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2011

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SZÉCHENYI ISTVÁN EGYETEM

Proceedings of

# Factory Automation 2011

25-26th May, 2011
Győr, Hungary

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SZÉCHENYI ISTVÁN EGYETEM

# GYÁRTÁS AUTOMATIZÁLÁS 2011 Konferencia PROGRAM

# FACTORY AUTOMATION 2011 Conference PROGRAM

| Május 25. szerda / Wednesday | |
|---|---|
| 8:00 Regisztráció / Registration | |
| 9:00 Sajtótájékoztató / Press conference | |
| 10:00 Megnyitó, plenáris előadások / Opening Ceremony, Invited Lectures | |
| 12:00 Ebéd / Lunch | |
| 13:20–15:40 Szekció előadások /Sections papers | |
| A szekció (E terem sárga folyosó) / Section A (E room yellow corridor) | B szekció (E terem kék folyosó) / Section B (E room blue corridor) |
| 15:40–16:00 Szünet / Coffee break | |
| 16:00–18:00 Szekció előadások /Sections papers | |
| A szekció (E terem sárga folyosó) Section A (E room yellow corridor) | B szekció (E terem kék folyosó) Section B (E room blue corridor) |
| 19:00 Koncert, fogadás Egyetemi Hangversenyterem (Zsinagóga) / Concert and Reception (University Concert Hall) | |
| Május 26. csütörtök / Thursday | |
| 8:30–10:00 Szekció előadások / Sections papers | |
| A szekció (E terem sárga folyosó) Section A (E room yellow corridor) | B szekció (E terem kék folyosó) Section B (E room blue corridor) |
| 10:00 - 10:30 Szünet / Coffee break | |
| 10:30–11:30 Szekció előadások /Sections papers | |
| A szekció (E terem sárga folyosó) Section A (E room yellow corridor) | |
| 12:00–13:30 Laborok bemutatása (ÚT 1. em. 110 folyosó) /Laboratory visit | |
| 13:30-14:00 Büfé ebéd / Lunch | |
| 14:00 Látogatás az Audi gyárában / Visit to the Audi Factory with lunch | |





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# PLENÁRIS/PLENARY

# Planning horizons were yesterday: The case for harmonised planning in automotive manufacturing

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*Abstract:* In the automotive industry long and medium-term sales and operations and medium to short-term production planning often employs cascading planning processes. A frequent shortcoming of cascading planning is the misalignment and lack of feedback between different planning processes. Often long-term plans do not mirror restrictions of subsequent levels caused by unavailable resources or limited supplier capacities, resulting in costly problems in production due to unfeasible production programs and necessary troubleshooting. This paper will establish a system for the classification of planning restrictions and their originators. Further, it will shed some light on the interrelations between single planning tasks and the interdependencies of restrictions between different planning horizons.

*Key-Words:* Sequencing, Constraint Programming, Integrated Planning, Harmonised Planning

## 1. Cascading planning

The automotive and other industrial sectors use various systems for planning sales, purchasing, production and supply chain management, which often are poorly synchronized, and in extreme cases, incompatible. This frequently results in a "planning cacophony" due to rival requests for scope, functionalities, planning horizons, spheres of influence and organisational structures that have developed over time. Looking at planning systems for short-term planning with sequencing capabilities based on a bill of materials, none of the currently available systems supports planning throughout the different levels. Usually, the sales department performs sales planning, as production planning is performed by production or logistics units. The task of supply chain planning often rests in between sales and production planning, due to the fact that selection of and negotiations with suppliers require forecasts of production output at a time, when only sales plans exist. In order to identify the aggregate material and part requirements, detailed forecasts about vehicle configurations and demands per part number are needed. The organisational separation described above seems reasonable, since departments are planning on different levels of abstraction, i.e. sales plans, overall car numbers and probabilities of attributes, while production planning deals with real customer orders and specific configurations. This fragmentation and a lack of harmonised systems cause inefficiencies. The tools typically used for those planning processes allow the incorporation of known restrictions into the planning model; however, only serious constraints are recognized. Less prominent impediments are only detected by chance or through the experience of the planner. If, i.e., sales overestimates the number of vehicles to be sold, internal or external capacities are adapted to enable production. Presently, such a change is escalated manually through all hierarchical planning levels, which is a drawn-out and fault-prone process. Most of the planning solutions for the long- and medium-term are not able to handle the resulting complexity and data volume generated by the explosion of the bill of material. The development of an integrated planning tool that harmonises the planning tasks is subject of an ongoing research project called HarmoPlan. Hence, this paper will classify the origins of planning constraints and outline an approach that makes the constraints available for each planning task along the planning cascade.

