

Chapter 2

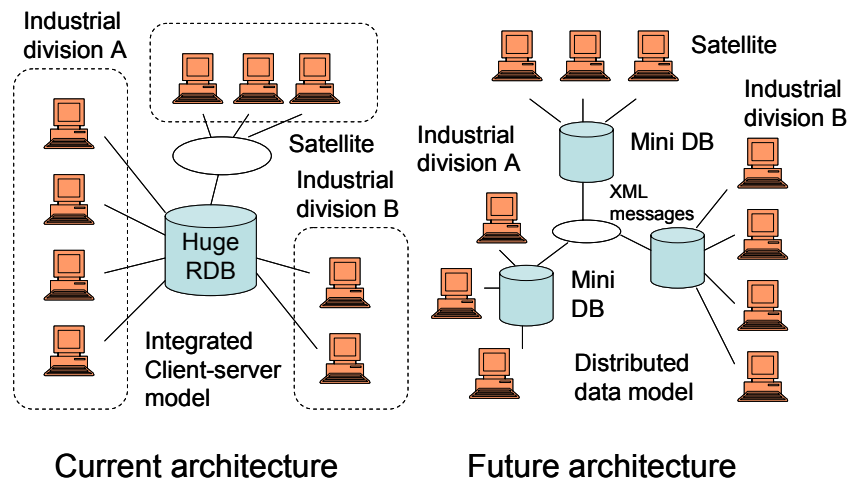
Information System Architecture for Manufacturers

Information Systems for APS

Current popular architecture for information systems is designed on the basis of client-server systems. However, there are disadvantages to running huge systems on this technology, in that all the detailed data that are not referred to in the schema remain outside of the system, and revision of the schema requires extraordinary effort because it can greatly affect many existing software applications. In order to adjust information systems to particular cases of plant floors, data representing each production process are very important. Furthermore, a schema representing a plant needs to be flexible so that it can be adapted in response to actual changes.

The information system architecture that PSLX Consortium is proposing features both the advantages of current client-server technology and further advantages that flow from distributed autonomous systems, which allow local systems to change in detail levels without any agreement with others. Fig. 2-1 shows the difference between the two information system architectures. Compared to the current architecture, which has all the data stored in a central database, the future architecture will have several small databases. Local and domain specific information is created and stored independently in local databases. These distributed databases are roughly integrated by occasional limited communications.

Fig. 2-1
Information
system
architecture



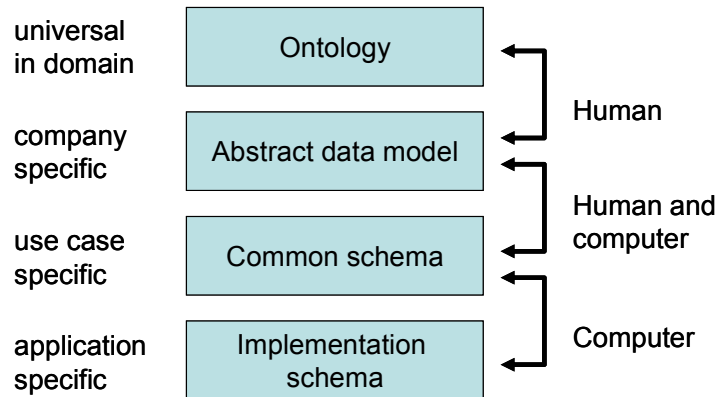
In the future architecture, consideration must be given to interoperability between autonomous databases, each of which has its related subsystems. Collaboration across different databases and data consistencies will be the issues for the designers. In order to establish communication among different data schemas, there needs to be proper discussion on the semantics behind the data schemas. An abstract data model is put in place for this purpose. Abstract data models can represent data elements of business processes in a particular enterprise independently of individual implementations of computer systems. It is useful to define components of business processes, input and output of components, resources and controls, etc.

