

MANUFACTURING EXECUTION: STOREROOM

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The interval for execution of a parts pick list in the AT&T Denver Works storeroom has been shortened from 1 week to 2 days or less—often as little as 2 hours. This has been achieved without costly automated storage retrieval systems. Instead, storeroom operations now use weigh counting, naturally balanced picking zones, and information automation. Storeroom information automation supports and synchronizes parallel activities in addition to tapping information from material requirements planning, integrated pull manufacturing, and shop operations to achieve prompt response to shop requirements. Material is now pulled from the storeroom as requested by the shops instead of being pushed to the shops according to forecasts as was previously done.

Introduction

In the past, materials and components arriving at AT&T's Denver Works from vendors were stored in the main storeroom. All the material required (for a batch of circuit packs, for example) was gathered into a "pick" for convenient use by the assembly shops. Pick requirements were generated by weekly forecasts rather than orders for actual systems. Forecasted pick materials were delivered to the shops, which in turn expedited assembly and testing of items needed to satisfy orders. Storeroom counting errors, parts damaged or lost in the shops, and the scavenging of parts from other picks contributed to variability that was covered by "pad" stock in the storeroom as well as parts storage on the shop floor. Of course, there were still shortages.

Denver storeroom operations were manual and paper-driven. Device programming [of programmable read-only memories (PROMs)], tape sequencing (taping axial-lead components to parallel strips in the specific sequence required by the automatic insertion equipment in the assembly shop), and component lead trimming and forming operations were also performed in the storeroom. These operations, as well as those of operators picking parts from storage zones, were traditionally

Panel 1. Acronyms and Abbreviations in This Paper

C.V.	coefficient of variation
IC	integrated circuit
IPM	integrated pull manufacturing
IMS	information management services
LED	light-emitting diode
MRP	material requirements planning
PROM	programmable read-only memory
SIRVIS	storeroom interval reduction velocity improvement system
WSL	work sequence list

done in parallel. The first step was the weekly delivery of all "pick sheets." The separate areas of the storeroom (zones) were then given their portion of the weekly tasks required to prepare all of the week's picks. The parts, independently worked on by each zone, were then brought together (collated) at a centralized location. The pick could not be completed until parts from each zone had been delivered. Because of the unsynchronized operations, picks were not completed until the last half of the "pick week" and into the first half of the following "build" week. This necessitated the use of "hot lists" to expedite crucial orders.

Goals for Storeroom Operations

The following goals were set to improve storeroom operations:

- *Preserve Count Accuracy.* Accurate material counts improve operations by supporting effective materials planning¹ and by ensuring delivery of exactly the amount the shop requires, thus eliminating the need to store extra material on the shop floor.
- *Provide Daily-Sized Picks When Requested.* Assembling daily-sized picks for high-volume circuit packs improves the manufacturing interval,² but requires processing 3 times as many picks as required with weekly picks.
- *Reduce Storeroom Interval.* Reduce the time between

receipt of material from the vendor and its assembly by the shop.

Operational improvements that contributed to achieving these goals will be described first. Later, the necessary reengineering and information system developments to support picking, the synchronization of parallel operations, and the collation of picks will be discussed.

Operational Improvements

Using a design-for-manufacturability (DFM) preferred components list² and eliminating inactive components reduced the number of component codes in the storeroom by 75 percent. Setup reductions for tape sequencing allowed efficient processing of daily-sized picks by the storeroom. Improvements in weigh counting and in balancing parts placement in picking zones will be described in the following two sections.

Weigh Counting. A critical operation in the storeroom is picking and delivering the correct number of parts to the appropriate lines. Large items (cabinets, panels) and prepackaged items [such as integrated circuits (ICs)] are manually counted. A separate problem exists for smaller and more frequently used parts [e.g., transformers, capacitors, light-emitting diodes (LEDs), and fasteners]. These are counted by estimating the unit weight (as described below) and then determining the correct number from the total weight. The major advantages of weigh counting over individual-part counting are that it is less prone to human error and it is considerably faster. The major disadvantage is that its accuracy is a function of the variability of the weights of individual items. This section will describe how to quantify the weight variation in individual parts, how to relate that to the total accuracy, and the conditions under which weigh counting will be satisfactory.

Weigh counting is carried out in two steps. First, sample parts are randomly picked to determine the average unit (piece) weight. In this step, some predetermined number (known as the sample size) of items is picked and weighed, and then the average is calculated. This is

done on a regular basis to ensure that any changes in parts supplied by vendors are compensated for in the process. Second, on the basis of this average unit weight, the total number of parts is calculated by finding the ratio of the total weight over the average unit weight.

