HIGH-OPTION MANUFACTURING: THE DENVER WORKS INFORMATION-SYSTEM ARCHITECTURE

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AT&T's business strategy for its PBX (private-branch exchange) product line is to offer customized products of the highest quality and with the highest service, and to sell them at a competitive price. To satisfy that business strategy, AT&T's Denver Works needed to put in place a system that would deliver the capability to support an efficient, assemble-to-order environment for high-option products such as PBXs. This required not only streamlined and short-interval processes but also well-designed and integrated information systems for material planning and order provisioning. The previous papers in this issue discussed some of the systems and process improvements that are prerequisites to an efficient, assemble-to-order operation. This paper reviews the requirements of the Denver Works information-system architecture that culminated in the integration of the operation mentioned above.

Introduction

A Definity® System 85 telecommunications system has over 700 unique hardware building blocks or subassemblies from which an almost limitless number of systems can be configured to satisfy a customer's requirements. For complex products such as the System 85 PBX, the intelligent strategy is to plan, manage, and manufacture, not at the end-item (system) level, but at the subassembly (e.g., circuit-pack) level. (*End item* refers to a product sold as a completed item or repair part, or any item that is subject to a customer order or sales forecast.)

Accordingly, the design objectives for the Denver Works information-system architecture were driven by the goal to facilitate a strategy that supports the planning, management, and manufacture of the subassemblies—most of which are optional—based on the configuration in each customer order. More precisely, the architecture must be able to:

- Rapidly receive a system order that is described by a list of features.
- Translate the features into the appropriate subassemblies.
- Respond quickly to changes in customer orders.
- Efficiently support the material planning and manufacture of the subassemblies.
- Support integrated and synchronized assembly and test of the subassemblies into the finished product.
- Be cost-effective.

This paper will review the major requirements of the information-system architecture that made this possible. (Panel 1 defines terms and acronyms.)

The Order-Realization Process

Figure 1 is a high-level view of the architecture of the information systems that the Denver Works uses for order realization. This architecture comprises two major processes: material planning and order provisioning.

Material Planning. The material-planning process involves planning and procuring the material required to manufacture the product, based on a forecast of expected customer orders.

The procurement lead times of many components are generally greater than the manufacturing interval at Denver (which begins with receipt of customer orders and ends with shipment of products). Therefore, Denver must order material based on a forecast of expected sales. This forecast is developed monthly by product management and manufacturing.

Because actual customer orders are not available, the precise configurations of the forecasted systems are not known. Consequently, Denver's production planners use expected configurations, which they call *typicals*, to estimate the demand for materials.

Typicals are planning bills of materials for an end item (e.g., a Definity System 75 telecommunications system), where component quantities reflect the average usage for the components in expected customer orders. These averages represent a forward look at configura-

tions on actual customer orders and are revised frequently to reflect changing market conditions, such as increased market demand for a specific feature.

A production plan is defined based on the forecasts (demand management) and on several typical systems. Next, the Production Order Scheduling System (*POSS*) translates the plan's requirements into the subassemblies that make up the typical system. POSS then routes this translation, i.e., the subassemblies requirements, into the master-production schedule (MPS) for each subassembly.

As Kinney explained earlier,[1] the MPS is an anticipated manufacturing schedule and, at Denver, master scheduling is done at the subassembly level. Denver uses an AT&T-developed software system called *IMPAC* to manage the MPS and materials-planning processes. [IMPAC is a material-requirements planning, or MRP, system. The name stands for *integrated manufacturing planning and control*.]