An example of an abstract data model is the APS domain model, which is defined by PSLX Consortium as a reference for various types of industrial data models. This is a kind of common data model that can be modified to adjust to each enterprise characteristic. Particular procedures and algorithms in business components are not included in this model. An abstract data model is all about business and engineering from the viewpoint of enterprise planning and scheduling. The number of abstract data models is equal to the number of enterprises. The model will be changed if the corresponding processes are changed.

Abstract data models need to have PSLX ontology behind their definitions. Ontology is the basis of all definitions of semantics, representing primitive elements and their relations. Each abstract data model of an enterprise can be represented by attempting modifications based on the APS domain model. Alternatively, a model can be developed from scratch without reference to the APS domain model. In both cases, PSLX ontology provides a basic semantic structure for interpreting data elements in different contexts in different industries. Data become information to be effectively used in a system based on the existence of PSLX ontology.

While an abstract data model is independent from system implementation, an information system designer needs a certain data schema for implementation. He or she designs an optimum schema with respect to each system environment. RDB schema and internal data structure in an application program are examples. However, as shown in Fig. 2-1, in the information system architecture proposed by PSLX, the data schema for implementation should never be created directly from an abstract data model. In terms of interoperability, there exists the serious problem of translation between the abstract data model and the implementation schema requiring human support, because the abstract data model contains subjective definitions using ontology. This means that precise data communication between applications cannot be obtained successfully.

Fig. 2-2
Layers for
application
interopera-
bility



In order to establish application integration between different business activities, there needs to be a common data schema that is defined in advance, together with agreed usage of semantics for the data elements in the schema. Fig. 2-2 shows the hierarchy of data models, all of which are necessary for the APS information system architecture. In Fig. 2-2, the common schema is defined as a data model, which acts to integrate different implementation schemas on different applications. A common schema should be defined for each business activity before application systems are implemented. Then, application system programmers can choose the most appropriate schema and interpret the semantics, using PSLX ontology, in order to apply this to their own implementation schema.

Decision-making in manufacturing

As a general principle, "decision-making" is regarded as a top-level human mental process. This paper uses the term more restrictively, to focus on decision-making as the process of determining information related to planning and scheduling for activities within an enterprise. It includes not only planning and scheduling, but also the associated processes that create and manage information for those purposes. Before discussing the features of decision-making in APS, we need to be aware of certain disciplines. For APS, decision-making should:

- (1) Be performed on the basis of correct and timely information;
- (2) Involve plant floor personnel;
- (3) Monitor actual activity to provide feedback;
- (4) Share information on causes and results in order to collaborate with others; and
- (5) Be simple and visible in terms of mechanisms.

With respect to APS, PSLX defines planning and scheduling as the primary aspect of decision-making in enterprises. Target actions of decision-making in APS may or may not be explicitly clear in advance. Sometimes, planners need to establish parameters within which they can make a decision at a particular stage. In order to design APS as the primary decision-making system in an enterprise, and to make it perform better, designers of enterprise information systems and business models should understand some features of decision-making. The basic features of decision-making could be described as follows.

(1) Feedback and feedforward

A decision on a particular action can be made using feedback mechanisms. Although relatively low-intelligence in nature, this is the most popular type of decision-making. In this type, the difference between the state of actual results and the projected state at the time of decision-making is considered, and used to assist future decision-making. This type of decision-making is called “feedback”, because the output of a decision is re-used as an input for future deliberations. Most control systems in the physical area utilize the feedback process.

On the other hand, “feedforward” systems can also be effective in situations where future events can be predicted at the time of decision-making. In the feedforward mechanism, planning and scheduling are used to avoid potential negative effects of the future event, and to optimize performance. This enables calculation of projected states, based on current conditions and actions decided. The feedback mechanism reacts after changes occur, so that errors are increasing during the

reaction “gap”. In the feedforward mechanism, performance down is relatively short, as a result of prediction and more elaborate decision-making.