The error introduced by the statistical variation in weights of individual parts is minimized in the following way. Define the relative accuracy as the deviation of the number of parts picked, N , from the number desired divided by the number of parts desired. Let \bar{Y} be the actual average weight. Note that both quantities, N and \bar{Y} , are unknown. Let \bar{y} be the sampled average unit weight, that is, the estimate of the average weight of an individual item from the predetermined sample. We would like to determine the proper sample size n so that a desired relative accuracy r is achieved. Because of the variation of the individual weights, there is always error in our estimate of the relative accuracy, attributable to the particular sample. Therefore the real goal is to determine how many items n to sample, so that the probability that the relative accuracy is larger than the desired limit is no greater than a prespecified amount α . In standard notation, for given values of r and α , we would like to find a value of n such that

$$\text{Prob} \left(\left| \frac{N - \frac{N\bar{Y}}{\bar{y}}}{N} \right| \geq r \right) \leq \alpha \quad (1)$$

Note that $N\bar{Y}/\bar{y}$ is the desired number to pick. Equation (1) implies that

$$\text{Prob} \left(\left| \frac{\bar{Y} - \bar{y}}{\bar{Y}} \right| \geq \frac{r}{1-r} \right) \leq \alpha \quad (2)$$

It can be shown³ that \bar{y} is an unbiased estimator of \bar{Y} with standard error $\sigma(\bar{y}) = \sqrt{f/n}$. S is the

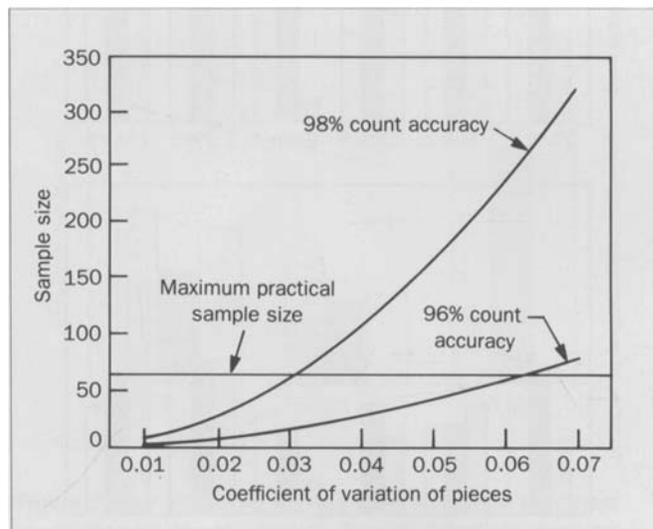


Figure 1. Sample sizes for weigh counting. The greater the accuracy and variability, the larger the sample size must be. In general, the sample size should be less than 65, as indicated by the horizontal line, to be practical.

population standard error, and f is the correction factor $(N - n)/N$. Assume that \bar{y} is normally distributed. Then equation (2) implies that

$$n = \frac{n_0}{1 + n_0/N} \quad (3)$$

where

$$n_0 = \left[z \left(\frac{1-r}{r} \right) \frac{S}{\bar{Y}} \right]^2 \quad (4)$$

and z is the abscissa of the standard normal curve that cuts off an area of α at the tails. Equations (3) and (4) suggest that for the desired accuracy r and the risk α of not achieving it, the sample size n is proportional to the

