



## ADVANCED PLANNING AND SCHEDULING FOR RESPONSIVE MANUFACTURING SYSTEMS - AN OVERVIEW

V. Mahesh

Dept. of Mechanical Engg  
S.R Engineering College, Warangal  
maheshvutukuru@rediffmail.com

A. Chennakesava Reddy

Dept. of Mechanical Engg  
JNTU, Ananthapur  
dr\_acreddy@yahoo.com

C.S.P Rao

Dept. of Mechanical Engg  
N.I.T, Warangal  
csp\_rao@rediffmail.com

**Abstract:** Materials requirements planning (MRP) and capacity requirement planning (CRP) systems have been gradually developed towards closed loop systems entitled Manufacturing Resource Planning (MRP II), which integrate both materials and capacity requirements. Latest, Enterprise Resource Planning (ERP) and Advanced Planning and Scheduling (APS) systems have improved the integration of materials and capacity planning by use of constraint-based planning and optimisation. Further many ERP and APS systems make it possible to include supplier and customer in the planning procedure and thereby optimise a whole supply chain on a real-time basis. This paper discusses features of APS and its relation to traditional planning systems.

**Keywords:** Material Requirement Planning, Manufacturing Resource Planning, Enterprise Resource Planning, Supply Chain Management.

### 1. INTRODUCTION

Manufacturing companies increasingly are looking to investments in manufacturing software to provide a competitive edge. To get a proper return, understanding underlying technical trends is important. However, it is even more important to understand how well any new manufacturing software solution fits with the company's existing software and overall business strategy. One can then decide to choose the latest evolution of the current software, or to adopt revolutionary new software approaches (Charles).

APS is a new revolutionary step in enterprise and inter-enterprise planning. It is revolutionary, due to the technology and because APS utilises planning and scheduling techniques that consider a wide range of constraints given below to produce an optimised plan:

- Material availability
- Machine and labour capacity
- Customer service level requirements (due dates)
- Inventory safety stock levels
- Cost
- Distribution requirements
- Sequencing for set-up efficiency
- APS is relevant for production-organisations. Also distribution-organisations can benefit from implementing APS for supply chain management.

Many recognize APS as an enabling technology to make manufacturing more responsive to customer needs. There are three major reasons.

- First, in order to offer a delivery commitment, you must be able to see how your capacity is booked.
- Second, if a change is requested or a problem occurs, you must know how it will affect existing customer commitments.

- Finally, the shop floor must execute to meet the delivery commitments without sacrificing efficiency. Companies are learning that traditional manufacturing software and ERP/MRP II systems were not designed with this in mind. Many of these companies are turning to APS (Andrew R. Gilman)

APS include a range of capabilities; from finite capacity scheduling at the shop floor level through to constraint based planning (Turbide, 1998). The appeal of APS to manufacturers is obvious, because companies can optimize their supply chains to reduce costs, improve product margins, lower inventories and increase manufacturing throughput. APS necessitates deciding when to build each order, in what operation sequence, and with what machines to meet the required due dates (Young et al, 2002).

With the emergence of memory-resident Advanced Planning & Scheduling (APS) software the simultaneous consideration of materials and capacity constraints is becoming a viable planning option (Lehtonen, et al, 2003).

### 2.0 PLANNING AND SCHEDULING

In a general sense, planning is more general decision-making than scheduling; however, distinctions between the two are usually fuzzy. In this paper, we provide clear definitions of and distinctions between planning and scheduling, in order to support an efficient APS design. First, planning is generally defined as an activity for clarifying actions or operations to achieve a given goal and reserve enough resource capacity to hit minimum targets. The process planning functions involve some important activities like selection of machining operations, sequencing of machining operations,



selection of machine tools, determining setup requirements, and design of jigs and fixtures. The information generated by the process planning activities is used as the inputs of scheduling (Rao et al, 2006). By comparison, the most general definition of the *scheduling* is that of assigning scarce resources to competing activities over a given time horizon to obtain the best possible system performance (Karl Kempf, 2000).

In terms of decision hierarchy, planning ranks higher than scheduling because a scheduling decision is made using the results of a planning decision. Some constraints and target levels for objective functions in scheduling problems are determined by planning problems in advance. Conversely, the results of scheduling show whether or not the result of planning is feasible and efficient. If it is not feasible, planning needs to generate another result for scheduling. Feasibility and efficiency of scheduling are types of constraints of planning. Figure 1 illustrates the relationship.

