Supply Chain Planning with Advanced Planning Systems

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Abstract: In the last years several software vendors such as I2, Manugistics, SAP and others have started to develop and sell so-called Advanced Planning Systems (APS). They claim to support the integrated, capacity-focused and optimal planning of operations in complex global supply chains. For a practical planner it is often not clear, what these APS really do, as the specific type of planning model and the solution algorithm used to solve a practical problem in general are not transparent. In this paper, we try to look behind the curtain of white papers published by software vendors. We analyze the principal structure of a typical APS. Based on a theoretical framework for supply chain optimization, we show which type of planning problem is currently supported by APS and which solutions are still missing.

Keywords: Supply Chain Optimization, Advanced Planning Systems, Hierarchical Production Planning

Introduction

Driven by the developments in information technology, internet and globalization, production planning and control procedures used in industry are subject to dramatic changes. Many companies have recognized that the currently used MRP II philosophy does not support planning in the sense that the capacities of the resources are adequately considered during the planning process. It is now common sense that ignorance with respect to capacity results in high work-in-process combined with decreasing service-levels and long customer waiting times. In addition, in highly integrated supply networks with small “slack” insufficient planning procedures become more evident than in non-integrated logistic networks. Being considered as waste, safety stock and safety time are reduced to a minimum. Generating feasible plans under these conditions is a real challenge for a planning system. However, feasibility is only achievable, if planning is based on a realistic modelling of the logistic processes that reflects the key factors having an impact on the system's performance.

Software vendors such as I2, Manugistics, J. D. Edwards, Fygir, SAP, and others are now marketing software-based solution procedures for many planning scenarios that were unsolvable in the past. Furthermore, it has become common understanding that the transactional-data based ERP/MRP systems must be enhanced through the addition of a structured set of dynamic planning data which is tightly integrated with the transactional data base. Only with up-to-date planning data available there will be a chance to develop feasible plans.

Considering early promotional publications distributed by software vendors, it appears that the structure of these so-called Advanced Planning Systems (APS) has developped historically with a two-dimensional view of planning as depicted in figure 1, one dimension being the business function involved and the other dimension being the planning horizon [see Stadtler and Kilger (2000)].

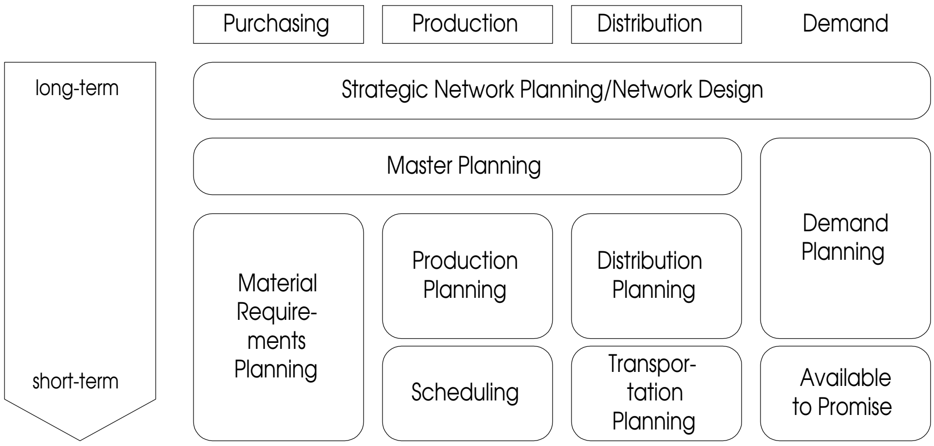

Figure 1: Functional and time-oriented view of planning in APS

This planning structure, which seems to be the basis for most of the APS, has several drawbacks.

1. The multi-location-based structure of the planning system is not visible.

2. The problems treated by the different planning modules are not clearly differentiated with respect to the type of production and logistics system considered. However, it is known that the planning problems faced by, say, a metal parts manufacturer producing with small lot sizes in a job-shop environment are different from the planning problems of a manufacturer who uses a fixed-position layout and project-oriented production processes. This difference must also be reflected by the planning models used to support decision making.