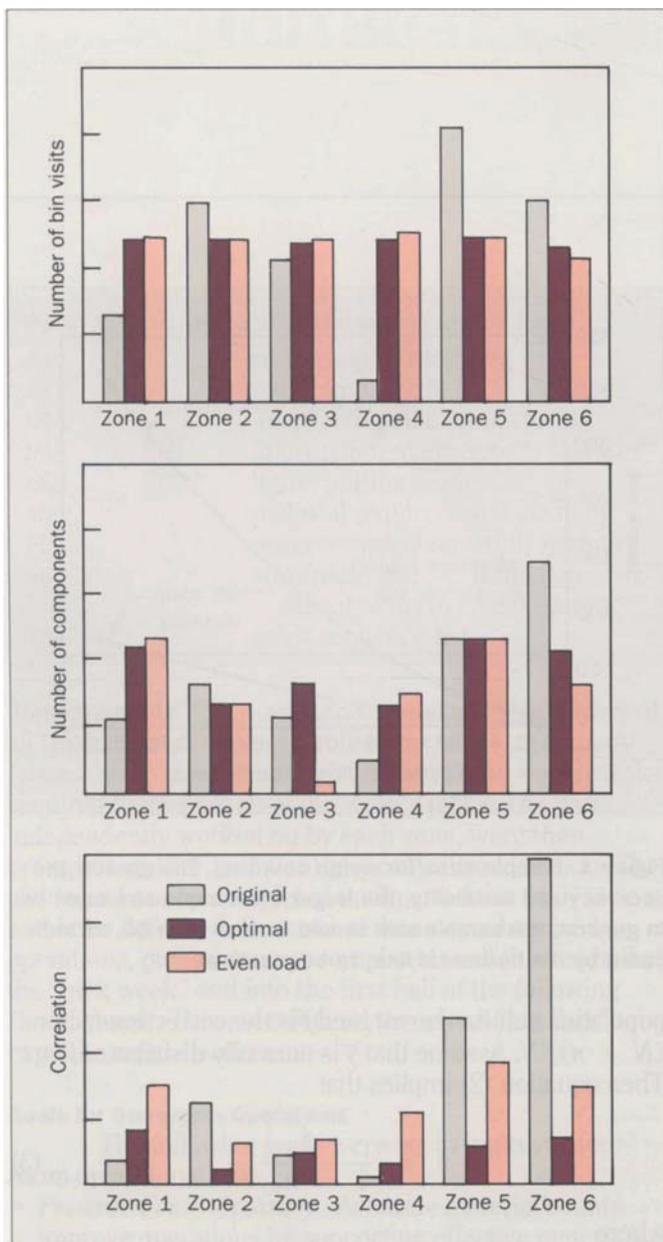


Figure 2. Ideally, parameters such as number of bin visits, number of components, and correlation should be the same for all zones of a storeroom. However, they were widely different with the original parts placement plan at Denver. The first approach to improving placement, by evenly loading parts without regard to correlation, yielded some improvement. The heuristic approach, here labeled *optimal*, produced even better results. Data are for the low bay area.

coefficient of variation (c.v.) S/\bar{Y} . To compensate for the error in estimation of the c.v. and to be conservative, we choose the sample size n_0 of equation (4) rather than n of equation (3). Figure 1 gives sample sizes for various values of c.v. with $\alpha = 0.01$ and $r = 0.01$ and 0.02.

In summary, weigh counting is far quicker than counting individual small, loose items and is not so subject to counting error. However, the average weight of an item must be estimated from a separate sample. Figure 1 defines the size of the sample so that a predetermined accuracy can be assured with high probability (also specified). The tradeoff here is that the higher the variability of the weights of the individual items and the higher the desired accuracy, the greater the size of the sample. In general, a sample size should be lower than 65 to be usable in a manufacturing environment.

Zone Balancing. The Denver storeroom is divided into three main areas: low bay, where small, weigh-counted items are stored; high bay, where large items, generally requiring a fork lift, are stored; and the IC area, where "sticks" (packaged stacks of integrated circuits) are stored. To give an idea of the complexity of the problem, in the low bay area, there were six zones containing over 4200 parts. Fortunately, only 4 percent of the parts account for 60 percent of the picking activity in this area. Pickers are assigned to a specific zone so that they can both become more familiar with their contents and have responsibility for a particular zone's stock (for balance accuracy).

It is desirable for each zone to have about the same amount of work to do in processing a group of picks. It can be assumed that the time to pick a part is roughly constant, since the travel time to the part is a small part of the effort, which includes retrieving, weighing (or counting), and logging the pick. Since picks corresponding to different types of circuit packs could be significantly different, balancing the parallel picking operations was equivalent to finding a placement of parts that equalized, over all possible picks, the number of required part codes in any one zone.

This is an extremely complex problem. One simple approach to approximate a solution is to load the parts in the zones evenly—specifically, to place parts in zones so that parts are required about the same average number of times from the various zones. The problem with this approach is that, although over the long term, load is equitably spread among the pickers, for any given group of picks there could be a great disparity in the number of parts in a zone.

Consequently, we solved a somewhat more complex problem. A slightly different way of thinking of optimal placement of parts is that parts that appear together in many picks should be in different zones and, equivalently, parts in the same zone should appear in fewer picks together. This means that no zone operator would be overburdened by any one pick; the load would be spread equitably, and the parallel pick operations in the zones would tend to be synchronized.