Based on the forecast, the work in process (WIP), and the materials on hand or on order, any additional
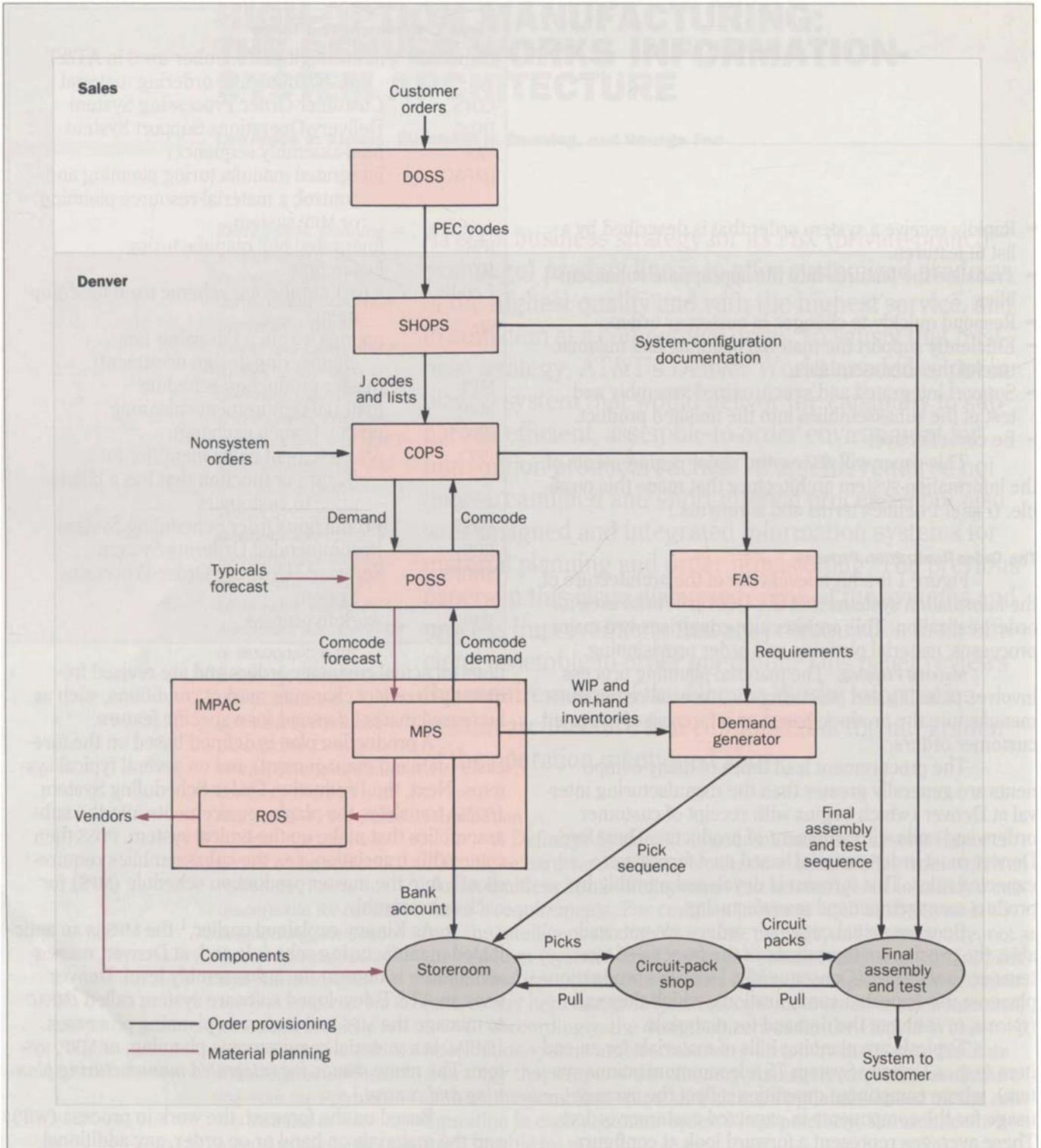
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Sales

Customer orders

DOSS

PEC codes

Denver

SHOPS

System-configuration documentation

J codes and lists

Nonsystem orders

COPS

Demand

Comcode

Typicals forecast

POSS

FAS

Comcode forecast

Comcode demand

Requirements

IMPAC

WIP and on-hand inventories

MPS

Demand generator

Vendors

ROS

Final assembly and test sequence

Pick sequence

Bank account

Components

Storeroom

Picks

Pull

Circuit-pack shop

Circuit packs

Pull

Final assembly and test

System to customer

Order provisioning

Material planning

material needed to satisfy the production plan must be ordered. Orders for raw materials and components are released to vendors, using the dates that the MRP system provided.

Order Provisioning. Material planning is a planning process to procure material, based on a forecast of expected orders. Order provisioning, in contrast, is the process of executing the actions required to deliver actual customer orders.

The order-provisioning process begins when SHOPS, the Software-Hardware Order-Processing System, receives an order for a PBX from an information system called DOSS, the Delivery Operations Support System. AT&T's sales force uses DOSS to enter actual customer orders and then track them.