3. Material requirements calculations (MRP) are assigned to the short-term planning phase of the purchasing function. Obviously, MRP is not confined to purchasing. Even classical ERP systems associate material requirements planning with the production function. Developpers of APS seemingly are not aware of the problems inherent in the classical MRP approach. Therefore, APS do not replace the MRP planning phase with a better solution approach, but they still rely on the classical MRP calculations. Allthough it is well-known, that the generation of feasible production plans requires an integrated view of lot sizing and material requirements planning, this problem is still completely neglected.

4. Roughly speaking, the planning problems emerging in a supply chain environment can be assigned to three layers: network design, node design, and operational planning.

   Network design is part of a company's strategic planning activities, which are concerned with defining the long-term objectives and the principal course of actions required to meet these objectives. This includes the building of strategic alliances with key suppliers (and key customers) as well as the definition of the locations of all nodes making up a supply (and delivery) network.

   Node design problems refer to the design of the infrastructure that must exist within a node in order to ensure the node's functionality within the supply network. For a production node (factory) the overall layout as well as the size (capacities) of the different production departments (e. g. flow lines, FMS, job shops) must be defined. Most of these node design problems are currently not supported by the APS available on the market. Therefore the corresponding layer is not depicted in figure 1.

   Operational planning problems are concerned with the efficient performance of the detailed processes in a supply network. In this planning layer, which is the main application domain of APS, decisions concerning order fulfillment and resource utilizations are made. In other words, operative production planning is confined to the economical usage of the resources under the constraint, that their capacity is more or less given.

5. The module "Demand planning" is assigned to the same (hierarchical) planning level as the other planning functions. Obviously, forecasting (which is the same as demand planning) is not planning as it is not based on a decision model. The function of demand planning is the generation of input data for the other planning functions. Therefore it does not fit into a matrix with the two dimensions shown.

6. Like forecasting, the module "Available to promise" as currently implemented by the software vendors has nothing to do with planning and does not fit well into the planning matrix. Up to now, it is only a data collecting function supporting several other functional areas in a company, e.g. the marketing department. From a more fundamental point of view, the complete column entitled "Demand" should be placed outside the body of the figure in a supporting module.

7. Transportation planning is assigned to the short-term planning part of the distribution function. However, especially in global supply networks many operational transportation tasks have to be planned and performed with tight integration with the supply and production function. It is a specific characteristic of supply chain optimization that purchasing and production decisions are made simultaneously with the corresponding transportation decisions.

In addition, planning is based on a *deterministic view* of the problems to be solved. Stochastic aspects are not or only insufficiently taken into account. As to our knowledge, currently the only stochastic aspect considered is the calculation of safety stocks. This calculation is taking a rather simple perspective of uncertainty which is basically the same as in the standard MRP systems. In addition, it is often assigned exclusively to the distribution function or the demand planning function. Uncertainties caused by breakdowns of resources and due to the variability of processing times and flow times are not handled at all.

From the planning structure described so far, for an industrial planner as a prospective user of an APS it will be difficult to locate his specific planning requirements within a systematical concept for supply chain planning.

A Hierarchical Planning Structure for Supply Chain Planning

An empirical analysis of real-life production systems reveals many characteristics which have a significant impact on the type of planning models that may be applicable in a specific decision making environment. In business practice one will observe different layout types, e.g. fixed position layout, process layout (job shop production), product layout (flow lines), JIT production systems, cellular layout, among others.