## 2. The planning of sequenced high variety production lines

Industrial production is the transformation of production factors into products. As shown in Fig. 1, factors for planning purposes and fundamental factors can be distinguished. The synchronization of production factors is key to a firm's success.

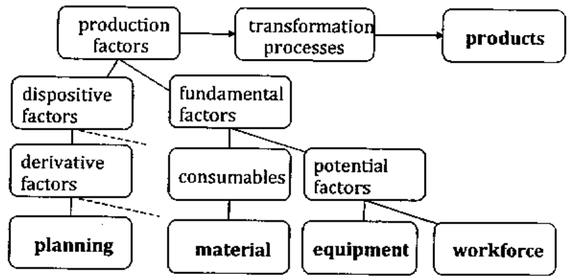


FIGURE 1
PRODUCTION FACTORS [1]

Synchronized flow production is a flow-oriented production system where parts are moved by means of a transportation system through the production stations arranged in sequence, in which the machining time is restricted by a cycle time [2]. HarmoPlan focuses on the planning of the final assembly in vehicle and component plants where variant flow production with low automation and high labor intensity exists [3]. Fig 2 shows a planning cascade of a synchronized production line. Production factors have to be taken into account on different aggregation levels.

The key objective of planning is to match market requirements with disposable production factors. In long and mid-term planning the restrictions for production are rigid and limitations of production factors are stated by context-related restrictions.

Charges and restrictions have to be adjusted to avoid conflicts as bottlenecks or under-utilization of the production factors. Planning starts with a market analysis. Next, an annual budget planning results in sales forecasts, which are continuously updated with a horizon from seven to ten years.

Then sales planning specifies models by main criteria like engines, auto body, gear box, etc. and allocates possible production sites to models and production volumes. The choice of a production site is governed by the location-related costs and local conditions for existing or planned production sites and suppliers. Input factors for production program planning are sales projections, installation rates and production numbers. Restrictions are i.e. minimum line load resulting from the model mix, the capacity of plants with regard to working hours, technical solutions and potential bottlenecks.

Production program planning is usually done on a continuous basis. Order allocation to weeks, days or shifts is called "slotting". At this point usually planned or real customer orders have been placed. Often, orders in daily or weekly order pools are not fully specified; so-called "dummy orders". If a real order is placed, an eligible dummy order is replaced and hence will turn into a fully specified customer order [4].

By moving orders within the sequence taking restrictions (i.e. capacity, material,) into account the production capacity is balanced. Planning and slotting is continued until the sequence is "frozen", which means that the sequence assigns a decided production cycle to each order from the order pool [5].

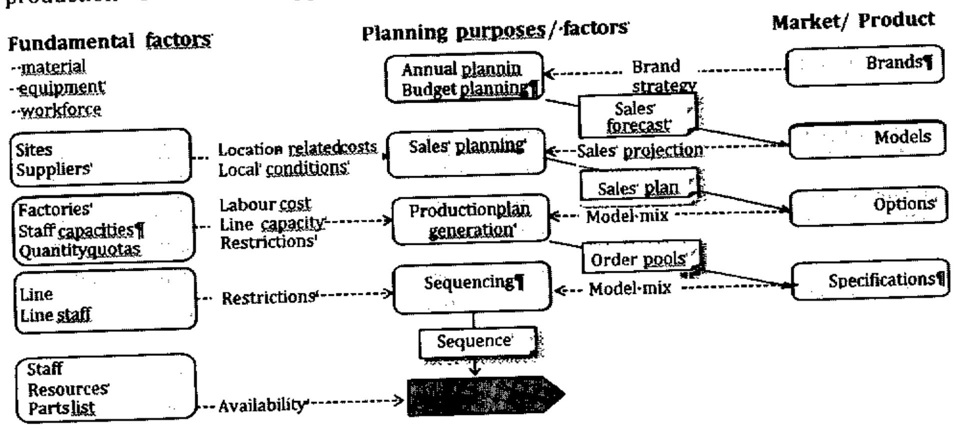


FIGURE 2 PLANNING TASKS AND INTERRELATIONSHIPS WITH FUNDAMENTAL FACTORS, PRODUCT AND MARKET





## 3. Planning restrictions

Production planning matches required capacities for a production program with the fundamental factors of production (workforce, equipment, material). The uncertainty of the requirements increases with the planning horizon. In the early planning steps (sales planning) only planned quantities and no real customer orders exist. These quantities are based on sales volumes of the last and forecasts for the next periods and are orders are specified by main items (engine, body design, etc.). In short term planning the sequencing requires fully specified orders. These orders have a delivery date and a dedicated customer (build-to-order) or a dealer or market allocation (build-to-stock).