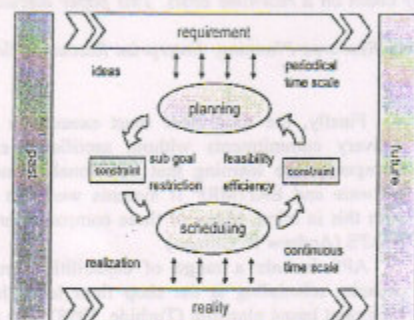


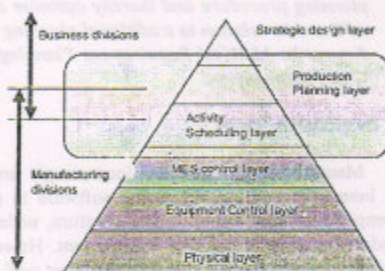
Figure 1: Planning and scheduling

Technically, the differences between planning and scheduling result from differences in the target data models. Decision parameters of planning and scheduling correspond to different types of data models, each of which are related to different aspects of time concepts. In planning, the main parameters will have values for certain periods of time. For example, "amount of production this month", "divisional sales next month", "summary of overtime hours for next week", etc. These decision parameters are not used for decisions on timing, but rather for any variables associated with a period of time. On the other hand, decision parameters in scheduling are defined as representing the particular timing of actions, e.g. start time and completion time of operation, inventory issue time, shipping time, etc. Parameters of sequence information for operations are also included as relative time representation. The relationship between planning and scheduling is asymmetrical, because a plan can have several possible schedules whereas a particular schedule corresponds to just one plan. There can be a very large number of applicable combinations for a solution to a scheduling problem. In such cases, planning has to reduce the number of combinations by addressing restrictions as a

result of the planning process. The length of period in the decision parameters for planning problems is significant. The shorter the time becomes, the more precise the planning required for resolving schedule problems. On the other hand, if the period is long, planning can take into account a great deal of information from a holistic viewpoint. Therefore, the length of period in planning parameters is important in order to achieve optimum integration of planning and scheduling (PSLX, 2005).

### 3.0 DECISION HIERARCHY OF APS

This section explains APS as a decision-making system for enterprises in the manufacturing industries. Typical modules and structure of APS are described from the viewpoint of companies overall. Decision making can be divided into six layers. Figure 2 identifies these as the strategic design layer, production planning layer, activity scheduling layer, MES control layer, equipment control layer, and physical layer.



equipment control layer, and physical layer.

Figure 2: Information processing hierarchy

APS controls the production planning layer, activity scheduling layer and the overlapping areas of the layers immediately above and below those two layers. As shown in Figure 2, business divisions cover the top two-and-a-half layers, while manufacturing divisions are responsible for the bottom four-and-a-half. The planning layer and the activity scheduling layer are handled by both business and manufacturing divisions. In addition, the lower three-and-a-half layers are sometimes distributed geographically.

The area covered by APS in the decision-making hierarchy can be further classified by some other considerations. The three levels shown at left in Figure 3 represent different granularity of the target of decision-making parameters. The top level deals with decision-making for total volume of production, where information on different product items is summarized in the same group or category. On the second level, each product item is distinguished and parameters associated with the products are decided. The third, or detailed level, is where not only information about final products but also information on their components, such as sub-assemblies, parts and materials, is discussed.



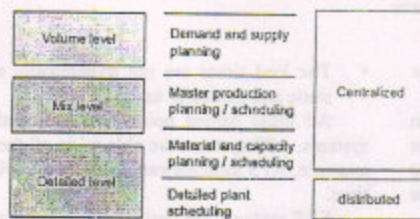


Figure 3: Level of decision-making for production

The right-hand category in Figure 3 indicates whether decision-making is centralized or distributed. In general, most decision-makers in manufacturing business divisions prefer the centralized approach. On the other hand, decisions for detailed manufacturing management are better made by the distributed method. As shown in Figure 3, the border between the two is at the detailed level, because all items from product to materials need to be considered enterprise-wide at least once in order to achieve synchronization across all processes.

According to the two views described above, decision-making in APS can have four detailed layers, each of which corresponds to a functional module of decision-making described below. In the hierarchy, one layer is usually managed by one business activity; however, some adjacent layers can be merged and managed by advanced integrated software.

#### (1) Demand and supply planning

In demand and supply planning, production is considered at an aggregate level, such as "product family". In terms of resources, demand and supply planning deals with capacity aggregated either at enterprise level or at particular area levels within factories. This decision-making cycle has a relatively long- or medium-term planning horizon. The maximum capacity of resources for production can be changed, if necessary. Financial aspects are involved in this decision-making so that enterprise-wide benefits can be optimized.

