Proceedings of DET2011
7th International Conference on Digital Enterprise Technology
Athens, Greece
28-30 September 2011

BEYOND THE PLANNING CASCADE: HARMONISED PLANNING IN VEHICLE PRODUCTION

S. Auer
Fraunhofer Austria Research GmbH
Fraunhofer Project Center for Production Management and Informatics at SZTAKI
Stefan.Auer@fraunhofer.at l

W. Mayrhofer
Fraunhofer Austria Research GmbH
Vienna University of Technology
Fraunhofer Project Center for Production Management and Informatics at SZTAKI
Walter.Mayrhofer@fraunhofer.at

W. Sihn
Fraunhofer Austria Research GmbH
Vienna University of Technology
Fraunhofer Project Center for Production Management and Informatics at SZTAKI
Wilfried.Sihn@fraunhofer.at

ABSTRACT

Medium-term sales and operations and medium to short-term production planning in the automotive industry often employ cascading planning processes. One of the shortcomings of cascading planning is the lack of coordination and feedback between different planning phases. Costly problems in production due to unfeasible production programs and necessary troubleshooting are often caused by unavailable resources or limited supplier capacities, because these restrictions of subsequent levels weren't discovered during the long-term planning. The establishment of a system for the classification of planning restrictions and their originators is the main topic of this paper. In addition, it will highlight the connection between single planning tasks and the correlation of restrictions between different planning horizons. Finally, an experimental setup for implementation approach for such a harmonized system will be presented.

KEYWORDS

Sequencing, Constraint Programming, Integrated Planning, Harmonised Planning

1. THE PERILS OF CASCADING PLANNING

In the automotive and other industrial sectors various systems for planning sales, purchasing, production and supply chain management are used. Those systems are often poorly harmonised, and in extreme cases, incompatible. Rivalling requests for scope, planning horizons, interest spheres, functionalities and organisational structure are frequently observed results of those shortcomings. None of the currently available "bill of material based" planning systems with sequencing capabilities supports planning throughout the different planning and organisational levels.

Experience from industry shows that the planning function often is congruent with the organisational structure, i.e. sales planning is done by the sales department and production planning is performed by the production or logistics department. Such a separated approach to planning seems reasonable, since departments are considering different levels of abstraction for their planning, i.e. the sales department plans overall car numbers and possible combination of the different product versions, while production planning deals with real customer orders and subsequently with specific configurations. However, this segmented planning approach causes inefficiencies that are also reflected in a fragmented planning systems landscape that are in operation.

As the negotiations with and selection of suppliers require forecasts of the production output generated from sales plans at an early stage, the function of supply chain planning often placed between sales and production planning. In order to identify cumulated material and part requirements, detailed forecasts about vehicle configurations and demands per part number are required.

Generally, the tools used in those planning processes allow for the integration of known restrictions into the planning model. However, only major constraints are recognized and less prominent impediments are only discovered by chance or the skill of an experienced planner. Small changes of the planning criteria, i.e., the sales department overestimates the number of vehicles to be sold are compensated by the adapting internal or external capacities to make production possible. At the moment, such changes are conducted manually across all hierarchical planning levels, which is tedious and fault-prone. The resulting complexity and data volume generated by the breakdown of the bill of material is not supported by most of the planning solutions for the long- and medium-term.

The development of an integrated planning approach as the basis of a software tool that harmonises the planning tasks over the different planning horizons is subject of an ongoing research project called HarmoPlan. This paper will present the groundwork for the integrated planning approach that is based on a classification of the origins of planning constraints and the resulting software tool to bridge the usually employed planning cascade.

2 PRODUCTION FACTORS AND THE SEQUENCING OF 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 differentiated. The key to a firm's success is the harmonisation of its production factors.