(2) Initial planning and re-planning

Decision-making for actions to take place in a certain future period can be divided into two types: Initial planning and re-planning. Initial planning makes decisions for the target period from scratch. The plan developed in initial planning will become obsolete if a different situation arises before the planned time for the action approaches. In such a case, re-planning is implemented to partially revise the plan in order to adjust to new circumstances that could not be foreseen at the time of initial planning.

In actual industrial situations, various kinds of actions are planned along the timeline from decision to eventual completion, and those actions are generally revised along the way. In other words, most decision-making activities occur in re-planning or re-scheduling, rather than during initial planning. Of course, some re-planning can be defined as initial planning when certain additional constraints are deliberately introduced.

In the target period of re-planning, there will be actions decided on the basis of previous planning. Some of these cannot be revised, some do not need to be revised, and some are completely open to change. Timing of particular actions is an important factor in their degree of change difficulty. Generally, the farther the time of action from the time of decision, the easier any revision of the action.

(3) Planning horizon and planning cycle

Two important parameters that characterize decision-making in a business model are the planning horizon and the planning cycle. The planning horizon is the target period of decision-making. Only the actions and events expected in that period are considered in the decision-making. The planning period is relatively defined by start time and end time (or

duration). For example, “from next Monday and over the following seven days”.

On the other hand, the planning cycle is the interval between a given decision-making process and the one that preceded it. Those two decision-making points address the same issue in an actual ongoing situation. The duration of a planning cycle is either fixed, variable, or a blend of the two. In fixed cases, the cycle would be defined as in, “every Wednesday”, “the 25th of each month”, etc. The variable type includes such cases as unexpected arrival of an order quantity, or inventory dropping below a certain level.

Planning and scheduling

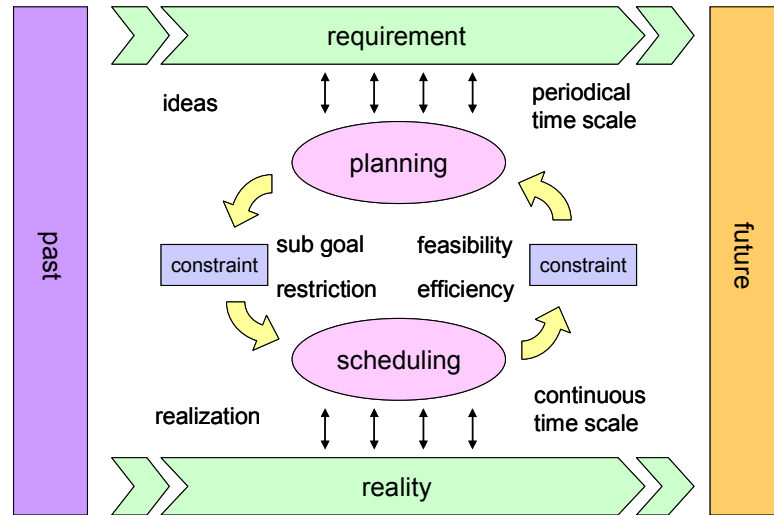
In a general sense, planning is more general decision-making than scheduling, however, distinctions between the two are usually fuzzy. In this white paper, we provide clear definitions of and distinctions between planning and scheduling, in order to support an efficient APS design. First, planning is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

By comparison, scheduling is generally defined as an activity for allocating actions and operations to particular resources at particular times, taking into account various actual constraints and optimization of several evaluation parameters. Scheduling decides many parameters for resources that deal with constraints on the continuous time scale that parallels real time.

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. Fig. 2-3 illustrates the relationship.

Fig. 2-3
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.