To achieve valid and consistent results over the planning cascade exact information about capacity limits and required capacities for each period is necessary. Basic planning data are also called constraints, if it limits the solution space by excluding certain events or sequences of events. Dangelmaier distinguishes between inherent constraints and task related constraints [6]. Inherent constraints are balancing equations or conditions valid for the entire production system. Task related constraints denote technical, organizational and economic characteristics of the production system. This paper focuses on task related constraints that are relevant in every planning step of sequenced assembly lines. Hence, the originators of planning constraints are classified within five groups: equipment, workforce, material, product and market. These five groups build the branches of the Ishikawa-diagram in Fig. 3. The top three branches depict the fundamental factors in describing the production system and are essential to achieve the required output:

- Equipment
- Workforce
- Inventory

The output of the production system is described by the branch product. It defines which brands, models and types are available and how those can be configured. The market branch – represents customers and their requirements as well as the outbound logistics, which became more important as minimization of transport is in focus [7]. For a better understanding, the constraints are illustrated with factual examples:

**Equipment:** The manipulator that is used to mount the front windshield of a vehicle has a constant cycle time of 90 seconds, limiting the overall cycle time of the assembly line to 90 seconds. The according constraint defines the number of vehicles that can be assembled per shift, day, week or month by multiplying the cycle time with the available working hours.

**Workforce:** A station to mount an electric sunroof is normally staffed with three persons to cope with a common production program. In spring and summer, when sunroofs are ordered more frequently, it might be necessary to loosen the restriction and opt for an additional worker.

**Inventory:** If every vehicle produced requires a certain part and the part supplier has a maximum capacity of 500 parts per week, the output of cars is also limited to 500 per week.

**Product:** Constraints on the product level mainly depend on the product structure and the interdependencies of possible options that can be ordered. In truck manufacturing the speed of the assembly line in combination with the truck length results in a cycle time and the number of three and four axle trucks in an order pool limit the number of trucks that can be produced.

**Market:** A British market survey resulted in an increased sales forecast for right hand drive vehicles in the next period with 600 vehicles per month. This setting as a strategic decision limits the number of left hand driven vehicles directly.

Constraints can be defined as absolute or relative constraints [6]. Absolute constraints are quantity or time constraints. A quantity constraint has a variable quantity and fixed time period (e.g. capacity 900 parts/week).

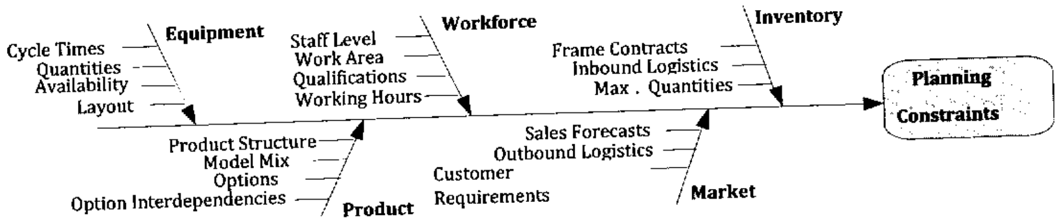


FIG. 3: ORIGINATORS OF PLANNING CONSTRAI

Time constraints have fixed quantities and a variable time period (e.g. product carrier has a capacity of 10 parts and will be shipped when full). Relative constraints are characterized by a combination of at least two events. Such constraints are, e.g., sequence or distance constraints. A sequence constraint prohibits, i.e., that a white car body is succeeded by a black in the paint shop. A distance constraint can define that there are three cycles required until the same option is allowed to be assembled again. Relative constraints are mainly relevant in short-term planning (sequencing). In long- and mid-term planning the relative constraints have to be translated to quantity or time constraints.

The limit of a constraint can also be flexible, which are called "soft constraints". An example for a soft restriction is a weekly delivery lot size of a supplier that can be exceeded under special circumstances. Other restrictions that are often caused by technological limitations cannot be violated and are dubbed "hard constraints". For the execution of the different planning tasks it is important to note that soft restrictions can turn into hard restrictions and that the limit is not necessarily constant during all planning steps.