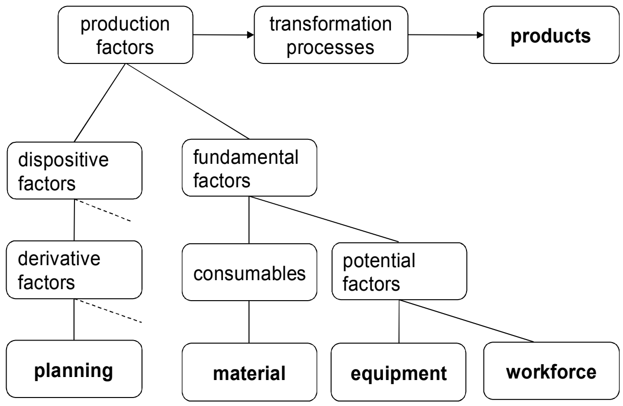

Figure 1 – Production factors (Gutenberg, 1983)

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 (Kis, 2004). The ongoing project, HarmoPlan focuses on the planning process of the final assembly in vehicle and component manufactories where variant flow production with low automation and high labor intensity exists (Boysen et al, 2009).

Figure 2 shows a planning cascade for a synchronized production line. Production factors have an impact on different aggregation levels and therefore have to be taken into account on every level involved.

The key target of planning is to align market requirements with disposable production factors. Production restrictions in long- and mid-term planning are fixed and production factors are limited according to stated context-related restrictions. Tasks and boundaries have to be coordinated to avoid conflicts like bottlenecks on the one hand or under-utilization of the production factors on the other hand.

Usually, a new planning cycle is triggered by a new or updated market analysis. The next step is an annual budget planning, which results in continuously updated sales forecasts, with a horizon from seven to ten years. Subsequently, sales planning specifies models by their main criteria as engines, auto body, gear box, etc. and assigns possible production plants and production volumes to them. Location related costs and conditions of existing or planned production plants and suppliers affect the decision about the production site. Sales projections, installation rates and production numbers are input factors for the production program planning. Examples for planning restrictions are i.e. minimum load of an assembly line resulting from the model mix, the capacity of plants with regard to working hours, technical situation and potential bottlenecks.

Typically production program planning is done on a continous basis. In a sub-process, the so called "slotting", real customer orders are allocated to usually produced quantities per week, day or shift. Orders in daily or weekly order pools are often not fully specified hence called "dummy orders". If a real order is placed, an eligible dummy order is replaced by a fully specified customer order (März et al, 2010).

The production capacity is balanced by moving orders up or down the planning sequence, in order to take restrictions (i.e. capacity, material,) into account. Planning and slotting is continued up to a certain point in time, where the sequence is "frozen", which means that the sequence assigns a decided production cycle to each order from the order pool (Auer et al, 2010).