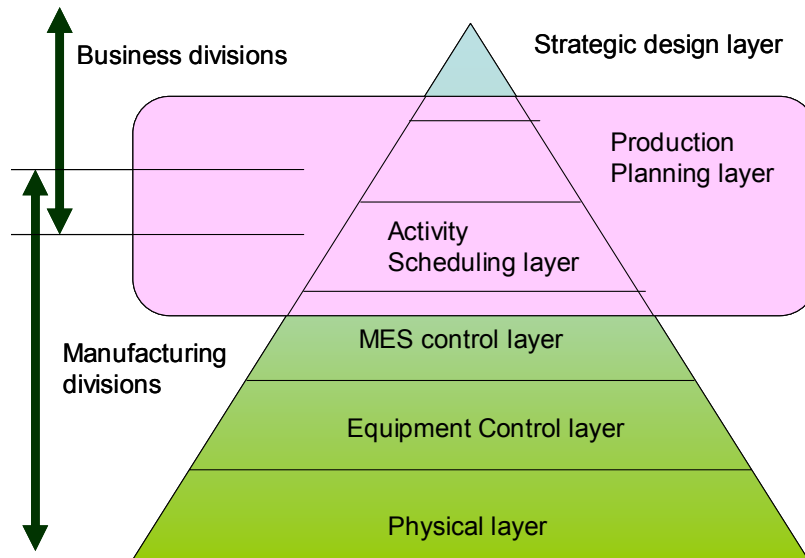
The relationship between planning and scheduling is asymmetrical, because a plan can have several possible schedules whereas a particular schedule corresponds to just one plan. There can be a very large number of applicable combinations for a solution to a scheduling problem. In such cases, planning 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 optimal integration of planning and scheduling.

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. Fig. 2-4 identifies these as the strategic design layer, production planning layer, activity scheduling layer, MES control layer, equipment control layer, and physical layer.

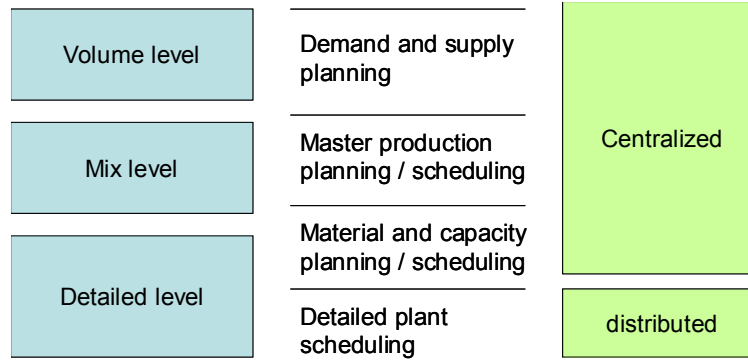
Fig. 2-4
Information
processing
hierarchy



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 Fig. 2-4, 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 Fig. 2-5 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.

Fig. 2-5
Level of
decision-making
for
production



The right-hand category in Fig. 2-5 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 Fig. 2-5, 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 products. Then, those operations are allocated to 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.