#### (2) Master production planning and scheduling

Master production planning and scheduling decides production volumes and timing for particular final products, according to customer demand. This is a short- to medium-term decision-making horizon. The quantity of each product is determined relative to a combination of received customer orders and projected orders calculated by demand forecasting. Target resources in this level are similar to those for demand and supply planning; however, the capacity limitation for a whole factory or particular area is based on constraint parameters rather than decision parameters. A schedule generated at this level is used to forge a kind of "contract" between the sales and manufacturing divisions. At the same time, all business activities are synchronized to this by confirming feasibility of the schedule according to their local capacity information.

#### (3) Material and capacity planning and scheduling

In material and capacity planning and scheduling, the quantity and production date of final products in the master production schedule provided by the upper level

are extended to operations necessary for producing the particular resources at certain times on the planning horizon. This decision-making process deals primarily with operations; subsequently, resource capacities and inventory of intermediate parts and components are discussed in relation to the associated operation. The concepts of MRP (Material Requirements Planning) and CRP (Capacity Requirements Planning) are included in this level.

#### (4) Detailed plant scheduling

Finally, detailed plant scheduling is addressed for actual plant floor operations. As with material and capacity planning and scheduling, this also focuses on operations. A feature of detailed plant scheduling is dealing with detailed constraints and requirements on each distributed plant floor. Furthermore, the granularity of scheduling outputs arrived at by this decision-making process is more precise than that of material and capacity planning and scheduling. Generally, the granularity of the elements of detailed plant scheduling corresponds to an appropriate unit of activities ordered by plant floor managers as part of daily procedures. Output of the detailed plant scheduling is used as a source for dispatching information when the time for an activity in a schedule is approaching and entering the action period. Work orders are forwarded to the corresponding plant operators (PSLX, 2005).

## 4.0 APS IN RELATION TO TRADITIONAL PLANNING SYSTEMS

The traditional planning systems like MRP I/II and ERP are not optimal. In this section the differences between these older traditional systems and APS will be explained.

### 4.1 APS versus MRP I/II

There are few assumptions underlying MRP I/II, which do not apply for APS (Turbide, 1998):

- All customers, product, and materials are of equal importance. In an APS system preferences can be inserted into the system, which means that for example some customers are more important than other customers.
- Lead times are fixed and known. With APS it is possible to reduce lead times, because the system is able to contact suppliers to get materials earlier (at a higher price).
- It is a top-down, one-pass, sequential process. With APS it is possible to adjust schemes in a multi-directional way.

Other disadvantages of MRP I/II are:

- MRP I/II runs are batch-oriented and take hours to complete. Because it is a time consuming process, it can only be done at night or in the weekend (Turbide, 1999). When you want to adjust the schedule, you have to wait for the next day to see if the adjustment turned out well. When an adjustment in a plan or schedule has been made, the APS system





recalculates the plan or schedule within a few seconds or minutes.

- MRP I/II does not give any possibilities for decision support or simulation (Turbide, 1999). APS has the ability to perform a what-if analysis. Different scenarios can be compared with each other and the best one can be filed into the transactional system.
- MRP I/II systems deliver long reports that force the end-user to dig through the details to find the problems. APS systems are easy to learn and they work with exceptions. When an exception occurs, the system reports a problem and the user-friendly interfaces allow the user to drill down into the specifications to identify where the problems occur. When the problem has been identified it is easy to administer solutions into the system.
- The material allocation in MRP I/II is done on a first-come-first-served basis. This can result in plans that are suboptimal (Bermudez, 1998). For example, you have 25 units in stock and there are two customers ordering this unit. Customer A is first and wants 50 units and customer B wants 25 units. Because customer A is the first the 25 units in stock are reserved for this customer and 50 units are scheduled to be produced. Both customer A and B have to wait until these units are produced and are unsatisfied with the delivery times. An APS system deals with this problem in another way. It allocates the 25 units in stock to customer B and starts the production of the 50 units for customer A. At least customer B is satisfied now, because he receives his units at once.

#### 4.2 APS versus ERP

ERP systems are very strong on transaction processing and execution of standard repetitive tasks, but their true planning and decision support capabilities are very limited, and as a result, frequently fail to deliver their full potential.