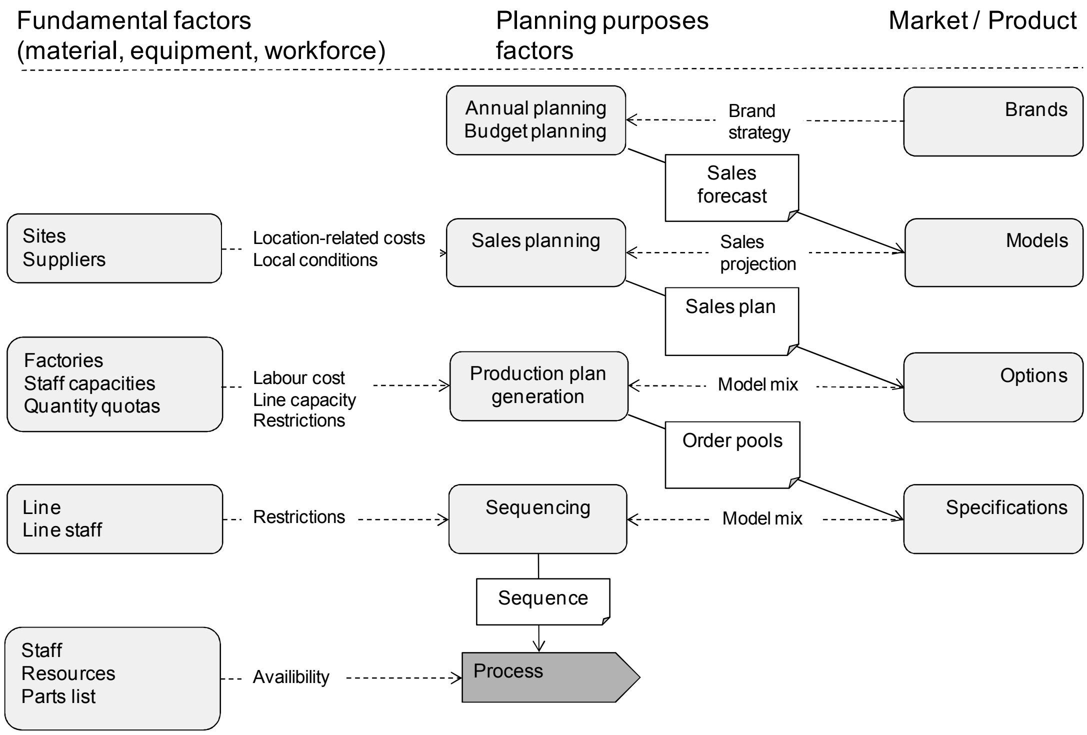

Figure 2 – Planning tasks and interrelationships with fundamental factors, product and market (Auer et al, 2011)

3. PLANNING CONSTRAINTS

Fundamental factors of production (workforce, equipment, material) are adjusted to needed capacities of a production program during the production planning. The uncertainty of the requirements increases with the planning horizon. In the early planning steps (sales planning) only planned quantities, based on sales volumes of the last and forecasts of the next period, which are specified by main items (engine, body, design, etc.) and no real customer orders exist. Whereas sequencing in short term planning requires fully specified orders, which include a delivery date and a dedicated customer (build-to-order) or a dealer or market allocation (build-to-stock).

Accurate information about capacity limitations and required capacities for the existing or planned orders of each period are necessary to realise valid and consistent results across the whole planning cascade. Basic planning data are also dubbed constraints, if solution space is limited by excluding certain events or sequences of events. Dangelmaier distinguishes between "inherent constraints" and "task related constraints" (Dangelmaier, 2009). Inherent constraints are balancing equations or conditions valid for the entire production system. Task related constraints denote technical, organisational and economic characteristics of the production system. This paper focuses on task related constraints, which are relevant for every planning step of sequenced assembly lines. Furthermore originators of planning constraints can be classified into five different groups:

- Equipment,
- Workforce
- Material
- Product
- Market.

These groups build the five branches of the Ishikawa-diagram in Figure 3. The diagram shows the fundamental factors to describe a production system, which are essential to ensure the needed output, at the uppermost three branches:

- Equipment
- Workforce
- Inventory

The output of the production system is presented by the branch "product", that defines which brands, models and types are available and how they can be configured. The "market" branch represents customer demands and needs as well as the outbound logistics, which became more important as minimization of transport is in focus (Bong, 2002). For a better understanding, the constraints are illustrated with factual examples:

Equipment: A manipulator that is used to mount the front left door of a vehicle has a constant cycle time of 120 seconds, limiting the overall cycle time of the assembly line to 120 seconds. The resulting production 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: In order to mount an electric sunroof a station is usually manned with three persons to cope with the workload of a common production program. In spring and summer, when sunroofs are ordered more frequently, it might become 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 different versions 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 driven 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 (Bong, 2002). Absolute constraints are quantity or time constraints. A quantity constraint has a variable quantity and fixed time period (e.g. capacity 900 parts/week).