To achieve this, we considered a correlation matrix whose rows and columns correspond to the parts and whose (i, j) th element is the average number of picks that have both part i and part j in them, where the average is based on the frequency of occurrence of the particular pick. We then developed a heuristic placement algorithm that was based on assuring that, if parts i and j are in the same zone, they have a small correlation, and if they are in different zones, they have a high correlation.

This algorithm was applied to the high-running parts in each of the areas in the Denver storeroom. Figure 2 shows the results in the low bay area; *optimal* refers to the heuristic algorithm, and *even* refers to the first approach of evenly loading parts without regard to the correlation. Figure 3 shows that the average time to pick was improved by 34 percent in the low bay and 15 percent in the IC area by using heuristic placement.

Process Integration and Support

The Denver Works storeroom processes have been reengineered to efficiently supply material required by the shops on a daily basis. The storeroom control

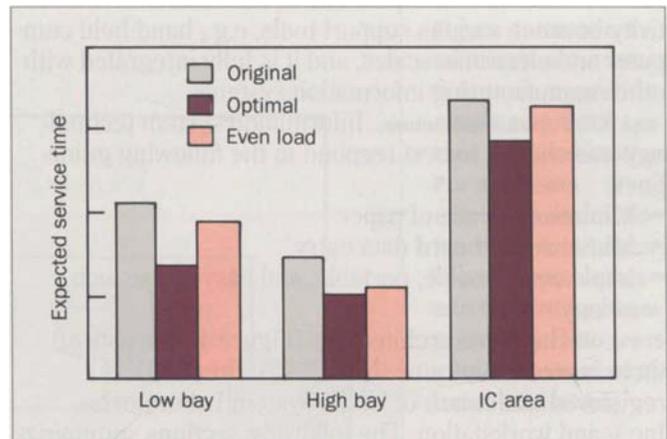


Figure 3. The expected service time for a pick improved markedly with the heuristic (optimal) approach to parts placement. No operator is overburdened by any one pick, and the workload is spread equitably among operators. As in Figure 2, data are for the Denver Works.

architecture of SIRVIS (storeroom interval reduction velocity improvement system) supports and synchronizes parallel activities in order to achieve high material velocities. The thrust of this control architecture is to respond to work requests (e.g., material requests) by generating a group of specific work instructions (e.g., directions to a specific bin location) that synchronize parallel activities. This is done through two levels of work partitioning and priority planning:

- Level 1 priority planning ensures that all storeroom functional areas (e.g., kitting, tape sequencing, picking, and delivery) are working on the same group of picks.
- Level 2 priority planning ensures that all operators within a functional area are working on the same group of picks at the same time.

SIRVIS also supports the labor-intensive and error-prone storeroom procedures, particularly picking and collation. SIRVIS provides a high degree of connec-

tivity between various support tools, e.g., hand-held computer and electronic scales, and it is fully integrated with other manufacturing information systems.

SIRVIS Architecture. Information system technology was chosen to best respond to the following guidelines:

- Minimize the use of paper
- Minimize keyboard data entry
- Implement flexible, portable, and easy-to-use technology.

The SIRVIS architecture (Figure 4) consists of three layers: mainframe, UNIX[®] system (UNIX is a registered trademark of UNIX System Laboratories, Inc.), and workstation. The following sections summarize the components of the architecture.

Mainframe layer. The mainframe layer extracts storeroom material requests from the material requirements planning (MRP) system and determines the work required by each functional area. The mainframe runs the information management services (IMS) database management system, which is also utilized by the MRP system.

UNIX system layer. The UNIX system layer helps plan the work load and execute the plan; e.g., it assists the storeroom coordinator in creating the pick groupings, downloading work instructions to the operators, and reporting transactions to update the MRP system databases. This layer also reports pick status to the MRP system on the mainframe layer. The UNIX system layer is composed of two AT&T 3B2-1000 minicomputers.

Workstation layer. The workstation layer provides necessary hardware and software to mechanize labor-intensive procedures, e.g., picking and collating. It consists of the following:

- Picking workstation. This is a mobile unit, designed to mechanize the labor-intensive procedures for picking and packing the parts and to maintain an accurate record of the on-hand inventory. The picking workstation integrates a hand-held computer running locally

developed software, a bar code scanner, a thermal bar code printer, a piece weight scale with RS232 interface, and a portable printer power supply capable of providing power for one full shift.