There are a number of reasons why ERP systems failed to improve manufacturing planning (Bermudez, 1998):

- The level of detail in ERP systems is too rough for adequate decision making. Also, the existing technology which is used for ERP systems does not allow greater detail for real time analysis and simulation, which enables adequate decision-making.
- The tools used within ERP systems are used infrequently and are sometimes incomprehensible for senior management.
- There is no consideration given to the interdependency of material and capacity availability.
- Multi-plant planning at one time is not possible.
- Actual results are not entered into the system to make process and data improvements.
- Optimisation of the production schedule to improve throughput is not possible.

- The lead times are not dynamically calculated but static and manually assigned.

All these named points are disadvantages of ERP systems. APS systems are able to do all these things. For example, APS systems can do multi-site planning at one time.

ERP systems are designed as a suite of applications around a database, which means that applications communicate with each other via the central database. The disadvantage of this procedure is an iterative procedure of going back and forth between applications, which make the transaction update time very long. As a result it is not possible to give real-time response to customer enquiries. Another disadvantage is that customer constraints or preferences cannot be dealt with in an easy way. APS systems, on the other hand use an integrated environment. The logic of the order entry is part of the logic of the planning and scheduling engine. In an integrated environment, the planning and scheduling engine will follow all "rules and preferences" before an answer to the customers inquiry will be given. Some examples of these "rules and preferences" are: 90% of product group S must be shipped on time, or all products for customer B must be shipped together.

#### 5.0 IMPLEMENTATION OF APS

APS is already a common property in many, mostly American companies'. In most European and Eastern Asian companies the introduction of APS is going slowly. The following are the reasons for not introducing APS in our industries.

- We don't have a strategy for supply chain management yet;
- We are not ready for central planning and managing of all the production and distribution centres;
- Our employees don't have sufficient knowledge;
- We can't deal with the frequent changes in planning;
- It is not possible to translate our planning in rules and strategies;
- Our data is not reliable enough;
- We won't regain the huge investments fast enough.

The key success factors, which are necessary to implement an APS system successfully, are as follows (Marjolein van Eck, 2003):

##### *Supply Chain management Concept:*

- The first pitfall is the lack of a strategic concept for supply chain management and the commercial strategic policy (for example the role of national sales organisations). It's evident that the concepts also enclose the role of suppliers and customers (chain integration).

##### *Experience:*

- APS is a rather new development where little experience has been gained. The development has not been completely evaluated, so one can encounter unforeseen problems.

##### *Nervousness*

- Continuous changes in the system should be avoided. These changes will result in nervousness in the organisation, what of course is not good. When a customer is told that he will receive his order at





date X, it is not right when the next day it is changed in delivery date Y.

#### *Human factor*

- At high level in the organisation one knows how to work with APS and how the system will look. Instead of the lower organisational level where they don't know this. These people need to get enthusiastic and motivated as well. Working with APS means managing from another central concept. Another point are the constant changes together with APS. A lot of processes and activities, like planning and the transfer of information go much faster now. One should take care that people don't lose the overview in the organisation and 'drown in' the new working method.

#### *Complexity*

- Because APS is not in the last stage of development, it is still the question which cases APS can handle and which not. During the implementation there are new software-releases and also the hardware is improved already.

#### *Financial resources*

- The financial resources of an organisation should be sufficient to complete an implementation. An implementation of an APS system throughout the whole chain of a big organisation can cost around 50 million euros. A small implementation is possible from one million euros.

#### *Data accuracy*

- The actuality, availability and purity of the data is often a big problem. A characteristic of an APS is that planning problems are solved with a mathematical model. APS-suppliers suggest that they offer an optimal solution. Those optimal solutions are based on submitted variables; not the whole chain with all its innumerable variables are optimised. When those predictions are not so hard, than a rather simple calculations gives much better results than a complicated optimisation method.

## 6.0 FEATURES OF APS

An APS system has a number of features that enable it to be clearly differentiated from traditional planning systems such as MRP I/II and DRP.

### 6.1 Concurrent planning

In the traditional planning process, as in the case of MRP I/II and DRP, three main variables can be distinguished:

- demand
- materials (raw material and semi-manufactured articles)
- capacity

The traditional planning process is the so-called 'waterfall approach', in which the planning process is undertaken sequentially. It starts with an MPS, after which MRP I/II and CRP are performed. The sequential approach decouples the plans from each other and cohesion can only be preserved by constantly repeating the planning process. In the traditional systems

production is based on a plan that is already outdated, since there are new orders and other changes.