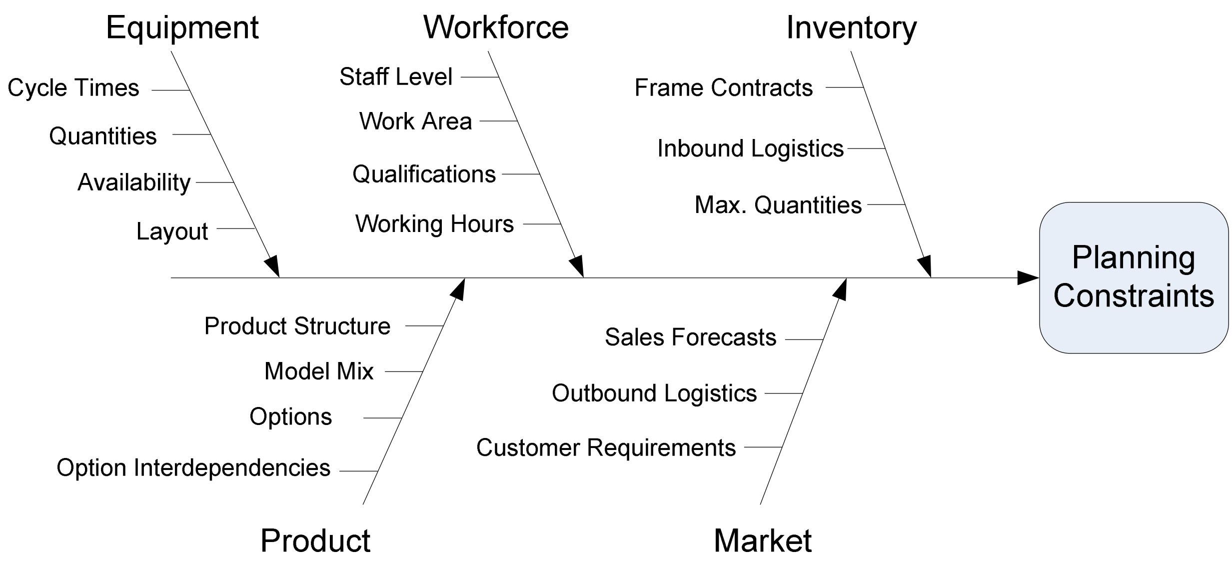

Figure 3 – Originators of planning constraints

Constraints regarding the time have fixed quantities and a variable time period (e.g. a product carrier has a capacity of 10 parts and will be shipped when full). Constraints can also represent a combination of two or more events. Such constraints are called relative constraints, e.g., sequence or distance constraints. Sequence constraints prohibit for example inefficient vehicle colour orders in the paint shop, i.e., that a white car body is succeeded by a black one. Distance constraints can set the minimum number of repetitions of a cycle, so that there are three cycles required until the same option is allowed to be assembled again. These constraints are particularly relevant in short-term planning (sequencing) and have to be reinterpreted in means of quantity or time constraints.

The boundary, presented by a constraint, can also be flexible, i.e. a weekly delivery lot size of a supplier, which can be adapted under special circumstances. These restriction are called "soft constraints", whilst restriction which are caused by technological limitations cannot be violated and are denoted as "hard constraints". During the implementation of the planning tasks it is important to take into account, that soft restrictions can turn into hard constraints and that the boundaries are not necessarily constant across all planning steps.

4. PRODUCT STRUCTURE

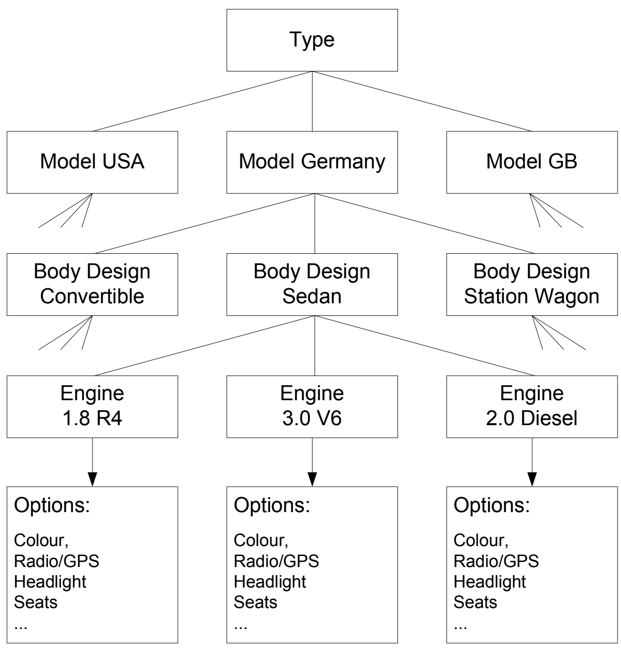

Figure 4 – Example of product structure (Wagenitz, 2007)

The generic planning model mentioned above was developed to balance the actual theoretical thinking with common practices of the European automotive industry (OEMs of passenger cars and trucks). 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) within this model. Every planning task has to deal with various different planning objects such as numbers of vehicles per type or model in sales planning.

Observing a shorter planning horizon the data needs to be more detailed, thence other planning objects are relevant (März et al, 2010). Figure 4 shows the relevant planning objects within the product structure, which allows the planner to derive a specific definition of each possible car configuration out of the different types of vehicles. The main level defines the different model versions. Each version can further be customized with the addition or removal of optional components (Michalos et al, 2010).