In each type of production system (layout) specific planning problems arise. For example, it is well-known that in a job shop production, where setup times are relevant, the so-called multi-level capacitated dynamic lot sizing problem (MLCLSP) must be solved. This problem is also the core of the MRP calculations. Unfortunately, standard MRP overemphasizes the easy demand explosion part of the problem and nearly completely neglects the difficult lot sizing part. This is one of the reasons that make the standard MRP approach fail. In a different layout, e. g. several production stages arranged on a line producing several different products with significant setup times, the so-called economic lot scheduling problem (ELSP) or one of its dynamic successors (CSLP, DLSP, PLSP, GLSP) arise requiring different solution techniques than the above-mentioned MLCLSP. As a third example, consider a fixed-position layout where single unit orders are processed with a project structure between components, subassemblies and end products. In this setting a resource-constrained project planning (RCPSP) type of solution approach is adequate.

Mainly with a single factory in mind and focussing only on the deterministic problem aspects, Drexl et al. (1994) propose a hierarchical planning structure for operational planning problems that explicitly emphasizes the above-mentioned matching of the type of a given production system and the associated modelling approach. They define a planning structure with several layers, where for each layer specific planning models are defined. According to the mainstream of POM literature, the **aggregate planning** layer focusses on the general course of action to find a production plan that reflects the dynamic aggregate demand forecasts as well as the cost arising through building up inventory and using overtime and variable workforce levels. The planning horizon is often one year or more. The plan shows the development of the resource requirements and the usage of the resources over time with a mid-term planning horizon. The planner is taking a longer perspective and minimizes the negative effects of short-term variations. The variables and constraints are defined in aggregate units. Caused by the wider perspective and the higher point of view of the problem, the planner should be allocated to a higher level in the production planning hierarchy.

Located immediately below the aggregate level, in the **master production planning level** the specific timing and sizing of production quantities of main products or end products are defined, thereby possibly taking into account the multi-level structure of the production processes. The resulting master production schedule defines the primary demands (for main products) that must be met through production activities. In the standard MRP approach this planning level is also called "Master Production Scheduling" and has up to now mainly been treated without a tailored decision model.

The next planning level considers the specific problems arising in the different production types (segments). Here different types of **lot sizing** problems arise in combination with different segment-specific **scheduling and sequencing** problems. Figure 2 points out the segmented structure of this layer of production planning. This segmentation of problem types and resulting decision models, in addition to the explicit consideration of resource capacities, is a significant difference to the standard MRP approach.

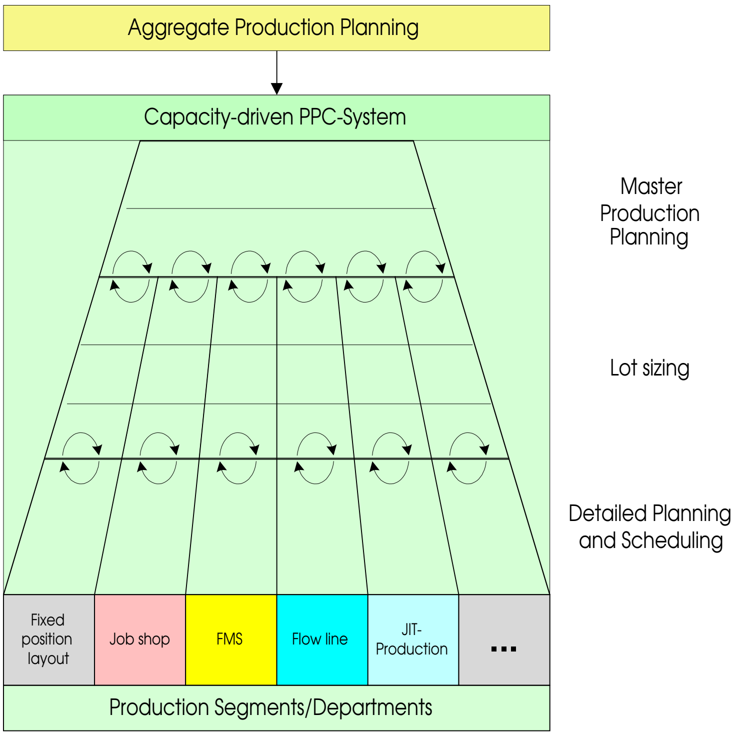

Figure 2: Hierarchical planning structure for a single location

In a **multi-location supply network**, where a company runs several factories, the top layers of the hierarchical planning structure must be designed such that the opportunities arising as a consequence of the multi-location network will be realized. In this case the planning structure shown in figure 2 should be extended with a top layer that provides an integrated view on the network-wide opportunities to satisfy demands through production in different locations, including external suppliers and the resulting transportation issues, as depicted in figure 3.

