequential arrangement [13].

$$\sum_{t=t'}^{t'\to N_o-1}\ \sum_{V=1}^{V} x_{v1} \times a_{vo} \le H_o \quad \forall o = 1,\ldots 0;\ t' = 1,\ldots,T-N_o+1 \tag{6}$$

Here a_{vo} is the demand of option o in type v. It has to be noted, that one type can have different options ($o = 1,\ldots,O$) [6].

3.3. Possibilities of an integration of sequencing rules in program planning

To integrate sequencing rules into the program planning, following condition is suggested as a basis for integrated planning [8]:

$$\sum_{i=1}^{N} d_{io} \times x_{it} \le \alpha \times \frac{H_o}{N_o} \times P \quad \forall_0 \in\ 0;\ t = 1,\ldots,T \tag{7}$$

d_{io} = demand factor; α = scaling factor.

Eq. (7) however represents only a reasonable and not a necessary condition for a solvable sequencing problem. Nonetheless, the knowledge about the single approaches for the solution is just the first step for the development of a comprehensive production planning approach. It is essential to fill up these algorithms with suitable inputs such as defining capacity constraints as well as other planning restrictions.

4. Applicable comprehensive planning approach

This part describes how the planning processes and the combination of program planning and sequencing steps will be executed. Therefore the overall planning approach is presented. The most challenging task for the comprehensive planning approach is to make planning restrictions of one planning task available in the other planning tasks. This mapping of constraints is also described in the following part.

4.1. Planning approach

The overall goal of the research project HarmoPlan is to define and develop a planning system that supports comprehensive