To simulate a possible demand situation for required materials at an early time, when no or not enough customer orders exist to perform a planning only based on real customer orders, an estimated percentage distribution is assigned to every branch in the product structure. The material requirements can be calculated with the help of a combination of the determined quantities of material, the planned amount of vehicles to be produced within a certain period and coding rules, which describe the interrelations of different versions (Sinz, 2003). An example for the coding rule for the part number "heavy battery" is given below.

- 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 (∨) the combination of vehicle heater and (^) high-level entertainment system are ordered. Below the notation of the rule:

$$O1 \vee (O2 \wedge O3)$$

A rule-based installation logic exists for each part number in the bill of materials (BOM). Moreover a hierarchical BOM, where every single product is documented, could be a possibility to organise such a logic coding.

The accumulated demand of materials has to be harmonised with existing capacities after the demand calculation. Subsequently the identified constraints need to be mapped according to the described product structure. Constraints can influence a single part number and the combined rule or it might be affecting another level of the product structure (e.g. body design level).

5. A NEW APPROACH FOR HARMONISED PLANNING

The development of a planning system, which supports a harmonised planning across all different levels, is the objective of the project HarmoPlan. Central issues of the research project are shifting responsibilities and different levels of abstraction along the planning cascade (i.e. the sales department plans based on the number of cars to meet market requirements, whereas production planning concentrates on planning objects like specific car configurations or lists of parts to charge the existing production facilities to capacity). The resulting complexity of the planning problem is an issue for a tool that harmonises long-, mid- to short-term planning. Therefore, the chosen approach should provide a marketable solution to implement planning constraints in each planning task.

The established quantities are represented as monthly, weekly and daily volumes or order pools in long- and mid-term planning or as order sequences in short-term planning. The different planning steps are influenced by various input data, which are contingent upon the respective planning horizons. It is important to detect appropriate constraints for each planning step and each possible configuration in order to align existing capacities with customer requirements and moreover to identify shortages at an early stage. Thus, constraints engendered by earlier described originators are saved in the so called "constraint manager", which collects the constraints and stores them in a standardised format.

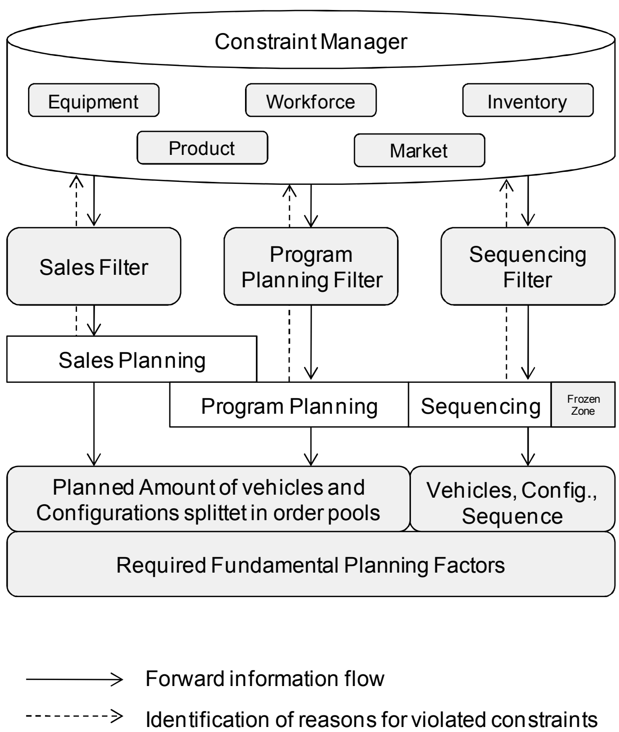

Figure 5 – Proposed planning approach

The most important attribute of the constraint manager is the traceability of the originator of each constraint within the database. If a planning task has to be conducted, a filter extracts the relevant constraints from the constraint manager. If a boundary is exceeded the planner needs to identify the reason, in order to set possible measures to widen the bottleneck – or to solve the problem by re-planning the process regarding the critical constraints. The concept of the planning workflow, which will be covered by one planning tool, is shown in Figure 5.

6. IMPLEMENTATION APPROACH

The target of the ongoing research project Harmoplan is the realisation of an executable prototype based on the planning approach described above. This includes suitable interfaces with a state of the art ERP system.