From an organisational point of view, it must be kept in mind that in each factory there will remain the responsability for the solution of all factory-specific decision problems. These are the segment-specific phases assigned to the lower levels in the planning hierarchy, where lot sizing and scheduling are performed.

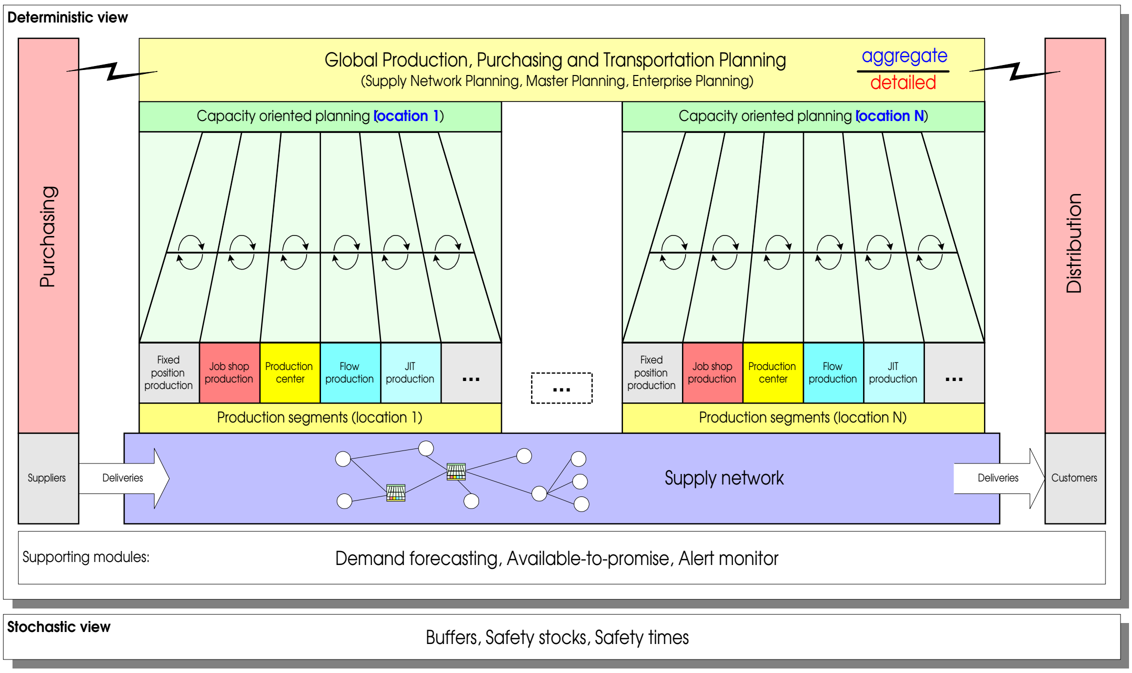

Figure 3: Multi-location based planning structure

Obviously, production planning must be connected with purchasing and distribution planning. New developments in B2B will require a tight integration of operational production and purchasing planning, including automated order sizing and supplier selection. The planning tools must be supported through the demand forecasting function that delivers aggregate as well as detailed forecasts to the different planning levels. Several additional supporting modules may be necessary. For example, due to the increasing availability of information the salesforce may be supported with a function called "Available-to-promise" that enables a system-wide view upon all inventory locations for a specific item demanded by a customer. From a practical point of view, also a controlling function termed "Alert monitor" might be necessary.