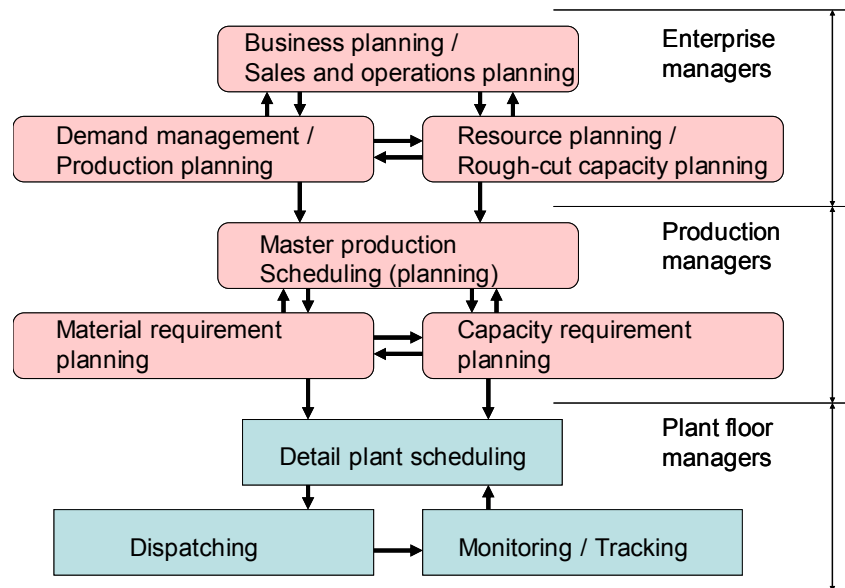
Mapping to legacy ERP systems

Recently, most medium to large manufacturers have used MRP II or ERP as their enterprise information systems. This section shows schematic relations and differences between these legacy systems and APS. First, a conventional enterprise information system framework is illustrated in Fig. 2-6.

In Fig. 2-6, there are three levels in the target decision-making for business activities. Each level is managed by enterprise managers, production managers, and plant floor managers, respectively. Different levels have different aspects and objectives developed by the different types of managers. Enterprise managers make decisions with respect to the profitability of the enterprise, while production managers deal with total throughput of the factory regarding plant-wide parameters such as average production lead-time, inventory levels and so forth. Ultimately, plant floor managers modify the final execution schedule in order to maintain safety and efficiency in the plant. They will know if the schedule developed by production managers is not feasible and requires more detailed information to be added at plant level. MES (Manufacturing Execution System) corresponds to this level.

Decision-making modules addressed in Fig. 2-6 are briefly described as follows.

Fig. 2-6
Legacy
information
system for
manufac-
turers



(1) Business planning/sales and operations planning

In business planning, or sales and operations planning, management executives who are responsible for final decisions relating to future profitability and strategies participate. New product development, investment in production lines, hiring or laying off workers, and alliances with suppliers are discussed in this module. Results of this decision-making will act as constraints in the lower modules.

(2) Demand management/production planning

To achieve a balance between demand and supply, this module makes decisions from the demand side. Demand forecasting and sales volumes for each period are decided, together with particular actions for future demand creation. Complementary problems, such as product inventory planning and transportation of inventory in order to meet any future supply requests, are included.

(3) Resource planning/rough-cut capacity planning

This is the highest level of decision-making from the viewpoint of balancing supply with demand. From medium- or long-term aspects, the overall capacity of the factory is considered and relative actions, such as additional requests for equipment and disposition of plant capacity are planned. Personnel management for overtime work should also be decided in this module.

(4) Master production scheduling (planning)

Master production scheduling determines a master schedule in terms of quantity and item of final products of the enterprise. From a resource viewpoint, rough-cut capacity planning is implemented to confirm feasibility. Information developed in this module is shared between the sales and manufacturing divisions. Capable to Promise is developed using this function.

(5) Material requirements planning

Material requirements planning (MRP) calculates the date of production and quantities of all parts and materials associated with the schedules for final products. Bill of Materials (BOM) information is used to expand the product structure. This is a short- to medium-term, periodic decision-making cycle; however, partial re-planning may occasionally be implemented.

(6) Capacity requirements planning

Capacity requirements planning (CRP) calculates the capacity requirements for each work center, so that their individual loads do not exceed capacity limits. This is done by shifting the timing of operations that are planned for the peak of the load. Routing information for each product is required for this module.

(7) Detailed plant scheduling

Detailed plant scheduling deals with various plant floor operations. The rough schedule developed through upper level decision-making is referred to over the next couple of days. Actual status of plant equipment and particular constraints are also considered, in order to decide detailed sequences and routing for manufacture of a particular product.

(8) Dispatching

Ultimately, work orders based on a detailed schedule are dispatched to each work center or relevant personnel on the day scheduled for execution of the work. Dispatch may be carried out simultaneously for work orders applicable within a certain period, such as a shift. Otherwise, an order will be released whenever the previous operation is completed. Plant floor personnel prepare tools and setups for the corresponding production.