In order to develop the software solution according to the needs of the future customers, it was planned from the beginning to develop the solution together with an industrial application partner. Possible application partners are companies which produce their products on sequenced assembly lines. This logically leads to the major OEMs from the automotive industry. However, since organisational structures at the OEMs known to the project consortium are not conducive for the implementation of a prototype, a company from the special vehicle industry was chosen. This company produces vehicles on various international sites and faces the problems that are expected to be solved by the proposed solution.

In this company the planning of quantities for the long, middle and short term planning horizon are performed with the help of Excel-solutions. The variant part lists were stored in the existing ERP-system. In order to be able to generate the required information concerning quantities and dates for purchased parts and assembly groups, orders are stored within the system too, whereas scheduling is exclusively performed with the mentioned Excel-solutions. The sequencing of the single lines is enabled mainly due to the experience of every single planner. A rough set of standard rules exists. However, those rules do cover the constraints only on a very rough level.

Permanently increasing numbers of parts, variants and additional options produce a considerable complexity of the planning problem along the process chain and beyond all planning horizons. This makes it nearly impossible for the employees to oversee the interdependencies of decisions between the different planning tasks. For this reason capacity overloads are often detected late and a mutual basis to exchange information within different departments does not exist.

The initial situation found in this company is ideal to implement a prototype of the planning system and enables a step by step implementation of the concept. The procedure used to analyse the processes and establish the prototype is described below:

In order to map all business processes it‘s essential to collect data about all information flows (manual and automated). Therefore a so called Function and Dataflow Chart (FDC) (Dürr, 2009) is used. The advantage of a FDC is its suitability for daily use and its easy application. The following figure shows a simplified example of a FDC.