However, when DOSS delivers the customer-order requirements to SHOPS, they arrive as price-element codes (PECs), a *sales* language. PEC codes are identifiers for features and functions that have a billable price to customers. The PEC codes need to be translated into a *design and manufacturing* language, such as J codes and lists. [J codes are part-numbering schema used in equipment-design documents (e.g., J drawings) provided by the product developers at AT&T Bell

Laboratories, and lists are options within J drawings.] SHOPS not only does this translation, but also generates system-configuration information that personnel in the final-assembly area use as a guide for assembling the PBX system from the required subassemblies. After the translation, part-number and quantity data are stored—by customer-order number—in *COPS*, the Customer-Order Processing System.

However, the MPS software does not recognize information formatted in J-code and lists combinations. But it does recognize unique numbers such as *comcodes*, the nine-digit numbers used within AT&T to plan and order material. Therefore, another translation of the customer requirements is required and is done by POSS.

Every night, POSS automatically accesses the COPS database and translates the J-code and lists combinations into unique subassemblies and planning units, each represented by the comcode number that the MPS software can recognize. (A *planning unit* is an item that has been master-production scheduled.) After the translation, the most recent customer requirements in comcode form are entered into the COPS database, which now stores the customer-order information as J-code and lists combinations and as comcodes.

Another key function of POSS is its nightly search of each customer order in COPS to add up the demand for each planning unit. This information about actual customer requirements is then transferred to the MRP system, which updates the actual customer demands in the master-production schedule for each subassembly, based on the scheduled shipping dates in the customer's order. That way, the master scheduler always has current knowledge about the total demand for each planning unit and is able to manage the supply of material according to the real demand. (By *master scheduler*, we mean the person responsible for maintaining the master-production schedule.) As the units listed in the MPS forecasts are consumed by the actual customer orders, it is the master scheduler's responsibility to balance supplies with demand and minimize inventories, but still ensure

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that the required material is present when needed.

When it is time to begin manufacturing the subassemblies, the master scheduler releases and controls the material needed for the subassemblies. To do this, he or she establishes a maximum authorization of material in predefined increments (e.g., ten units)—i.e., a limit on the amount and type of material that a shop can withdraw from the storeroom. The maximum authorization is similar to an electronic *bank account*,[2] where the manufacturing shop can withdraw up to, but no more than, the amount that has been deposited in its account. The bank-account feature is important because it takes the master scheduler out of the shop-floor execution phase and allows him or her to focus entirely on material planning.

The final-assembly area's schedule drives, or *pulls*, the material from the feeder shops. Therefore, it is feasible to minimize manufacturing intervals and maximize resource utilization by establishing for the cabinets an assembly sequence that will generate the most level load for the week on the feeder shops.

The final-assembly sequencer (*FAS*),[3] which is run each night, performs this leveling function. First, it collects up-to-date information on all system and spare-parts orders and due dates from the COPS database. Next, FAS segments this information by week, based on the due date. The cabinets due (i.e., needed by the final-assembly area) during a specific week are then sequenced in a way that minimizes the fluctuation of the requirements (i.e., demands) on the feeder shops. All the subassemblies required for each cabinet are scheduled for completion on the same day. Because of this philosophy, the assembly schedule for each of the feeder shops is not perfectly smooth, but the variability is minimized.

There are several fundamental principles in the use of the sequencer:

- Some subassembly manufacturing is not leveled. The leveling process gives greater weight to the subassemblies that have the highest variability and highest cost, along with the longest manufacturing lead time (e.g.,

circuit packs). All the other subassemblies are pulled based on the final-assembly sequence of the cabinets.
- Cabinet shipments scheduled during a specific week will not exceed the capacity of the final-assembly shop for that week. All cabinets are sequenced in the week that they are scheduled to be shipped.

Once the assembly sequence of the cabinets is established, FAS derives the sequence for the subassemblies. Subassemblies in the existing finished-goods and WIP inventories are subtracted from this subassembly demand, with its associated due dates. The remainder from this calculation is the demand requirements for the raw-material storeroom. *Equipment shop* subassemblies (e.g., carriers, power distribution subassemblies, shelves) are pulled into the final-assembly area via a manual kanban system,[4] based on the final-assembly sequence.

Although manual kanbans and replenishment strategies are desirable because of their simplicity, they are not feasible approaches for circuit-pack manufacturing, because of the high volatility of demand and high economic value of the circuit packs.[4] Instead, the expected manufacturing-lead times for the circuit packs are used to determine when manufacture of the circuit packs should begin. Based on this calculation, a priority list of manufacturing *starts* is generated for the circuit packs.