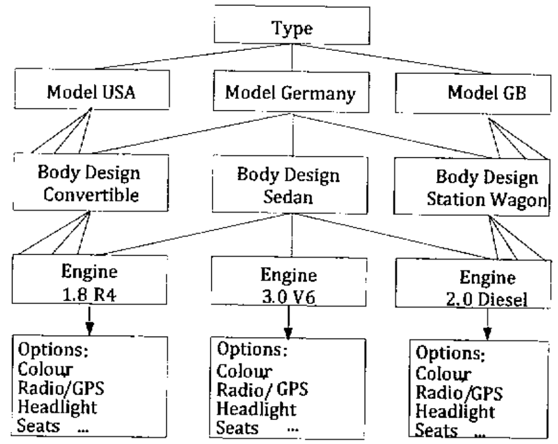


FIGURE 4
EXAMPLE OF A PRODUCT STRUCTURE [8]

### Product structure

The generic planning model described above 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 and operational) and horizons (e.g. short-term, mid-term, long-term). The different planning tasks have to deal with various planning objects such as numbers of vehicles per type or model in sales planning.

For a shorter planning horizon the level of detail needs to be increased and hence other planning objects are relevant [4]. The planning objects are mapped in the product structure in Fig. 4. The product structure allows the definition of each possible car configuration for the overall type of vehicle. To determine material requirements at a time when no or not enough customer orders exist, every branch in the product structure has a expected percentage distribution. In combination with the planned amount of vehicles for a defined period and coding rules that describe the interdependencies of the different options the material requirements can be determined [9]. Subsequently, an example for the coding rule for the part number "heavy battery" is described.

- Option start-stop (O1)
- Option independent vehicle heater (O2)
- Option high-level audio/ video system (O3)

A heavy battery is required if a start-stop system or (v) the combination of vehicle heater and (^) high-level entertainment system are ordered. Below the notation of the rule: O1 v (O2 ^ O3)

For each part number in the bill of materials (BOM) such a rule-based installation logic exists. Another option is a hierarchical BOM, where every single product is documented.

After all material requirements are calculated, the aggregate material demand has to be aligned with existing capacities. Hence all constraints identified need to be mapped according to the described product structure. A constraint can affect a single part number and the combined rule or it might to be associated to another level of the product structure (e.g. body design level).

## 4. Approach for harmonised planning

The goal of the project HarmoPlan is to develop a planning system that supports harmonised planning throughout the different levels. A major concern are shifting responsibilities and various levels of abstraction along the planning cascade (i.e. *sales* plans on the level of number of cars to meet market requirements, production planning is dealing with planning objects as specific car configurations or bills of material to utilise production capacities). A problem is the resulting complexity of the planning problem in a tool that harmonises long-, mid- to short-term planning. Hence, the chosen approach should show a realizable solution to convert planning constraints for use in each planning task.

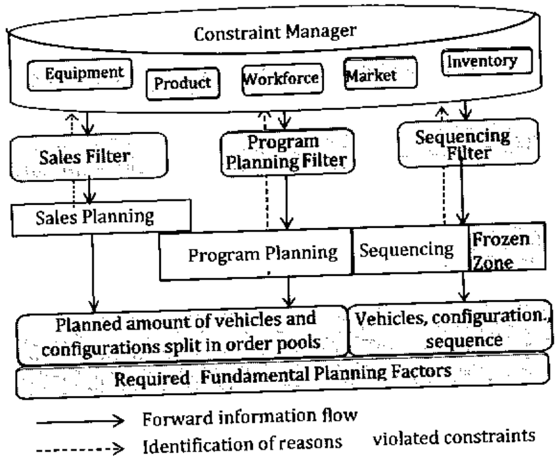


FIGURE 5
PROPOSED PLANNING APPROACH

As every single planning step deals with various input data depending on the planning horizon the planned quantities are presented as monthly, weekly and daily volumes or order pools in long- and mid-term or as order sequences in short-term planning. To align existing capacities with customer requirements and to identify bottlenecks as early as possible constraints need to be defined for each planning step and each required configuration. Thus, the constraints caused by the earlier described originators are stored with the so called "constraint manager". The manager collects the constraints and stores them in a standardized format and it is important that the reason for each constraint is traced within the database. If a planning task has to be executed, a filter pulls the relevant constraints out of the constraint manager. 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. Fig. 5 shows the concept of the planning workflow that will be covered within one planning tool.

Its function is described in the example below: Two different vehicle types (A and B) are assembled on the same line. Monthly capacity (4 weeks, 20 working days) of the line is 1600 cars. This allows weekly order pools of 400 vehicles and a daily output of 80 cars. This shows how one constraint that is related to a single part no. (part01) is cast to different planning horizons and tasks. Part01 has one dedicated relative distance constraint with a echnological reason from its assembly station stating, that just every fourth car is allowed to contain part01, e.g. an engine with intensive mounting time. Fig. 6 and 7 show the product structure of the vehicle types including their percentage distributions.