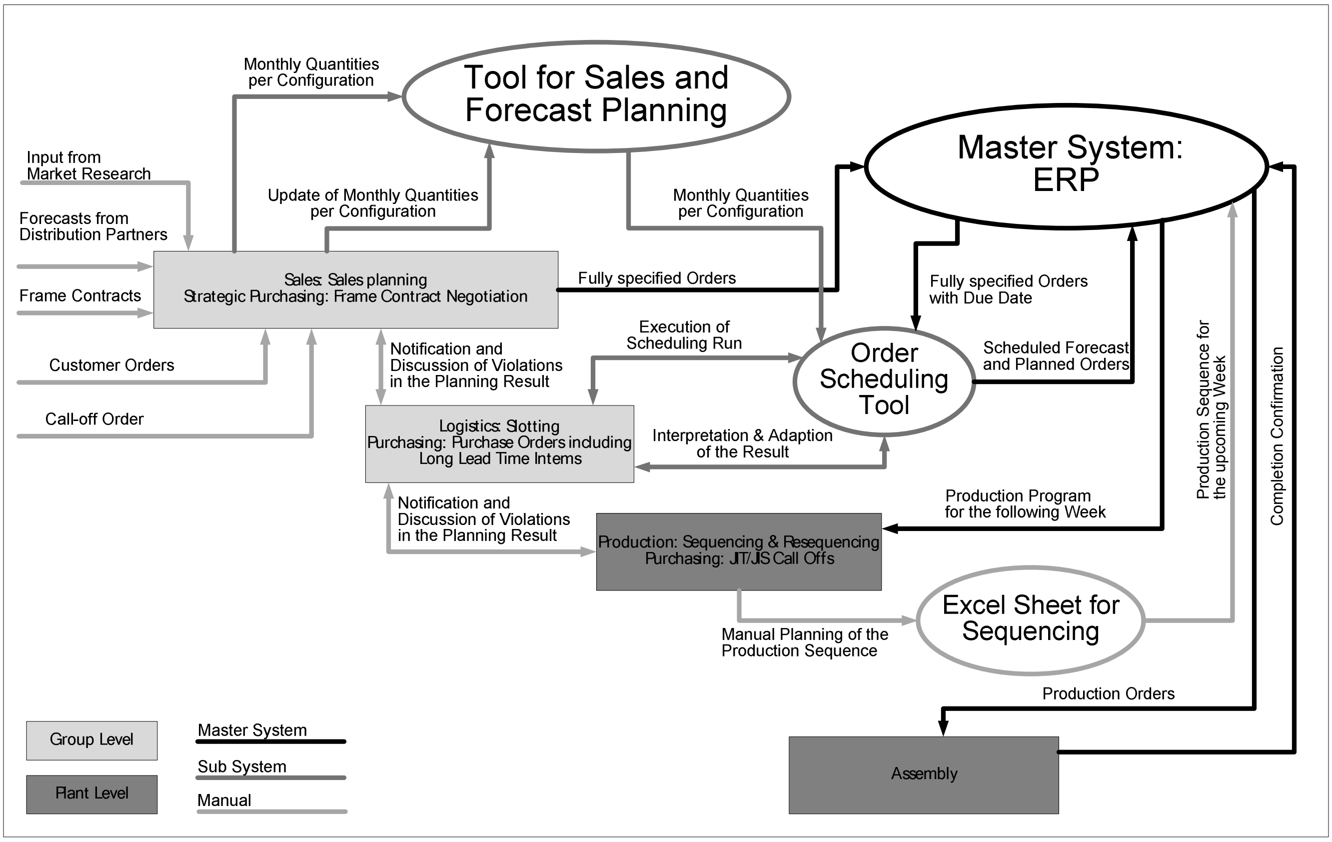

Figure 6 – Function and Dataflow Chart (FDC) of the implementation

In addition to the process mapping the analysis of data and data structure is needed. This includes the following topics:

- Product structure
- Part lists structure
- Options
- Code rules
- Building rates of different options
- Existing sequencing rules

This concept of the future planning processes can be adapted to the needs of the different departments and to the planning tasks within different planning horizons. As mentioned before, this is done best by means of generic planning processes.

Provision are made for a step-by-step implementation of the planning solution. A critical point for the success of the implementation is the right modelling of the sequencing tool and the according restrictions. That is the reason that the implementation starts with the short term planning and the solutions will be extended to the other planning horizons step-by-step in order to finally cover the whole “planning chain” with one solution.

7. CONCLUSIONS

In order to obtain the goal of a harmonised planning process and to harmonize 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. For the purpose of collecting 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. In order to have the constraints easily available, for each planning task the constraints 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 potential:

- 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. Due to the high complexity of the combined planning problem future work needs to focus on efficient solving algorithms that support well founded and prompt decisions of the planning personnel. From a technical point of view one of the key problems will be interoperability and necessary interfaces between the ERP systems and the tool to be developed. 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.

REFERENCES

Auer S., Winterer T., Mayrhofer W., März L., Sihn W., „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, Vienna, 2010, p 900-908

Auer S., März L., Tutsch, H., Sihn W., Classification of interdependent planning restrictions and their various impacts on long-, mid- and short term planning of high variety production", Proceedings: 44th CIRP Conference on Manufacturing Systems in Madison, Wisconsin, 2011

Bong H.-B., "The Lean Concept or how to adopt production system philosophies to vehicle logistics", *Survey on Vehicle Logistics*, ECG – The Association of Vehicle Logistics, Brussels, 2002, p 321-324

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

Dangelmaier W., "Theorie der Produktionsplanung und Steuerung", Springer, Germany, 2010

Dürr P., Fröhlich, T., „Optimierung der IT-Struktur im Auftragsabwicklungsprozess von kleinen und mittleren Unternehmen", *Industriemanagement*, Vol. 3/, 2009, p 61-64

Gutenberg E., „Grundlager der Betriebswirtschaftslehre", Springer, Germany, 1983

Kis T., „On the complexity of the car sequencing problem", *Operations Research Letters*, Vol. 32/4, 2004, p 331-335

März L., Tutsch H., Auer S., Sihn W., „Integrated Production Program and Human Resource Allocation Planning of Sequenced Production Lines with Simulated Assessment", Dangelmaier, W., et al, *Advanced Manufacturing and sustainable Logistics*, Springer, Germany, 2010, p 408-419

Michalos G., Makris S., Papakostas N., Mourtzis D., Chryssolouris G., "Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach, CIRP Journal of Manufacturing Science and Technology 2, 2010, p 81-91

Sinz C., "Verifikation regelbasierter Konfigurationssysteme", Fakultät für Informations- u. Kognitionswissenschaften der Eberhard-Karls-Universität, Tübingen, 2003

Wagenitz A., "Modellierungsmethode zur Auftragsabwicklung in der Automobilindustrie", Düsseldorf, 2007

.