(9) Monitoring/tracking

All actions resulting from [work order] dispatching are monitored and stored as tracking performance data, which is used for route tracing and quality analysis of each product. Furthermore, these performance data become real-time input fed back to the detailed plant scheduling for comparison of the schedule against results. Then, work orders already executed are eliminated in the next detailed scheduling.

In Fig. 2-6, the boxes with rounded corners represent planning, which means a decision-making process with parameters on a certain time bucket or time phase. The other boxes in the figure represent scheduling, which is decision-making on a continuous time scale. The left-side modules of demand management/production planning and master production scheduling (planning) have a product-and-material-centric view, while the right-side modules of resource planning/rough-cut capacity planning and capacity requirements planning have a resource-capacity-centric view.

The conventional framework of decision-making modules described above suffers from three serious problems: (1) First, in the development of a production schedule the information flow between plant floor managers and production managers is one-way. A production manager is not fully aware of details about the actual plant floor situation. (2) Second, in both the enterprise managers' and the production managers' decisions, a module of product-and-material-centric view and a module of resource-capacity-centric view are separated. This can lead to inefficiency and inflexibility in the system. (3) Finally, it should be noted that not all of the modules have explicit collaborative relations with plant engineering, production design, and financial or cost accounting functions.

To replace the conventional system framework, PSLX proposes a new framework based on the APS concept. Fig. 2-7 shows an overview of the proposed framework, which includes demand and supply planning, master production planning and scheduling, material and capacity planning and scheduling, and detailed plant scheduling. These four modules are the nucleus of APS and correspond to the basic decision-making layers shown and explained in Fig. 2-5.

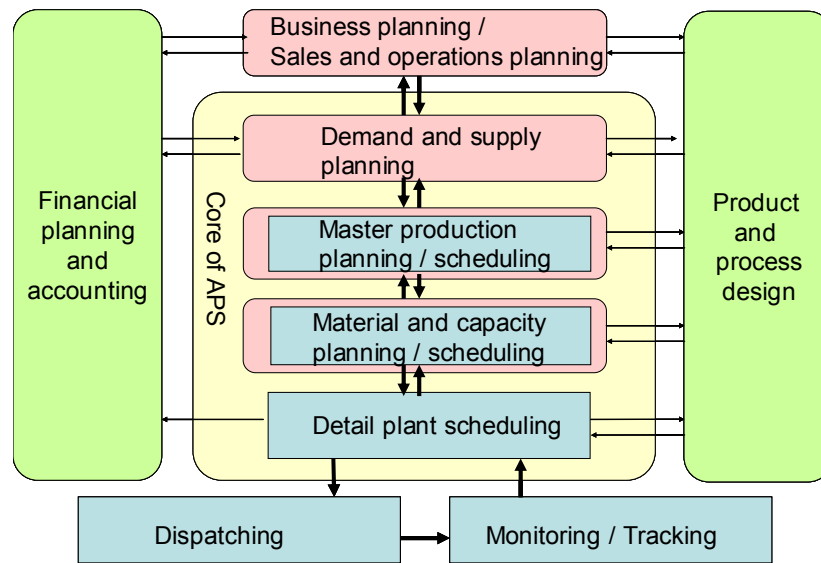
Comparing Fig. 2-6 and Fig. 2-7 demonstrates several schematic features of APS. First, master production planning and scheduling, and material and capacity requirement planning and scheduling (Fig. 2-7) have both planning and scheduling aspects. In other words, both decision-making processes can deal with continuous time scales as well as conventional time-bucket-based decisions. This is a very important feature that PSLX provides by integrating the schema of planning and scheduling.

Second, two pairs of separated modules (Fig. 2-6) are merged into single decision-making processes. Demand management/production planning and resource planning/rough-cut capacity planning become demand and supply planning. Material requirements planning and capacity requirements planning are merged into material and capacity planning and scheduling. This can be achieved with the PSLX ontology and APS domain model, which represents explicit relations between a concept of

products or materials and a concept of resources. such as equipment and work centers.