All the modules of the planning structure discussed so far mainly have a **deterministic perspective** of the planning problems. However, with respect to the flow of material and information in a supply network, many stochastic influences may be observed. These influences require a treatment with the help of risk-absorbing mechanisms such as safety stocks. The planning of these mechanisms is based on a **stochastic view** of the supply network that is different from the deterministic operational planning. In integrated supply chains, under uncertainty the question arises to which nodes safety stock should be allocated. Here two types of problems may be identified: The primary problem is to find the minimum total safety stock in the supply chain required to guarantee a specified system performance. In order to solve the primary problem, one must be able for any given total safety stock to find the optimal allocation of safety stocks to the different nodes. The answer to these problems depends on the structure of the supply chain and requires modelling techniques different from those currently applied in APS.

APS support of planning in supply networks

As stated earlier, APS have been developed step by step. The early developments were scheduling tools (e.g. Numetrix Schedulex, I2 Factory Planner). The next step was the development of LP model generators to support multi-location und multi-period supply, production, and distribution planning (including transportation facilities).

Master planning, aggregate planning. In contrast to standard POM literature, the available APS do not explicitely differentiate between "aggregate" planning and "master" production scheduling. As both planning layers use the same OR technology, namely linear programming, a typical APS offers the planner a set of tools to generate problem scenarios that may be routinely applied in planning. Based on a sophisticated graphical user interface, the planner can deliberately define locations (customers, plants, suppliers) on a geographical map, assign products to locations, define process structures for the different products, connect locations through transportation links etc. Thereby it is left to the planner to find an adequate level of aggregation or detail that fits into his company's planning environment. Through the selection of the appropriate parameters a specific planning model will be constructed. The modeling features offered to the user comprise a large variety of characteristics, including options such as setup times that may only be modeled with the help of integer variables. The user interacts with the APS via a user-friendly (graphical) interface which allows the selection of the relevant problem characteristics.

In the process of defining a planning model, the planner usually selects only a subset of all possible variables and constraints. If all available problem characteristics would be activated, then the resulting problem instance would probably not be solvable in reasonable time, if at all. Based on the user's selections a model generator builds up the linear programming model which is then solved by a standard LP/MIP-solver or by a heuristic solution procedure, if applicable. It is a dramatic progress compared to former planning practice that it is now routinely possible to develop an optimal master production plan for one or several plants with all opportunities available throughout the whole supply network in mind.

APS-based LP model generation does not require LP modeling or solution knowledge from the planner. This is provided by the model generator and the LP solver. Therefore, a typical planner, which in many cases does not hold a university degree, will be generous in defining variables and "plausible" constraints. However, there is the danger that a planner will tend to abuse the LP/MIP modeling opportunities for detailed scheduling purposes which are not part of master production planning. Another possible modeling trap is the abundant use of discrete variables. It is very easy to generate a problem instance that goes far beyond the capabilities of the MIP solver. For example, often a planner will impose constraints with respect to the minimal production quantity to be produced, if production is scheduled at all. Logical constraints of this type will result in unsolvability even for problem instances of moderate size. This may be an issue that requires some amount of understanding from the planner.

If used by a well-educated planner who is aware of the types of problems that are solvable and which are not, an APS may play a productive role in the network-wide coordination of purchasing, production, transportation and distribution. However, for a non-educated planner frustration may result which may lead him back to the old type of planning, which means making decision based on rules of thumb. Also, a careful assignment of planning competences must be considered as a prerequisite for the successful implementation of APS.

Network design. Following the development of LP-models for operative supply-chain planning it was detected that these models may also be applied to support long-term decisions of the type "Which product type shall be assigned to which factory and how are the resulting transportation flows between the suppliers, factories, distribution centers and key customers or customer agglomerations?" While questions of this kind may be answered based on scenario techniques, where different product-to-plant allocations are defined and the resulting LP model is used to compute the overall costs (this is the way LP models are used by the german car manufacturer BMW), a logical extension would be the formulation of discrete multi-commodity plant location models. These models can be formulated as mixed-integer linear optimization models. Again, as standard MIP solvers are applied, it is not clear whether the specific algorithmic knowledge available for the solution of plant location problems that is documented in hundreds of scientific papers is drawn upon.