- Collation workstation. This integrates AT&T 6300 PCs, a bar code scanner, printers for hard copies, and a hand-held computer.

Daily Pick and Daily Delivery of Picks. The daily pick and daily delivery of picks is accomplished as follows. Storeroom material requests are used to trigger the storeroom production activities. First, the storeroom material requests are prioritized into a work sequence list (WSL). The priorities are assigned to ensure that a target shop is neither starved nor flooded with work. Each line item from the WSL is broken down into functional area assignments that are scheduled for synchronized work execution. Next, the storeroom functional areas execute the work assignments, and materials are collated. Finally, the using shop is notified that the pick is available, and the pick is delivered upon request. Details of the process follow.

Anticipated shop demands are received directly from the MRP and integrated pull manufacturing (IPM) systems. The anticipated shop demands are delivered once a day in batch, and the delivery requests are accepted during the day in real time. The storeroom turnaround time varies from 2 to 24 hours, depending on the type of pull signals.

Anticipated shop demands indicate the total requirements by code for a day. The total anticipated daily demands are rounded to standard-sized picks according to predetermined rules and checked for authorization by master production scheduling.

The storeroom generates the store-wide WSL from the material requests. The material requests are sorted and merged according to product/code priority guidelines to generate the WSL. This is a daily production instruction that lists assembly picks and their daily priorities. The priority guidelines are used to ensure that all