Finally, Fig. 2-7 shows that APS provides mechanisms for collaboration with decision-making in financial planning and accounting activities, as well as product and process design activities.

Fig. 2-7
APS system
components
and structure



Target categories of business models

Design of system implementation on information system architecture requires knowledge of the classification of each manufacturer in terms of characteristics of production processes, and business strategies for sales and manufacturing integration. The overall APS decision-making system contains every kind of business process, each of which has a different context in its particular business circumstances.

This section shows management classification from the viewpoint of APS. Before going into design detail of APS, the category of the target enterprise should be clarified. First, there are three groups in terms of

physical production systems.

(1) Flow manufacturing

Flow manufacturing includes continuous manufacturing, such as chemical and petroleum plants, and repetitive discrete manufacturing, such as final processes in the automotive industry. In this type, production velocity is stable and resource load is always flat. Most of the inventory in this type of production is part of pipeline inventory, and work-in-progress inventory awaiting the next production step is minimized. Scheduling of work orders in production processes is not an important issue, but line balancing and release control take place.

(2) Intermittent manufacturing

This type represents production that is repetitive but usually involves a greater variety of items and broader range of quantities. Most manufacturing enterprises come under this category. It includes discrete manufacturing that turns out several varieties in small lot sizes, and batch manufacturing runs in process industries. Management to eliminate loss of efficiency during changeover operations, and detection/control of bottlenecks are important considerations in the scheduling process. Planning issues include creating a balance between demand and supply to meet various customer requirements with minimal investment in plant resources.

(3) Project manufacturing

Project manufacturing is not repetitive, and all materials, components, production equipment and labor are procured once during the period of production, and then released. Most examples of this type of manufacturing include design processes, e.g. production of large size products such as ships and aircraft, construction of factories or production lines. Project scheduling methods such as PERT and CPM are available.

The classifications described above are defined automatically by the respective products and services of the enterprise. On the other hand, the following classifications arise out of the business strategies of the particular enterprise, with the objective of developing a competitive business model for the relevant market. Each manufacturer is able to choose an appropriate strategy.

(1) Make-to-Stock strategy

The Make-to-Stock strategy allows manufacturers to make their products according to forecasting data on projected customer orders. Once final products are produced and stored as inventory, customers draw their purchases from the finished inventory. Inventory holding cost will be much higher. However, customer order lead-times can be minimized, and production costs are also lower as a result of larger, more economical lot sizes. This strategy works better when future demand is predictable, and the products have long shelf lives, or will not become obsolete in the near future.

(2) Make-to-Order strategy

The Make-to-Order strategy, on the other hand, recognizes customer orders as a “trigger” to activate production. Manufacturers using this approach try to ship the final product as soon as the production processes are finished. However, they never initiate production before receiving an order from a customer. Therefore, order lead-times will be much longer, and inventory can be reduced to zero. Purchasing processes for materials are sometimes included in the lead-time, sometimes not. This strategy works better when the production process involves less repetition and greater variety.

(3) Design-to-Order strategy

The Design-to-Order strategy can be applied to one-of-a-kind production, in which the product does not have a stock design. Manufacturers carry

out particular types of design and manufacturing according to customers' preferences, chosen from a number of options. The customizing processes may refer to types of templates or standard components of products in order to minimize production input. Customer lead-times are very long and unreliable. Standardization of components is an important factor in reducing lead-times.

(4) Finish-to-Order strategy

The Finish-to-Order strategy is an intermediate one, falling between Make-to-Order and Make-to-Stock. This features a certain stocking point between the processes from raw materials to final products, corresponding to the BOM. Processes upstream of that point are managed by the Make-to-Stock strategy, while downstream processes come under Make-to-Order operations. There is no inventory of final products in order to reduce stockholding costs. At the same time, this strategy allows manufacturers to reduce customer lead-times, as compared to the Make-to-Order strategy. This type has many advantages if the products have BOM, in which product variation can be implemented in the final steps of the production processes.