Node design. The problem domain of node design, which means developping the infrastructure of a plant is currently almost completely neglected by standard APS. The reason may be that node design problems can also be solved without a tight integration with the transactional data base. It will be a major challenge for researchers to provide standardized planning models and algorithms that fit into the planning structure of an APS for this broad type of problems. Currently, SAP seems to be the only APS vendor that offers a rudimentary support for flow line balancing (called "line design"). However, much is left to be done, as the current procedures implemented are mainly using manual assignments of tasks to a predefined number of stations, whereas from POM textbooks it is known that the number of stations is the result of the optimal workload assignment.

Stochastic performance evaluation of system alternatives, which can be considered as one of the main problem areas of node design, is completely neglected. Therefore this problem domain constitutes a non-developed space on an APS solution map.

Forecasting. As forecasted demands are a necessary input to any production planning model, a forecasting module entitled "Demand planning" is part of most APS. The forecasting procedures supported mainly use exponential smoothing techniques. Therefore one finds standard forecasting procedures as described in many textbooks (single, double, Holt, Winters, Croston). Also linear multiple regression models are supported by several APS.

Scheduling. In the area of production scheduling, research has provided a large number of modeling approaches. In APS, however, it seems that only general-purpose scheduling algorithms (using meta-heuristics such as genetic algorithms) are available. It is not clear, how good these general-purpose algorithms are compared to specialized procedures.

Transportation. Transportation issues are also part of master planning. In the short-term planning environment, mainly vehicle routing is considered as a planning problem. However, this area is a well-developed field with many stand-alone competitors specializing on vehicle routing. Only the seamless integration with the transactional data base will trigger the switching of current vehicle routing software users to APS vehicle routing solutions.

Purchasing. The purchasing function will gain importance with the increasing use of B2B systems. If the human purchaser as a decision maker is replaced by a B2B software solution, then an automated procedure for the order sizing and supplier selection decision is required. A look into the relevant literature on economic order sizing reveals a large gap between models and solution approaches and practical requirements. SAP is currently the only APS vendor who offers its customers a heuristic solution approach to this problem [see Tempelmeier (2000)].

Currently unsolved problems

As the discussion has shown, APS provide a number of solution approaches for several practical problems. However, there are several areas with much work left to be done.

The most disappointing characteristic of APS is that **lot sizing** issues are still handled in an unsatisfactory way. If lot sizing is supported at all, then this is done on the master planning level, where the planner is offered the opportunity to include fixed setup costs in his planning model. However, it is known that standard general-purpose MIP algorithms based on standard modeling approaches will not be able to solve even small lot sizing problem instances. Considering that under the presence of setup times and with scarce capacity the treatment of lot sizing issues plays a central role in the generation of feasible production plans, one may wonder how this planning phase would perform in industrial practice.

As lot sizing is neglected, the production planning phases covered by APS are master planning and detailed scheduling, leaving out a complete planning phase in-between that must be solved in the presence of setup times in order to produce feasible plans. The multilevel computation of derived demands (demand pegging) is completely done in the same way as in the standard MRP approach – neglecting that this is the major reason for the bad performance of MRP. Therefore, the lot sizing and detailed planning phase are an open area of possible improvements. This is true for all production segments, where lot sizing problems arise.

As mentioned above, **node design** is also an open field of unsupported problems. One may expect that APS vendors will try to include standard node design problems, such as assembly line balancing. Problem candidates that are considered for support in an APS, however, must require input data, that can be easily provided by the transactional data base the APS communicates with. If only a small amount of data is required, then the inclusion of these problems into an APS may not be necessary. This will probably be the case for the design of asynchronous flow lines or the design of Flexible Manufacturing Systems (FMS).

Currently it is not clear, which methods are applied to handle the **stochastic** factors in a supply network. In all APS, safety stock computations are supported. The algorithms used, however, seem to be copied from the standard MRP systems.

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