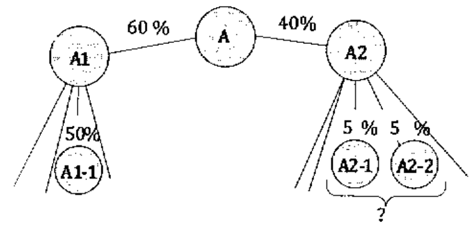


FIGURE 6
PRODUCT STRUCTURE AND PERCENTUAL DISTRIBUTIONS OF VEHICLE TYPE A

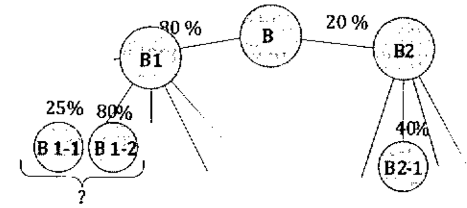


FIGURE 7
PRODUCT STRUCTURE AND PERCENTUAL DISTRIBUTIONS OF VEHICLE TYPE B

Each vehicle type has two different models and three options that are relevant for the part no. in question. If a coding rule is true, one piece of part01 needs to be assembled. The plan derived from the market forecast states, that for one week 100 vehicles of type A and 300 vehicles of type B need to be assembled. Table 1 shows the calculation of required quantities for part01 according to the assigned distributions: Assuming B1-1 and B1-2 as well as A2-1 and A2-2 are independent, the sum of part01 in the relevant week for all models (A1: 30, A2: 10, B1: 48, B2: 24) is 112. Considering the original dependency of the options, other demands may result. If A2-1 is 50% and A2-2 is 50%, that (A2-1 ^ A2-2) can be between 0% (mutually exclusive options) and 50% (interdependent options). Next, the amount calculated is matched with constraints regarding part01. The relative distance constraint cannot be directly applied to the sales planning horizon. It has to be altered into a quantity constraint, as the relative distance constraint can just be used for planning the order sequence. In this case, sales planning does not deal with order sequences but order pools on a weekly basis. The translation of the relative distance constraint that states that every fourth vehicle is allowed to contain part01, into a daily quantity constraint means that out of the 80 possible cars per day just 20 can contain part01. For five working days per week the maximum weekly quantity is 100 parts. The result of a comparison of planned (112 pieces) and actual data (max. 100 pieces) shows a gap of 12 vehicles that can't be equipped with part01. The planner has now the option to identify the reason for the constraint and try to open the bottleneck. If not possible, the impact on the production program can be gauged and i.e. sales can attempt to promote other options so bottlenecks won't occur.

TABLE 1

| Type | | Model | | Coding rules for part01 | |
|---|---|---|---|---|---|
| A | | A1 | 60 pcs. | A1-1 | 60 x 0.5 = 30 pcs. |
| | | A2 | 40 pcs. | A2-1 ? A2-2 | 40 x 0.5 x 0.5 = 10 pcs. |
| B | 300 pcs. | B1 | 240 pcs. | B1-1 ? B1-2 | 240 x 0.25 x 0.8 = 48 pcs. |
| | | B2 | 60 pcs. | B2-1 | 60 x 0.4 = 24 pcs. |

DETERMINATION OF REQUIRED PARTS

## 5. Outlook

To reach the goal of a harmonised planning process and to abrogate the planning cascade from long- and mid-term to short-term planning all relevant constraints have to be available for each planning task in the required dimension.

In order to collect all required factors that influence the available and required capacity their originators can be classified in five groups:

- equipment
- workforce
- inventory
- product
- market

Planning restrictions from each group can be defined as absolute or relative constraints. To have the constraints available, for each planning task they are stored in an overall constraint management database in a standardized format. The realization of an integrated planning tool can help to realise the following potentials:

- A harmonised planning process that reduces friction between different departments
- A common data set without redundancies
- Early detection of bottlenecks and ability to reference to causes, resulting in a reduction of expensive troubleshooting
- Validation of the production program in each planning horizon and task
- Constraints based on common planning language for interdepartmental planning
- Detection of objects in product structure causing bottlenecks and setting of adequate measures in re-planning

Based on the methodology described in this paper, system specifications and the conceptual design of the envisaged planning tool are derived. For an extensive testing phase and in order to secure the viability of the approach an experimental setup of the solution is developed in cooperation with industrial partners.

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