In case of 'concurrent planning', however, the three main variables are considered simultaneously. This results in synchronised, optimal planning for the chain as a whole, based on the most up-to-date data (van Eck, 2003).

### 6.2 Constraint-based planning

A second important characteristic of APS systems is that account is taken of the constraints present in an enterprise, such as capacity and materials. APS systems use these constraints to model the production and distribution environment. The performance that an enterprise can achieve is determined by the constraints. Various constraints can be identified:

- Material availability
- Available capacity
- Enterprise policy
- Cost
- Distribution requirements
- Sequencing for set-up efficiency

### 6.3 Speed

The speed of planning is an important characteristic. An improvement in computer processing power and software design has led to good response times. As a result, a customer can be informed about the delivery possibilities within a few seconds. The person in contact with a customer who wishes to place an order has a strong negotiation position since he has a picture of the possibilities that the company can offer the customer. If the company is not able to satisfy the customer's wishes, he is immediately able to offer alternatives to the customer. Speed is also important during the planning cycle. Since all the links in the chain are now closely coordinated, delays in one link can have an amplified effect in the subsequent links.

### 6.4 Preferences

It is possible to indicate preferences in APS for purposes of strategic decision making. It is possible to regard certain customers as strategically important. In APS this is interpreted as a customer with a higher priority. These strategic customers must be considered as such throughout the whole organisation. This avoids a situation in which one sales organisation regards a particular customer as strategic, while for another sales organisation the same customer is unimportant.

### 6.5 What-if simulation

One of the first, and still most common applications for advanced planning and scheduling products, is decision support using the facility for what-if simulation. It is possible for various alternatives to be entered into the system and for the system to maximise company profit and/or minimise costs, subject to the condition that the order can be delivered on the date required by the customer. The planner can examine various scenarios under which the order is delivered and the system subsequently indicates the consequences of the various





scenarios for existing orders. A graphical interface makes it easy for the planner to compare the various alternatives computed by the system, so that the most acceptable solution can then be chosen. The planner can 'play around' with the data, with the most acceptable alternative being chosen and used as new input.

### 6.6 Bucketless planning

In the case of traditional planning methods the planning process uses 'time buckets' with a schedule being drawn up for a specific period. In scheduling-centric APS, planning in terms of time buckets is abandoned and continuous short-term planning is undertaken. Planning is undertaken as far as possible on the basis of actual orders rather than forecasts. Planning for the medium and short term continues to be undertaken in terms of buckets.

### 6.7 Reliability

This is the possibility of making promises concerning delivery times and delivery dates and also fulfilling such promises. It is possible to inform the customer of the ultimate delivery date. When the customer places his order, the company gives the delivery date and has the possibilities to adhere to that promised date.

### 6.8 Chain approach

Considering the entire chain simultaneously makes the chain more transparent. The planner can use graphical interfaces to visualise the entire chain and drill down into these chain parts to look closer at possible problems that occur. The planner can, for example, when a specific order cannot be produced drill down into the production system to look at the machine experiencing a capacity problem. The planner can alter the schedule to solve this problem, for example by rescheduling the orders regarding the machine (van Eck, 2003).

### 6.9 Optimisation

Optimisation means generating the best solution to a specific problem. APS can be used to optimise both tactical and strategic business issues. At the tactical level the system can help to optimise sourcing, production and distribution plans. At strategic level APS supports in optimising the network configuration. Different techniques can be used to solve the optimisation problems (Bermudez, 1998):

- Linear Programming
- Genetic Programming
- Theory of constraints
- Heuristics

## 7.0 CONCLUSION

The APS market is getting a lot of attention. This is primarily driven by the increasing complexity of manufacturers' supply chains. This complexity is caused by both the trend towards globalisation and the myriad products, materials, facilities, trading partners, and trading relationships that need to be planned. In many

companies, planners are becoming overwhelmed by complexity in decision-making. An APS-system can be seen as an integrated information system, but APS is only supportive but also a driving force. APS systems can contain the whole chain, so the entire supply chain can be optimised and not just one link. The packages advance algorithms to optimise the supply chain.

If an organisation fulfils the conditions introducing an APS-system, then there are a lot of advantages to gain: shorter time-to-money, lower cost due to a depreciation of supply, better use of capacity, a better availability of stock for customers. Benchmark studies have shown that APS tools improve final performance and customer service. A successful introduction asks for more than attention to implementation of the IT system alone. An APS-system should be installed the right way (the logistical process) in a fruitful environment (the organisation, the culture) and managed in a sensible way (the management planners).

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