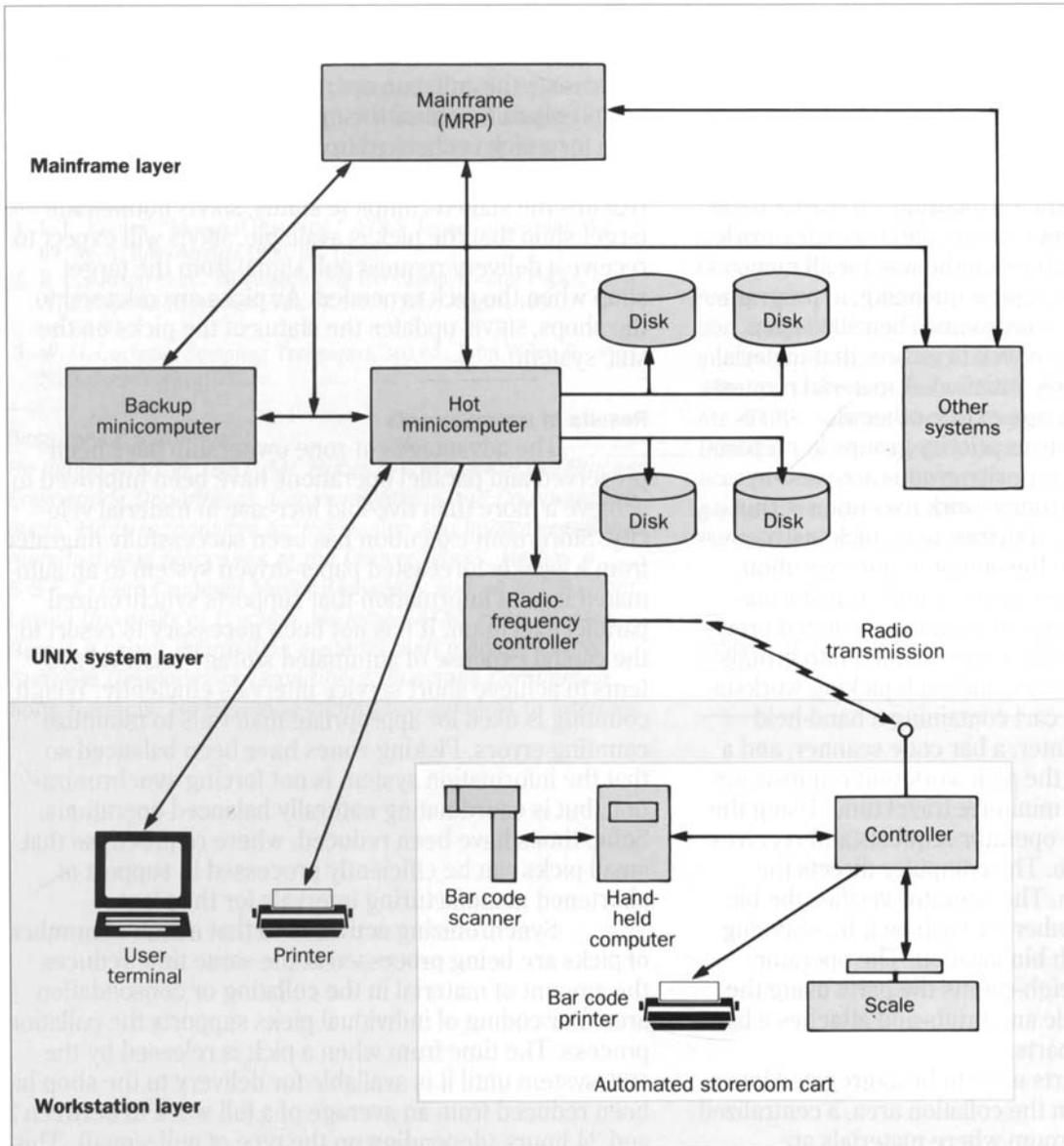


Figure 4. Hardware architecture for SIRVIS is in three layers: mainframe, UNIX system, and workstation. For maximum efficiency and mobility, the link between the storeroom carts and the UNIX system layer is by radio transmission instead of the usual hard wiring.

assembly shops receive their fair share of the daily picks, which are distributed evenly throughout a day. The guidelines are established and maintained jointly by the storeroom and the manufacturing shops.

Each line item from the WSL is exploded into work unit requests (e.g., piece part work unit, IC programming work unit) and prioritized for synchronized work execution in the various storeroom areas. SIRVIS creates work unit requests from the entries on the WSL for all functional areas (e.g., picking, tape sequencing, IC programming) within the Denver storeroom. Then SIRVIS performs a material shortage check to ensure that material requests can be completely satisfied. A material request may be deferred if a shortage exists; otherwise, SIRVIS assigns work unit requests to priority groups in preparation for execution. These priority groups are used by functional areas to synchronize work execution within a day. SIRVIS defines all line activities (e.g., pick instruction) and assigns them to the operators for execution.

Execution includes material pick, transformation, and delivery to storeroom collation. As noted previously, the picking functional area is divided into groups of adjacent aisles called *zones*, and each picking workstation has its own portable cart containing a hand-held computer, a bar code printer, a bar code scanner, and a scale. Within each zone, the pick work unit requests are sorted by bin location to minimize travel time. Using the hand-held computer, the operator requests and receives pick instructions by radio. The computer directs the operator to a bin location. The operator verifies the bin location and the part number for each pick by scanning the bar code label at each bin location. The operator either hand-counts or weigh-counts the parts using the integrated electronic scale and prints and attaches a bar code label to the bag of parts.

After picking, parts need to be aggregated into pick units. This is done in the collation area, a centralized location within the storeroom where materials are brought together before delivery to the shops. SIRVIS

collation receives and checks incoming materials with bar code scanners. It assigns a collation location address and assists the collation operator in aggregating picks. SIRVIS collation notifies the operator when the last line item for a pick is checked in and changes pick status from "staged partial" to "staged complete." When a pick reaches the staged-complete status, SIRVIS notifies the target shop that the pick is available. SIRVIS will expect to receive a delivery request pull signal from the target shop when the pick is needed. As picks are released to the shops, SIRVIS updates the status of the picks on the MRP system.

Results of Improvements

The advantages of zone ownership have been preserved and parallel operations have been improved to achieve a more than five-fold increase in material velocity. Storeroom execution has been successfully migrated from a weekly forecasted paper-driven system to an automated flow of information that supports synchronized parallel execution. It has not been necessary to resort to the capital expense of automated storage retrieval systems to achieve short service intervals efficiently. Weigh counting is used for appropriate materials to minimize counting errors. Picking zones have been balanced so that the information system is not forcing synchronization, but is coordinating naturally balanced operations. Setup times have been reduced, where required, so that small picks can be efficiently processed in support of shortened manufacturing intervals for the plant.

Synchronizing activities so that a limited number of picks are being processed at the same time reduces the amount of material in the collating or consolidation area. Bar coding of individual picks supports the collation process. The time from when a pick is released by the MRP system until it is available for delivery to the shop has been reduced from an average of a full week to between 2 and 24 hours (depending on the type of pull signal). This has allowed storeroom operations to change from a

forecasted push of material to the shops to the processing of picks pulled, or requested by the shops. In addition, the storeroom operations and execution systems now support increasing volumes of material shipped directly from the receiving dock to the using shop.

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Biographies (continued)

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