The raw-material storeroom is considered the first operation in the assembly process. A computer-generated priority display, which receives input from FAS, instructs the storeroom about the correct sequence for component-picking activities.[5] (*Picking* is the process of withdrawing components from stock.) A *pick list* identifies all the components needed to manufacture products. But before a pick list is available for picking operations to be started, the master scheduler—as previously discussed—must have electronically deposited enough material into an electronic bank account.

When the picking operations are completed, the material is staged (i.e., made ready to move onto the shop floor). As described by Albano et al.,[6] maximum WIP levels are established within the shop, and material

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Panel 2. Components of the Architecture

This panel summarizes the key features of some major components of the Denver Works information-system architecture for order provisioning.

SHOPS. The Software-Hardware Order-Processing System translates PEC codes (i.e., sales language) into a set of J codes and lists (i.e., design and manufacturing language). It then provides system-configuration information that manufacturing uses to support the final assembly of the PBX. This information also serves as documentation for the customer.

COPS. The Customer-Order Processing System maintains the customer-order database, which stores customer-order information along with related information (e.g., shipping date). COPS also receives and stores information about orders that do not go through DOSS (e.g., spare-part orders). In addition, COPS provides shipping documentation for the order, as well as information for billing.

POSS. The Production-Order Scheduling System receives typical end-item (i.e., system) forecasts and translates them into the subassemblies (e.g., circuit packs) required to assemble the end item. It then routes the demand forecasts for each of the subassemblies into their respective master-production schedules.

POSS also maintains data that relates the J-code and lists information for customer orders to their planning units. This provides the link between COPS and the MPS for actual customer orders.

In addition, POSS checks that the customer orders received do not differ significantly from the planned typical forecasts. If an order's content (i.e., the system configuration requested) differs appreciably, POSS flags the order for review. This process ensures that material is available to produce even those orders that deviate significantly from the typical configuration.

FAS. The final-assembly sequencer receives customer-order information in the form of planning units from COPS. During its nightly runs, FAS determines a final-assembly sequence that optimizes the manufacturing flow for the various feeder shops that manufacture the subassemblies. (FAS is fully described in the paper by Luss, Rosenwein, and Wahls.[3])

IMPAC. The IMPAC system is a full-featured MRP system that includes a bill of materials, a master-production schedule, material planning and ordering support, and a storeroom-control module. These capabilities are interleaved with the POSS, FAS, and storeroom systems to support the integrated information-system structure.

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is delivered to the shop only when the shop is below the WIP threshold, and only when the shop transmits a pull signal to the storeroom that it is prepared to accept the material. On the shop floor, manual JIT (just-in-time) techniques—such as a kanban system and WIP control—are used to pull material from one work area to the next in a first-in, first-out manner and into the final-assembly area. Computer-based, shop-floor control systems are not required, because the material flow is so fast that the tracking and expediting capabilities these systems offer are not needed.

When assembly of the circuit packs is completed, the circuit packs are delivered to a finished-goods storeroom. The final-assembly area for the cabinets pulls the circuit packs from the storeroom, based on the final-assembly sequence. Finished cabinets are then sent to system test where, after successful testing, the completed systems are shipped to the customer.

The production-control concept described above embodies what has been called *integrated pull manufacturing* (IPM) at the Denver Works.[7]

In 1990, the finished-goods storeroom was eliminated, and completed circuit packs now go directly into the final-assembly area. This concept of eliminating a storeroom for a finished subassembly also conflicts with traditional MRP principles. One objective of an MRP

system is to balance material supply with demand. To do this, an MRP system needs to keep track of the material. Conventional MRP systems mandate that completed sub-assemblies go through a storeroom where their entrance and exit are recorded. However, this archaic policy adds no value and impedes the flow of material. At Denver, a *backflushing* feature in the IMPAC system allows the material to flow directly into the final-assembly area, while maintaining accurate WIP inventory. As subassemblies are completed, backflushing decrements the WIP (in the MPS) at the end of the process.

Summary
    The architecture necessary to support an efficient assemble-to-order environment for high-option products has been described. (Also see Panel 2.) The critical architectural design requirements include having a system that:
- Supports a strategy that allows the materials management and manufacturing, at the subassembly level, of all the buildable options or building blocks that form a configured order for a PBX.
- Integrates the order-processing, materials-management, and manufacturing systems. Key to this is a common, integrated, customer-order database.
- Provides current information on customer orders through nightly updates from the customer-order database, which—in turn—is used to update the materials-management and manufacturing systems that drive operations.

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Biographies (continued)
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